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Final Report
July 1990

Washington State Department of Transportation
Planning, Research and Public Transportation Division

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

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16. ABSTRACT

This document outlines the best methods and materials available to rehabilitate the asphalt pavements under the jurisdiction of the cities and counties in Washington State. A prioritization scheme is presented which can be used to select the most appropriate repair alternative to correct a specific problem. Information is provided on the state-of-the-art in materials and procedures being used throughout the country to accomplish the various repair alternatives.

In conjunction with this work, the delineation between "maintenance" and "construction" work is discussed. It is recommended that the legal definitions of maintenance and construction be modified to combine both activities under a general road preservation category. This general category would provide agencies with the flexibility to perform life cycle cost analysis to determine, for a given project, which repair activity is most cost effective.

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Final Report

Research Project Y 4298

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, or Department of Transportation. This report does not constitute a standard, specification, or regulation.

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SUMMARY AND RECOMMENDATIONS
ASPHALT PAVEMENT REHABILITATION RESEARCH

OBJECTIVE

The main objective of this research project was to provide cities and counties in Washington State with a document outlining the best methods and materials available to rehabilitate the asphalt pavements under their jurisdiction. At present, many cities and counties in Washington State utilize only two or three repair techniques to maintain their asphalt pavements. In this report, additional repair techniques and materials are identified for future consideration by Washington agencies. A prioritization scheme is presented which can be used by cities and counties to select the most appropriate repair alternative to correct a specific problem.

In conjunction with this work, the delineation between "maintenance" and "construction" work was investigated. The legal definitions of maintenance and construction have an impact on which funding sources an agency can utilize to finance a given repair. Also, the category of the repair activity may determine if a road must be brought up to current design and safety standards when the repair is performed. In this report, the current definitions are discussed and recommendations are made pertaining to potential modifications to these definitions.

APPROACH

This study was divided into the following major activities:

1. an evaluation of the asphalt pavement repair techniques and materials used by agencies in this and other states, through the distribution of a questionnaire;
2. an extensive literature review on asphalt pavement rehabilitation techniques;

3. development of recommendations pertaining to asphalt pavement rehabilitation in Washington State; and
4. an investigation concerning the present legal definitions of "construction" and "maintenance" activities.

FINDINGS

The major findings of this study are summarized below:

1. The distress types causing the most concern within Washington are alligator cracking, edge cracking, lane-shoulder drop-off, patching, potholes, and weathering and raveling.
2. Only a few alternatives are considered by most Washington agencies to repair asphalt pavements, namely chip seals, overlays, and patching. Additional repair alternatives are available, and are recommended for use within Washington State.
3. Some repair methods are being applied inappropriately, such as the use of a fog seal to correct alligator cracking.
4. The use of poor repair materials is common. In addition, many repair procedures are not being performed in the most effective manner possible. For example, patching is often not being performed properly. Also, in some cases very little, if any, pre-repair work is being performed prior to placing chip seals or overlays.
5. Fabrics and modified asphalts are performing well in Washington.

6. Many Washington agencies are concerned and confused about the delineation between construction and maintenance activities. Current definitions make it difficult for them to use limited budgets in a way which will maximize the benefits realized.
7. Available funds are not sufficient to correct existing pavement deficiencies, and many smaller agencies are overwhelmed.

RECOMMENDATIONS

Pavement Repair

It is recommended that Washington city and county agencies consider additional repair methods to those currently being utilized. Chapter 5.0 of this report contains prioritized repair lists which provide general guidance pertaining to the selection of an appropriate repair method which can be used to correct an identified pavement deficiency. The use of these repair lists will enable an agency to identify cost-effective repair alternatives which might otherwise be overlooked. The goal of these lists is not to dictate which repair alternatives an agency can utilize in a given situation, but to provide insight into which alternatives are considered appropriate and cost-effective for use within Washington State.

Whichever repair method is ultimately selected, it is very important to use the proper materials and methods. A repair method incorrectly applied, or made with inadequate materials, will probably not provide the life expected, and may increase maintenance needs and costs. It will certainly be a waste of scarce maintenance dollars. It is recommended that an agency refer to Chapter 3.0 once an appropriate repair method has been selected. This chapter provides information on the state-of-the-art materials and procedures being used throughout the country to implement asphalt pavement repairs. Agencies may be unaware of recent advances in asphalt pavement repair technology. A review of Chapter 3.0 will allow an agency to identify techniques and/or materials which will improve the performance of their repairs.

Legal Definitions

It is recommended that modifications be made to the legal definitions of maintenance and construction to enable agencies within Washington to optimize the use of available maintenance and construction funds. Current definitions are confusing, and in some situations significantly restrict the ability of an agency to utilize limited road funds effectively. Many city and county agencies are not selecting pavement repair activities based on those that provide the most cost-effective solutions to their problems, but are selecting repair methods based on which "category" they fall under.

The overall objective of each city and county agency should be to obtain an optimum combination of expenditure for maintenance and rehabilitation to get the best possible value for total available funds. It is recommended that maintenance and rehabilitation expenditures be programmed simultaneously to avoid incompatibilities in an operational sense and to approach a truly optimum allocation of available funds.

The creation of a general road preservation category would permit simultaneous programming of maintenance and rehabilitation expenditures. Rather than defining repair activities as maintenance, preventive maintenance, rehabilitation, construction, etc., all these activities would be considered together. This general category would provide agencies with the flexibility to perform life cycle cost analysis to determine, for a given project, which repair activity is most cost-effective. While a change in definitions will not provide any additional funding to city and county agencies, it will permit them to select the most cost-effective methods for maintaining their roads.

CHAPTER 1.0

INTRODUCTION

1.1 BACKGROUND

As the asphalt-surfaced roads in Washington State age, maintenance and rehabilitation activities become more complex and difficult to manage and finance. It has become increasingly important that the most cost-effective maintenance and repair procedures be utilized within Washington, in order to conserve limited monetary, manpower, and energy resources. Recognizing the importance of this issue, the Washington State Department of Transportation (WSDOT) selected Pavement Consultants Inc. (PCI) to identify techniques and materials which will allow city and county agencies to maximize the benefits received from asphalt pavement maintenance and repair activities.

At present, many cities and counties in Washington State utilize only two or three repair techniques to maintain the asphalt pavements under their jurisdiction. In this report, additional repair techniques and materials are identified for future consideration by Washington agencies. A prioritization scheme is presented which can be used by cities and counties to select the most appropriate repair alternative to correct a specific problem.

In addition, the issue of what constitutes a "maintenance" activity and what constitutes a "construction" activity, according to legal documents, is addressed in this report. These definitions have an impact on which funding sources an agency can utilize to finance a given repair. Also, the categorization of the repair activity may determine if a road must be brought up to current design and safety standards when the repair is performed.

1.2 SCOPE OF WORK

The main objective of this research project was to provide cities and counties in Washington State with a document outlining the best methods and materials available to rehabilitate the asphalt pavements under their jurisdiction. In conjunction with this work, the delineation between "maintenance" and "construction" was also addressed.

The study was divided into the following major activities:

1. an evaluation of the asphalt pavement repair techniques and materials currently used by agencies in this and selected other states;
2. an extensive literature review on asphalt pavement rehabilitation techniques;
3. the development of recommendations pertaining to asphalt pavement rehabilitation in Washington State;
4. an investigation concerning the present legal definitions of "construction" and "maintenance" activities; and
5. the preparation of final documents, including a final report.

1.3 PRESENTATION

This report documents the work completed during this research effort. All findings and recommendations are presented under the following chapter headings:

Chapter 1.0	Introduction,
Chapter 2.0	State and Local Practice,
Chapter 3.0	Literature Review,
Chapter 4.0	Feasible Alternatives, and
Chapter 5.0	Recommendations.

Appendix A contains a copy of the questionnaire which was distributed as part of this study. Appendix B contains detailed questionnaire results. Appendix C contains guideline and code information on maintenance versus construction activity definitions. A glossary of terms is provided to facilitate the use of this report.

CHAPTER 2.0

STATE AND LOCAL PRACTICE

2.1 BACKGROUND

During the first phase of this research effort, questionnaires were distributed to more than 550 state, city, and county agencies which have jurisdiction over pavement-related issues. All city and county agencies within Washington State were included in this poll, and over two hundred Oregon city and county agencies received the questionnaire.

The major objective of this work task was to document the approach towards asphalt pavement repair currently being taken by Washington cities and counties. One goal was to determine what pavement problems these agencies are experiencing, and how they currently select a repair action to correct the identified problem. In addition, information pertaining to repair procedures, cost, materials, equipment, and performance were also requested. Completed Oregon questionnaires were used to supply supplemental cost and performance information.

The questionnaire results were used during final project phases to help develop a list of potential repair alternatives, and to prioritize feasible alternatives. In addition, the questionnaire responses were used to identify situations where Washington agencies could benefit from improved repair procedures and/or materials.

2.2 QUESTIONNAIRE DEVELOPMENT

The questionnaire, which is presented in Appendix A, was developed with the assistance of the Washington State Department of Transportation and the King County Department of Public Works. A brief summary of the questions follows:

1. What types of asphalt pavement distresses do agencies have to repair, and which distresses present the greatest maintenance/repair concerns?

2. What actions would an agency consider to correct the various pavement distresses?

3. For a specific repair activity, such as patching, what is the repair procedure, materials used, equipment required, cost, and expected repair life.

4. Does the agency currently use a pavement management system? If so, what system has been implemented?

5. When more than one repair action is available to repair a given distress type, what criteria are used to determine which to utilize?

6. How does an agency decide when to schedule major rehabilitation on a distressed road, rather than using short-term maintenance techniques?

7. What repair activities are considered maintenance, and which are considered rehabilitation/construction? How is this differentiation made?

8. Is the agency aware of any repair projects that have been conducted in their area involving new techniques, materials, or equipment?

2.3 QUESTIONNAIRE RESPONSE

Unfortunately, the response to the questionnaire was limited. Almost 50% of the counties within Washington State responded, but a much lower percentage of counties within Oregon, and cities within Washington and Oregon, returned completed questionnaires. Various reasons were given by agencies for not returning the questionnaires, including:

1. Extreme manpower constraints limit the work performed by an agency to only the most fundamental. This was a common explanation given by the smaller counties and cities, which are often managed by "one-man" operations, for not returning the questionnaires.

2. Too many questionnaires come across an agency's desk, and the agency is forced to choose which questionnaires to complete. For example, at the same time as this study's questionnaire was being delivered, the American Public Works Association (APWA) was distributing an 18-page questionnaire to many of the same agencies.
3. The study is expected to be of limited usefulness. This viewpoint was commonly expressed by agencies with such limited funding that they are virtually constrained to emergency-only type road repairs. Oregon agencies also expressed this viewpoint.

2.4 QUESTIONNAIRE RESULTS

Once the completed questionnaires had been returned, the results were compiled and analyzed. The responses from agencies within Washington were divided into two major groups: cities and counties. Both of these groups were analyzed as a whole, and then further divided into climatic zones (western and eastern Washington). The results are presented in tabular form where possible, and each question contained in the questionnaire and its responses are discussed separately below. The questionnaire responses from Oregon were used to provide information on potential repair techniques and materials not currently being utilized in Washington State.

2.4.1 Distress Types

The questionnaire requested the respondents to estimate the percent of their pavements which exhibit a given distress type, as defined in Table 2-1. In addition, they were asked to identify which distress types caused the greatest maintenance concerns to their agency. Figures 2-1 to 2-4 contain the results of this question for Washington counties and cities, respectively. Tables B-1 and B-2, in Appendix B, contain detailed results for this question. The following general conclusions may be drawn from the results.

__2.4.1.1 Washington Cities__. City pavements in eastern Washington exhibit a large percentage of alligator cracking, transverse and longitudinal cracking, potholes, and patching. In addition, rutting, edge cracking, and weathering and raveling were reported to be moderately common occurrences. The distresses which these agencies indicated concerned them the most were alligator cracking, weathering and raveling, transverse and longitudinal cracking, potholes, patching, and bleeding.

City pavements in western Washington were reported to exhibit a large percentage of alligator cracking. Potholes, edge cracking, weathering and raveling, and patching are also moderately prevalent. The distresses reported to cause the greatest concern are alligator cracking and potholes. In addition, edge cracking, corrugation, transverse and longitudinal cracking, and weathering and raveling were reported to cause some concern.

Overall, Washington cities reported that alligator cracking occurred on the majority of their pavements. Moderate amounts of transverse and longitudinal cracking, potholes, and patching were also identified. The two major concerns with respect to maintenance are alligator cracking and potholes. Weathering and raveling and transverse and longitudinal cracking were also of concern to many cities, and corrugation, patching, bleeding, and edge cracking were reported to be a problem by a few cities.

__2.4.1.2 Washington Counties.__ Pavements managed by eastern Washington counties exhibit a large percentage of alligator cracking, potholes, rutting, edge cracking, and depressions. In addition, transverse and longitudinal cracking, swelling, weathering and raveling, and patching are common occurrences. The distress types reported to cause the most problems are alligator cracking and edge cracking. Potholes, patching, and lane-shoulder drop-offs were also reported by several Eastern counties, and depressions and shoving were reported by a few to cause concern.

Pavements managed by western Washington counties were reported to exhibit a high percentage of rutting. In addition, a moderate percentage of weathering and raveling, patching, edge cracking, and lane-shoulder drop-offs were identified. The major concerns with respect to maintenance are alligator cracking and edge cracking. Weathering and raveling and patching were also of concern to a few counties in this region.

Overall, counties within Washington State reported that patching and edge cracking occurred on the majority of their pavements. Alligator cracking, rutting, depressions, transverse and longitudinal cracking, and potholes were also present on many of the pavements. The major maintenance concerns were alligator and edge cracking, with patching, potholes, and lane-shoulder drop-offs reported to cause some concern. Depressions and weathering and raveling were reported by a few agencies to cause maintenance problems.

2.4.2 Repair Actions

Washington cities and counties were polled to determine what repair actions they currently consider when deciding how to correct a given pavement distress. A detailed summary of the results of this question are presented in Appendix B, in Tables B-3 and B-4, for counties and cities, respectively. The terminology used by the respondents is repeated in these tables. While some of the repair techniques listed could probably be grouped together, an effort was made to reproduce the actual responses.

Agencies outside Washington State were also asked to describe the repair actions they consider appropriate to correct a given pavement distress. It was hoped that feasible repair alternatives would be identified which are not currently being utilized by Washington agencies. While most of the repair actions cited by the outside agencies were similar to those used within Washington, a few additional techniques were identified. The installation of improved drainage was reported as being useful in the repair of Oregon pavements, and infra-red heaters are being used to correct shoving and rutting problems.

The majority of agencies, both within and outside Washington State, only consider a few repair alternatives when faced with a distressed pavement. Patching, surface treatments (primarily chip seals), and overlays are the only repair actions considered by many agencies, with some also considering crack sealing as a potential technique.

2.4.3 Repair Procedure, Cost, and Performance Life

As part of this survey, agencies were asked to describe how they perform typical repair activities (such as crack sealing, patching, etc.), to list the equipment and materials they use to perform the activity, and to estimate repair cost and performance life. Typically, the agencies listed very similar repair steps for the individual repair activities, which were generally in accordance with standard maintenance practice. However, the patching procedures outlined in completed questionnaires varied considerably.

Tables B-5 and B-6 in Appendix B contain a summary of respondents' repair activity cost and performance life estimates. Figures 2-5 and 2-6 provide a graphical illustration of repair service lives. <u>It should be understood that for each repair activity, the values provided by the different agencies cover a broad range of repair materials and methods.</u> In particular, the reported costs for the different patch types varied considerably. While the information is useful in relative terms, it should not be used to prepare project estimates or perform life cycle cost analyses.

No data were available on the use of cape seals, full depth recycling, rejuvenators, sand seals, and slurry seals for Washington counties. Also, no Washington city respondents provided cost or life estimates pertaining to the use of cape seals, full depth recycling, fog seals, rejuvenators, or surface recycling.

The completed questionnaires from agencies outside Washington State provided useful cost and life information pertaining to repair techniques which were not addressed by the completed Washington questionnaires. Rejuvenators were estimated to last 4 years, with an average cost of $0.16 per square yard. Cold recycling was estimated to last 20 years by an Oregon agency, with an average cost of $6.80 per square yard. Another Oregon agency predicted surface recycling would last 10 years.

2.4.4 Pavement Management Systems

When asked what, if any, pavement management system was used by an agency, the following replies were submitted.

2.4.4.1 **Washington Cities**. In the Western region, 40% of the cities which responded indicated that they currently do not use any pavement management system, 30% use WSC2-PMS, 10% use a manual system based on visual inspection, and 10% use the CHEC pavement management system. In the Eastern region, 71% of the cities that responded do not currently utilize any pavement management system, and 14% use the WSC2-PMS.

2.4.4.2 **Washington Counties**. In the Western region, 14% of the counties which responded do not use any pavement management system, 71% use the WSC2-PMS (or variation thereof), and 14% use a manual system based on visual inspection. In the Eastern region, 33% do not use a pavement management system, 56% use WSC2-PMS, and 11% use a manual system based on historical records and field review.

2.4.5 Triggering Criteria Used to Determine Repair Needs

Each agency was asked to list the determining factors they consider when deciding when to schedule major rehabilitation work. The factors listed were varied and showed no geographical demarcation or difference between Washington counties and the cities. The triggering criteria cited by respondents are described below:

- Funding was cited frequently as the major, and often, only, determining factor. Stop-gap maintenance is continued until the funds become available to provide a more permanent repair.
- Traffic volume and traffic type, along with road classification, were also considered by many agencies when prioritizing road rehabilitation projects.

- The extent and severity of distress, subgrade condition, time of year and the weather, safety, life cycle cost analysis results, priority ratings, riding quality, deflection data, maintenance history, and the reason for pavement failure were all listed as additional criteria to be considered when determining when to perform major rehabilitation.

2.4.6 Maintenance versus Construction Activities

There is confusion and inconsistency among the cities and counties regarding when a given repair activity is considered maintenance, rather than rehabilitation or construction. To obtain more data pertaining to this situation, each agency was asked to identify which activities they considered to be maintenance, and which they considered to be rehabilitation/construction. Detailed results pertaining to this question are provided in Appendix B, in Tables B-7 and B-8.

The questionnaire results reveal that Washington agencies generally make the same differentiations between maintenance and construction activities, except concerning chip seals and overlays. The counties and cities were almost equally divided between defining the placement of a chip seal as a construction or a maintenance activity. Most agencies defined "thin" overlays as maintenance, and "thick" overlays as construction. However, the differentiation between thin and thick overlays varied among the agencies. The definition of a thick overlay ranged from an overlay greater than 3/4 of an inch in thickness, to an overlay thicker than 2 inches.

The questionnaire asked each agency to describe how repair activities were categorized into maintenance and construction actions. Many criteria were cited as being used to make the differentiation, including: funding, repair life, manpower requirements, repair cost, local guidelines, state guidelines, federal guidelines, maintenance cycle, potential change to structural capacity, traffic volume, extent of pavement damage, and location. Some agencies said the definitions were purely subjective, and others relied upon their pavement management system to make the differentiation for them.

2.4.7 Experimental Projects

Each surveyed agency was asked to provide information on any asphalt pavement repair projects conducted in their area which have involved new techniques, materials, or equipment. Several different projects were described by the questionnaire respondents.

The use of fabrics was reported by many agencies as providing good performance life when used in overlay projects and during patching activities. Asphalt additives have proved useful for many agencies, particularly in the form of rubberized asphalt. Rubber-modified asphalt cements have been used successfully in overlays, chip seals, seal coats, and crack sealants within Washington and Oregon States. One eastern Washington city is incorporating the rubber into the asphalt cement through the use of recycled tires. In western Washington, one county agency is correcting excessive edge deterioration on low volume roads through the use of an asphalt-treated base prelevel covered with a seal coat. The county states that this technique provides a smoother ride and corrects surface irregularities at a cheaper price than an asphalt concrete overlay.

2.5 DISCUSSION

While the number of returned questionnaires was limited, useful insight into the problems and concerns of agencies responsible for maintaining asphalt pavements within Washington was obtained. A review of the completed questionnaires yielded the following information:

1. The distress types causing the most concern within Washington are alligator cracking, edge cracking, lane-shoulder drop-off, patching, potholes, and weathering and raveling.

2. Only a few alternatives are considered by most agencies to repair their pavements, namely chip seals, overlays, and patching.
3. Some repair methods, while certainly useful in many situations, were being applied inappropriately. For example, seal coats are being used to correct extensive alligator cracking.
4. Many repair procedures described by respondents involve the use of poor materials, or are not being performed in the most effective manner possible. For example, patches are being compacted with vehicle tires, or are being constructed with materials that have been demonstrated to provide inadequate performance.
5. Agencies within Washington are having success utilizing fabrics and modified asphalts in their repairs.
6. Many agencies are concerned about the construction versus maintenance issue, and feel that the current definitions make it difficult for them to use limited budgets in a way which will maximize the benefits received.
7. Many of the smaller city and county agencies feel overwhelmed. Extremely limited budgets and available manpower restrict their pavement work to emergency repairs.

2.6 SUMMARY

The completed questionnaires were very useful. The answers provided insight into which distress types the cities and counties have to correct frequently, and which cause them the most trouble. This information allowed the next phases of the project to be concentrated on the areas of greatest concern. Also, determining the state of current city and county practise was the first step in developing recommendations for improving future repair alternative selection and techniques.

Table 2-1. Flexible Pavement Distress Types

Distress Type	Distress Definition
Alligator Cracking	Fatigue cracking, a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading.
Bleeding (Flushing)	Film of bituminous material on the pavement surface which creates a shiny/glasslike, reflecting surface that usually becomes quite sticky.
Block Cracking	Interconnected cracks that divide the pavement into approximately rectangular pieces; caused mainly by shrinkage of the asphalt concrete and daily temperature cycling and not by traffic loads.
Corrugation (Washboarding)	Series of closely spaced ridges and valleys occurring at fairly regular intervals, with the ridges perpendicular to the traffic pattern.
Depressions (Birdbaths)	Localized pavement surface areas with elevations slightly lower than those of the surrounding pavement.
Edge Cracking	Cracks that are parallel to and usually within 1 to 2 feet of the outer edge of the pavement.
Lane/Shoulder Drop-Off	Difference in elevation between the pavement edge and the shoulder.
Patching	Area of pavement which has been replaced with new material to repair the existing pavement.
Polished Aggregate	The surface aggregate is smooth to the touch.
Potholes	Small, bowl-shaped depressions/holes in the pavement surface.
Rutting	Surface depression in the wheel paths.
Shoving	Permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading.
Slippage Cracking	Crescent-shaped cracks produced when braking or turning wheels cause the pavement surface to slide or deform.
Swells	Upward bulges in the pavement's surface.

Table 2-1. Flexible Pavement Distress Types (Continued)

Distress Type	Distress Definition
Transverse & Longitudinal Cracking	Longitudinal cracks run parallel to the pavement's centerline or laydown direction; transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of laydown.
Weathering & Raveling	Wearing away of the pavement surface caused by the loss of asphalt or tar binder and dislodged aggregate particles.

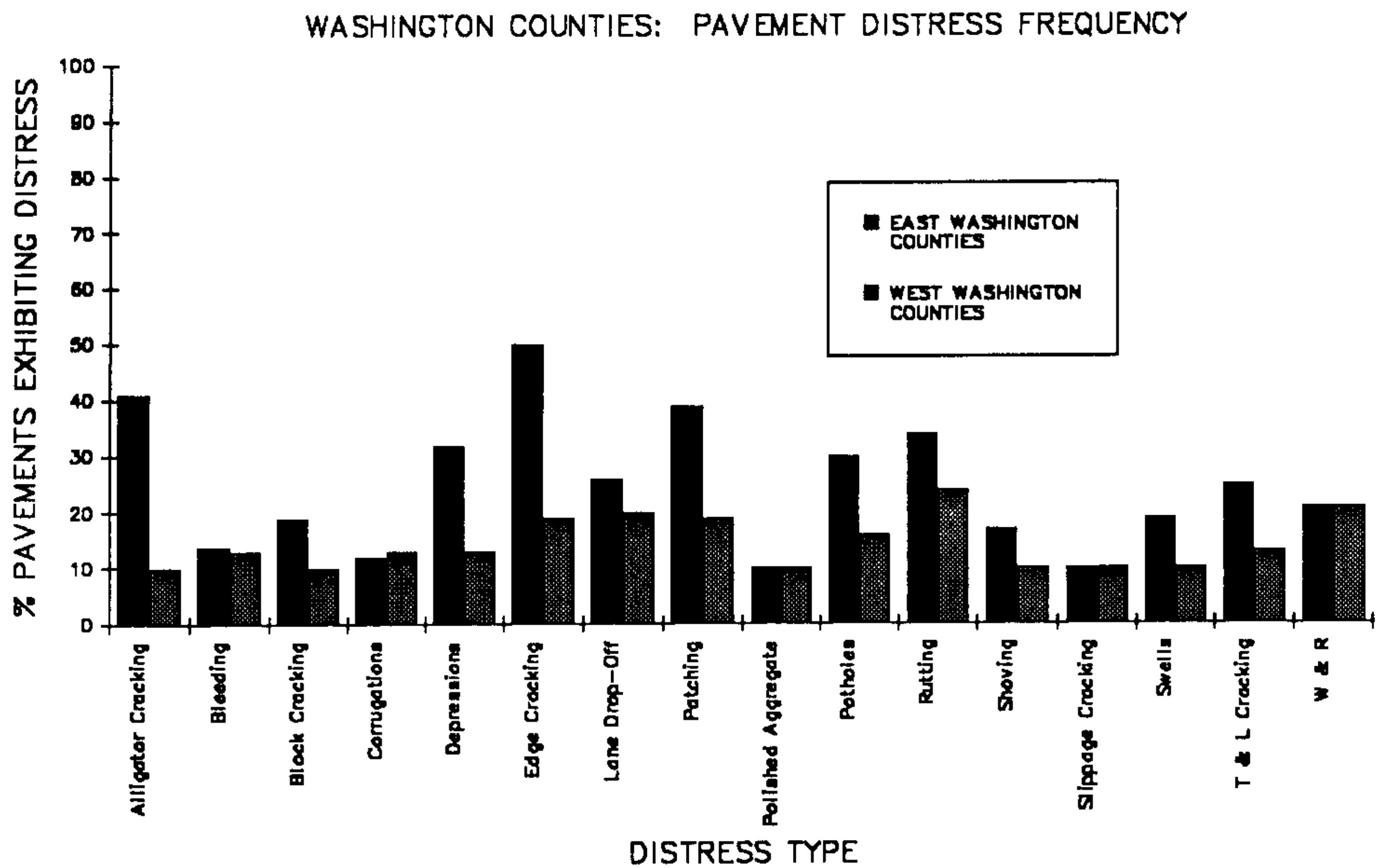

Figure 2-1. Pavement Distress Frequency, Washington Counties

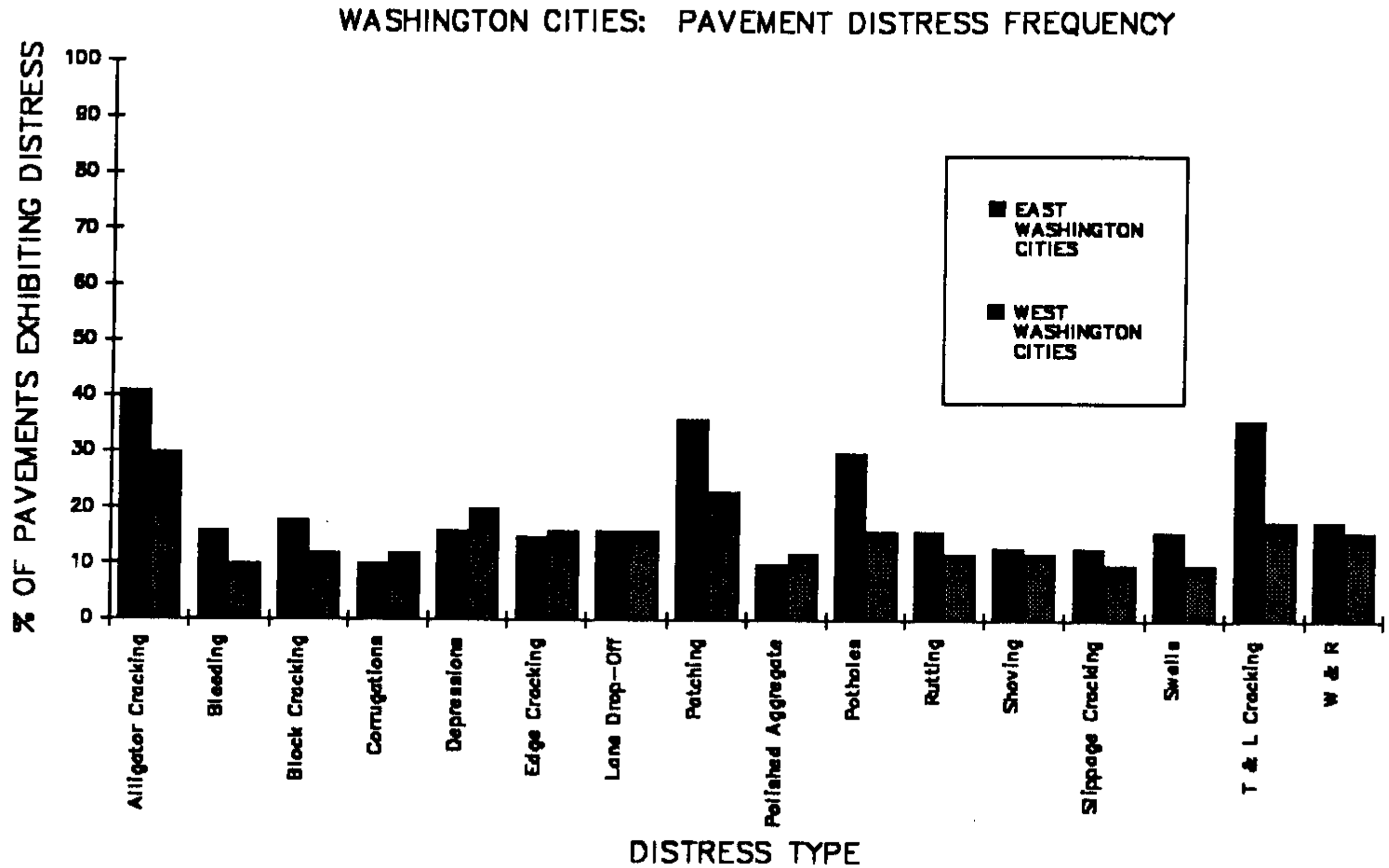

Figure 2-2. Pavement Distress Frequency, Washington Cities

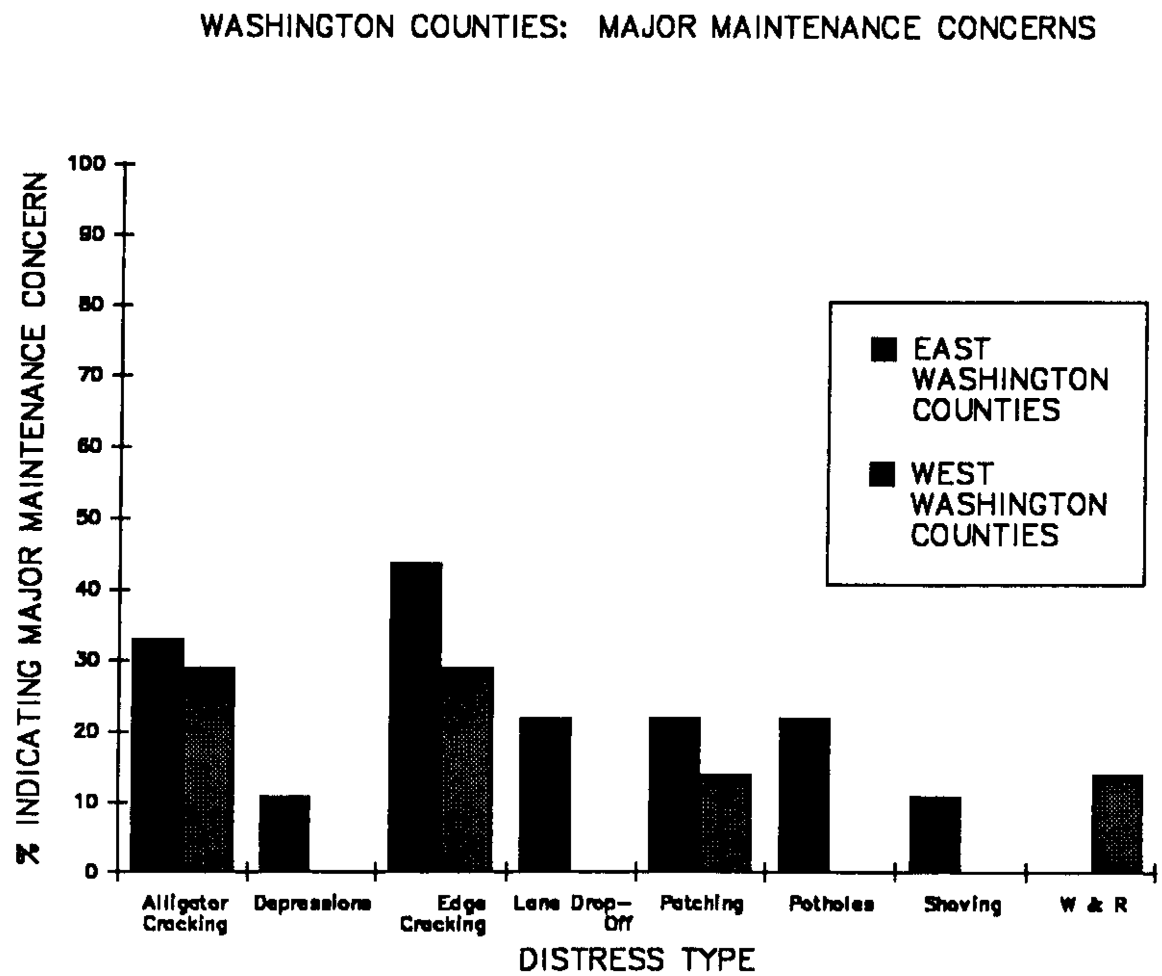

Figure 2-3. Major Maintenance Concerns, Washington Counties

WASHINGTON CITIES: MAJOR MAINTENANCE CONCERNS

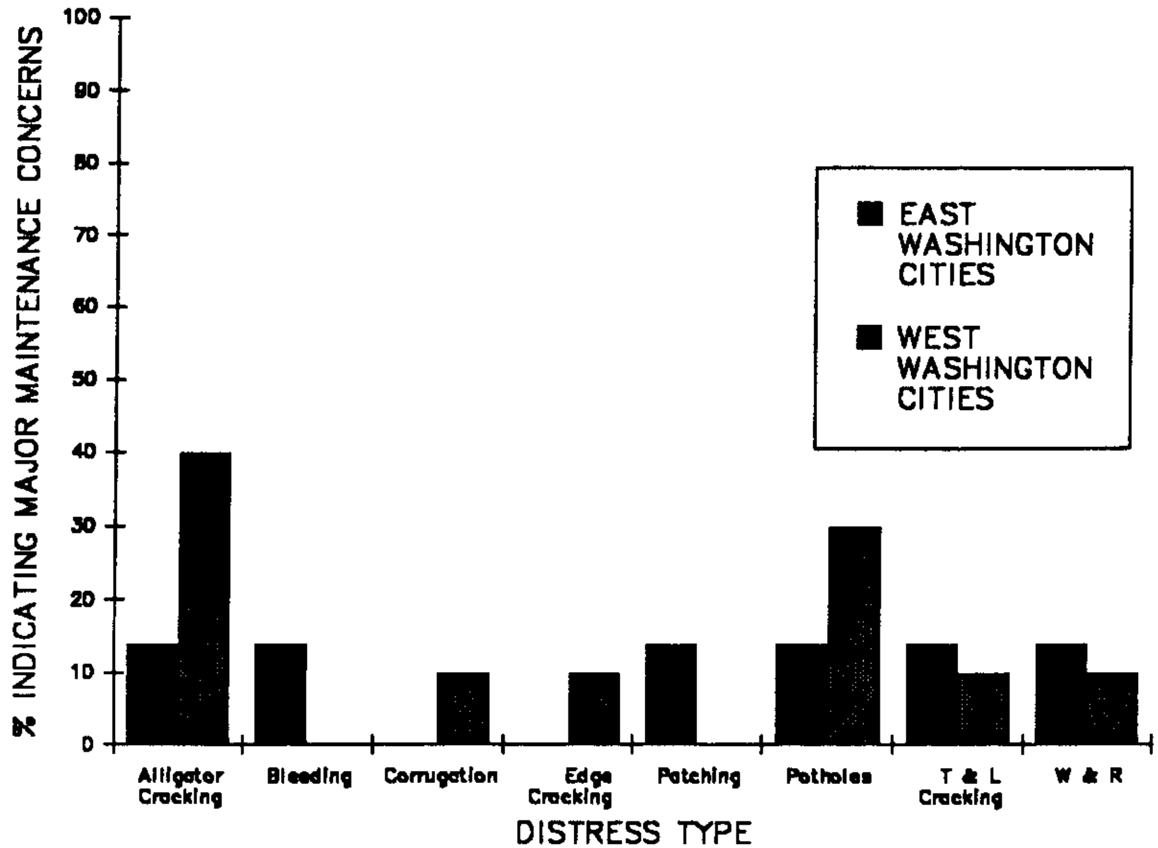

Figure 2-4. Major Maintenance Concerns, Washington Cities

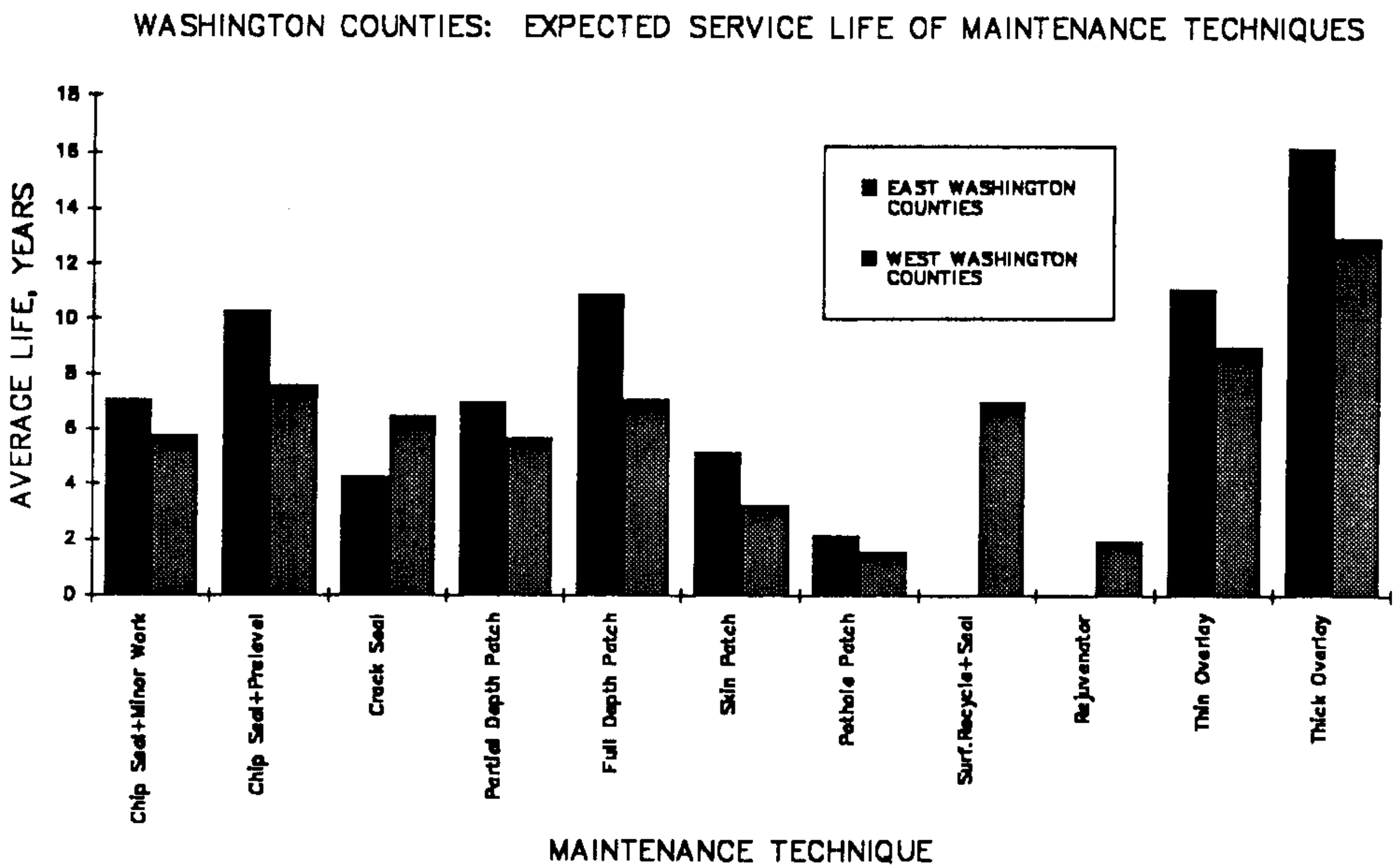

Figure 2-5. Expected Service Life of Maintenance Techniques, Washington Counties

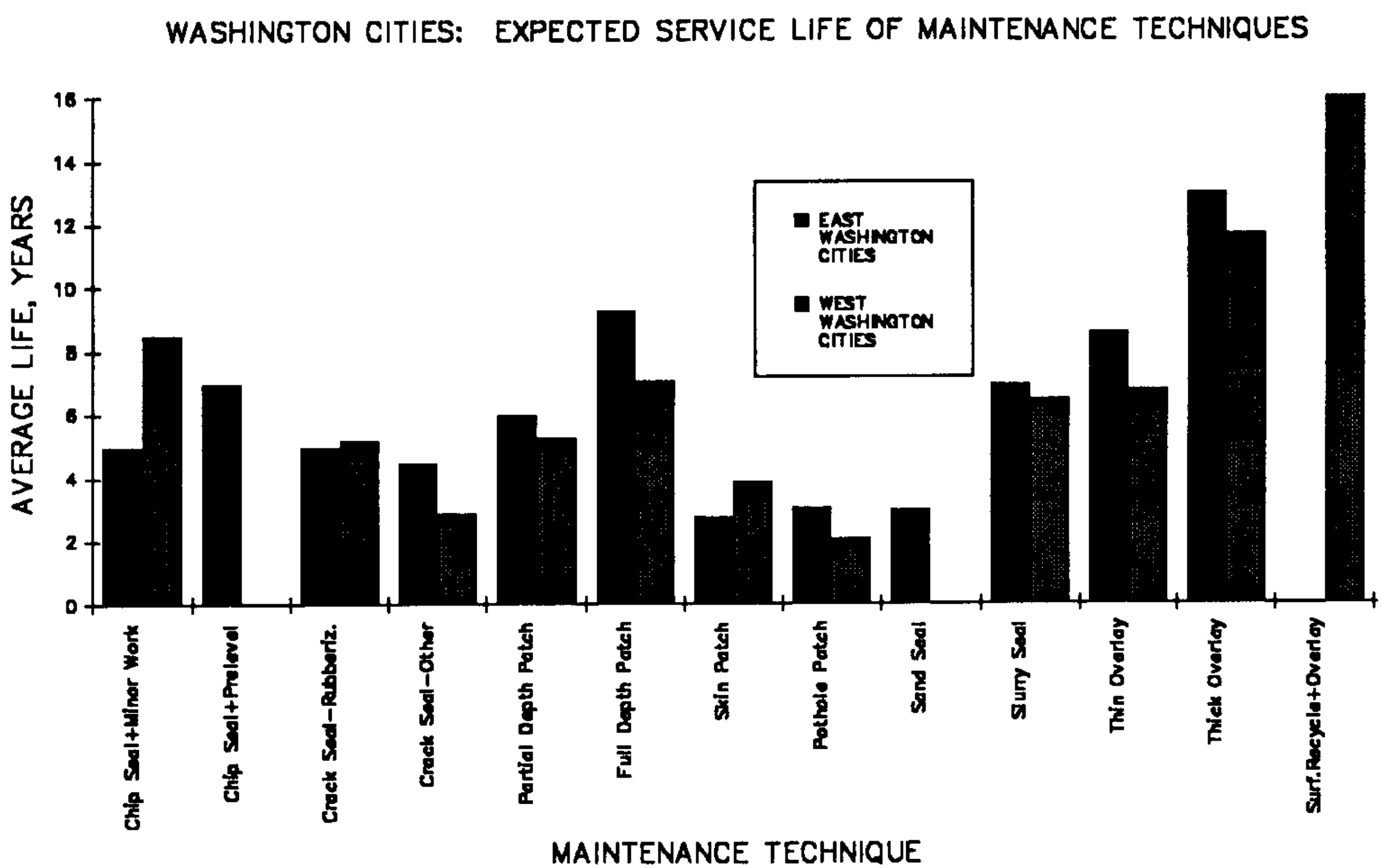

Figure 2-6. Expected Service Life of Maintenance Techniques, Washington Cities

CHAPTER 3.0

LITERATURE REVIEW

3.1 BACKGROUND

Concurrent with the distribution of questionnaires (Chapter 2.0), an extensive literature review was undertaken as part of this project to determine the state-of-the-art in asphalt pavement rehabilitation techniques and materials. Through reviewing past and current research efforts worldwide, it was hoped that feasible repair techniques and materials not currently being used in the State of Washington might be identified. In addition to reviewing published reports and articles, equipment manufacturers and material producers were contacted. Manufacturer literature, material product information, and specifications were gathered from these sources.

The objective of the literature review was not to provide detailed design, construction, and specification information pertaining to each identified repair alternative. Rather, enough information was collected so that the next phase of the project, which involved determining which repair alternatives are feasible within Washington State, could proceed in a logical, efficient manner. In addition, a synopsis of the reviewed material is presented in a concise and organized form, with a reference list available for the reader to review for more detailed information.

In most cases, the repair alternatives described in this chapter will be familiar. However, improved techniques and materials are often identified which have good potential for application within Washington State. The situations where each repair alternative is appropriate are described. An improved understanding of techniques and materials available will help Washington agencies determine if they are using the most effective materials and procedures for asphalt pavement maintenance and repair.

3.2 DESCRIPTION OF WORK

The literature review was conducted in three phases:

1. computerized data base searches,
2. review of collected abstracts, and
3. in-depth review of selected publications.

The computerized data base searches were conducted through the Washington State Department of Transportation library. Key words pertaining to asphalt pavement maintenance, repair, and rehabilitation were identified. Several data bases were searched using these key words. The principal data base accessed was the Transportation Research Information Services (TRIS), which contains the following subfiles:

- Highway Research Information Service (HRIS),
- International Road Research Documentation (IRRD),
- Transportation Libraries (TLIB),
- Urban Mass Transportation Research Information Service (UMTRIS),
- Air Transportation Research Information Service (ATRIS),
- Highway Safety Literature (HSL),
- Maritime Research Information Service (MRIS), and
- Railroad Research Information Service (RRIS).

The searches were limited to the years 1980 through the present. The searches identified over 700 potentially useful publications, and the abstracts of these publications were obtained. After screening the abstracts, over 100 publications were found useful and obtained for in-depth review.

3.3 PRESENTATION

The information reviewed is summarized in this report under the following section headings:

Asphalt Seal Coats,

Crack Sealing,

Asphalt Recycling,

Patching,

Overlays, and

Asphalt Additives.

For each alternative, the following information was gathered and summarized:

Definition,

Purpose,

Materials,

Equipment,

Procedure,

Cost, and

Estimated Performance Life.

Equipment and material literature was reviewed and pertinent information was incorporated into the appropriate sections. Cost and performance life estimates obtained directly from completed questionnaires (see Chapter 2.0) are also presented when available.

3.4 ASPHALT SEAL COATS

3.4.1 Definition

Seal coats consist of sprayed asphalt treatments, with or without cover aggregates, and asphalt-aggregate mixtures.

3.4.2 Purpose

There are many reasons for applying a seal coat. They include:

1. improving skid resistance,
2. preventing water infiltration,
3. repairing extensive surface wear,
4. providing a temporary fix,
5. improving the roadway appearance or providing further visual delineation between mainline pavement and shoulder,
6. sealing cracks temporarily,
7. correcting pavement surface problems by waterproofing openness and enriching under-asphalted pavement, and
8. delaying or eliminating further aging due to the harmful effects of water and sun.

It should be understood that asphalt seal coats do not increase the structural capacity of a pavement. However, they can reduce the rate of pavement deterioration thus extending pavement life. Once structural deterioration has occurred, surface treatments are ineffective. If the existing pavement is not structurally sufficient to carry the projected traffic for the next few years, a surface treatment should not be considered except as a temporary fix until reconstruction funds become available.

3.4.3 Types

There are several types of asphalt seal coats, including:

1. fog seals and sand seals,
2. slurry seals,
3. aggregate seals, and
4. open-graded friction courses.

The individual surface seal types are applicable in different situations. Each seal coat type will be discussed separately in the following sections. In addition, a brief review of the use of rejuvenators will be presented.

3.4.4 Fog and Sand Seals

3.4.4.1 Definition. Fog seals are very light applications of emulsified asphalt to an existing pavement. A sand seal consists of an application of liquid or emulsified asphalt followed with a light covering of fine aggregate.

3.4.4.2 Purpose. Fog seals are used to reduce the entrance of air and water into the pavement and to restore or rejuvenate the surface of a pavement. When placed on pavement shoulders, fog seals provide sharp delineation between the shoulders and main roadway. They are also placed on new pavement surfaces, particularly during late season paving. In this situation, the fog seal is often referred to as a "construction seal". Many agencies apply fog seals as the first preventive maintenance procedure as soon as hairline cracks appear or raveling of the surface is apparent [3.4-1].

Sand seals are placed on pavements that have lost some of their matrix. They are used to seal against air, reduce raveling, and to provide a slight improvement in surface friction.

3.4.4.3 Materials. Slow-setting asphalt emulsions SS-1, SS-1h, CSS-1, and CSS-1h, diluted with an equal amount of clean water, are generally used for fog seals [3.4-2]. CRS-1, CRS-2, CMS-2 and CSS-1 have been used successfully with a sand seal. Cutback asphalts are also used for fog and sand seals, but emulsions are favored because of availability, ease of handling, and environmental considerations. Polymer additives have been used in fog and sand seals to improve their performance. The sand used in a sand seal should be 3/8 minus aggregate, clean, and easy to handle. Some Washington districts have found 1/4 minus material to be better suited for sand seals [3.4-3].

3.4.4.4 Equipment. Fog seals and sand seals require asphalt distributors. Pneumatic tired rollers are desirable for sand seals, but not required.

3.4.4.5 Procedure. Before placing any type of seal coat, a thorough surface examination is required to determine needed repair. Potholes, cracked edges, raveling edges, and other surface defects should be repaired prior to sealing.

All equipment should be carefully checked prior to placing a fog or sand seal. The spray nozzles on the asphalt distributor must be the correct size for the job conditions, and the nozzle angles must be checked. The spraybar should be adjusted to provide constant, uniform pressure along its entire length, and it must be clean. The correct height of the spray bar above the pavement surface must be maintained during the entire application. If pneumatic-tired rolling equipment is used, the tires must be checked to ensure that they are equally inflated to the correct pressure.

Fog seals are sprayed onto the pavement at a rate of 0.1 to 0.2 gallons of diluted material per square yard, depending on the texture and dryness of the old pavement. If possible, traffic is kept off the pavement until the emulsion cures. Under normal conditions, the break is rapid, permitting traffic within an hour or two. If traffic must be allowed onto the pavement before the emulsion cures, the traffic speeds must be reduced.

When applying a sand seal, the asphalt is sprayed onto the pavement first, typically at a rate of 0.1 to 0.2 gallons per square yard. The sand is then applied, typically 10 to 15 pounds per square yard. If the sand is applied immediately after the asphalt is applied, maximum stick will be achieved. If the emulsion breaks prior to sand application, the sand will be held only in the pores of the pavement, resulting in a surface similar to the original texture of the asphalt pavement [3.4-2].

3.4.4.6 Cost. A study published in 1987 estimated that the average U.S. fog seal cost was $0.19 per square yard in 1984 dollars [3.4-4]. According to Washington agencies that completed the questionnaire distributed as part of this study, construction and fog seals cost between $800 and $1830 per mile (approximately $0.06 to $0.13 per square yard).

Sand seals were reported to cost $2500 per mile (approximately $0.18 per square yard) to place.

3.4.4.7 Estimated Performance Period. A survey conducted in 1988 found that the average fog seal life expectancy in the U.S. was 4 years [3.4-5]. The AASHTO Design Manual [3.4-6] estimates that fog seals last 1 to 3 years when used on roads experiencing low and moderate traffic levels.

3.4.5 Slurry Seals

3.4.5.1 Definition. Slurry seals are a mixture of emulsified asphalt, fine aggregate, and mineral filler applied to an existing pavement surface.

3.4.5.2 Purpose. Slurry seals are used to seal a pavement and reduce weathering effects, to provide temporary mass crack filling, to improve skid resistance, to enhance appearance, and to reduce studded tire wear. Slurry seals do not perform as well as chip seals when the pavement surface is cracked. Many agencies only use slurry seals on local streets, due to striping costs, user costs, and the reduced performance life in high-traffic areas [3.4-7].

3.4.5.3 Materials. Slurry seals are composed of CSS-1, CSS-1h, or CQS-1h (Cationic Quick Set) asphalt emulsions with aggregates normally following ISSA grading specifications [3.4-2]. The fine aggregate used should be crushed [3.4-8]. Polymer-modified slurry seals are gaining acceptance, with natural rubber latex being the primary polymer source for this application.

3.4.5.4 Equipment. Slurries are produced in transit mix trucks or specially designed slurry seal equipment and are laid through a drag box with a rubber squeegee strike off.

3.4.5.5 Procedure. Prior to placing any type of seal coat, a thorough surface examination is required to determine needed repair prior to sealing. Potholes, cracked edges, raveling edges, and other surface defects should be repaired prior to sealing [3.4-3].

The surface must be clean of dust, and a light tack coat of similar emulsion should be applied to worn or oxidized surfaces. For newer surfaces, a light spray of water to dampen the surface may be sufficient. Emulsion and aggregate are mixed and are spread to 1/8 to 1/4 inch. A creamy, uniform consistency is desired. The mixture should flow in a wave about two feet ahead of the strike-off squeegee. This will allow the slurry to flow down into the pits and cracks in the pavement and fill them. Rolling may be recommended when surface integrity is critical and extended durability is desired. Do not allow pneumatic rollers on the slurry until it has broken. After the slurry seal is placed, traffic must be kept off the pavement until the slurry has cured. Place the slurry at a temperature that results in a good bond.

3.4.5.6 Cost. A study released in 1987 estimated that the average U.S. slurry seal cost was $0.62 per square yard in 1984 dollars [3.4-4]. In 1988, an article in Better Roads magazine estimated that the slurry seal cost was $1 to $3 per square yard at that time [3.4-8]. In 1987, a unit price history document prepared by the Seattle Engineering Department reported a bid price of $3 per square yard for slurry seals. According to Washington cities that responded to a questionnaire distributed as part of this study, slurry seals cost between $1 to $2.50 per square yard in Washington State.

3.4.5.7 Estimated Performance Period. In the City of Los Angeles, California, slurry seals are expected to last 5 to 7 years [3.4-7]. A national survey conducted by Roads and Bridges magazine in 1988 revealed that agencies expect slurry seals to last 5 years on the average [3.4-8]. Questionnaire respondents from Eastern Washington expect slurry seals to last 6 to 8 years, while those from Western Washington expect them to last 3 to 10 years. The AASHTO Design Manual estimates that slurry seals have a service life of 3 to 5 years when applied to roads receiving low and moderate traffic levels [3.6-6].

3.4.6 Aggregate Seals

3.4.6.1 Definition. Asphalt aggregate surface treatments consist of a layered application of asphalt material and aggregate. There are several types of asphalt aggregate surface treatments, including chip seals and cape seals. A chip seal is an application of asphalt followed with an aggregate cover. A cape seal is a chip seal topped with a slurry seal.

3.4.6.2 Purpose. Asphalt aggregate treatments are used to protect underlying pavements from oxidation, to provide skid resistance, and to seal cracks. The exclusion of water from cracks extends the pavement life. The use of a chip seal is often restricted to low traffic roads, due to short life expectancy and the potential for vehicular damage on high volume, high speed roadways. The purpose of a cape seal is to provide a chip seal that is better suited for roads with high traffic volumes. Cape seals are used to rejuvenate oxidized surfaces, seal cracks, and provide improved skid resistance.

3.4.6.3 Materials. The aggregate used should be clean, high quality material, since dusty aggregate appears to be a major cause of chip seal failure. The aggregate should be tested thoroughly to ensure that it has satisfactory durability. The aggregate must be monitored to insure that fines do not accumulate in the stockpiled material. The ideal aggregate shape is either cubical or pyramidal, and the largest size for surface treatments generally should be no more than twice the smallest size [3.4-3]. The size of the aggregate should be as uniform as economically practical. The Washington State Department of Transportation Maintenance Manual [3.4-3] suggests that minus 5/8 cover aggregate be used, with minus 1/2 aggregate preferable. Smaller aggregate results in a smoother, quieter riding surface and less windshield damage claims.

Asphalt cement, cutback asphalt, and asphalt emulsion have been used successfully in chip seals. Historically, cut back materials were the most common asphalt material used, however, cutback usage has been limited due to environmental concerns. Rubberized additives, such as latex or ground rubber tires, have been incorporated into the asphalt material to provide extra elasticity to hold the aggregate tightly. The use of rubberized asphalt also provides a material which bridges cracks well and maintains an effective seal. The use of high-float emulsion or a polymer additive is particularly beneficial when clean, uniform aggregate is not available. A standard slurry seal is used during cape seal construction.

3.4.6.4 Equipment. Typical equipment used when placing an aggregate seal includes an asphalt distributor, pneumatic-tired rollers, aggregate spreader, trucks, and brooms.

3.4.6.5 Procedure. All equipment should be carefully checked prior to placing an aggregate seal. The spray nozzles on the asphalt distributor must be the correct size for the job conditions, and the nozzle angles must be checked. The spraybar should be adjusted to provide constant, uniform pressure along its entire length, and it must be clean. The correct height of the spray bar above the pavement surface must be maintained during the entire application. The tires on the pneumatic-tired rolling equipment must be checked to ensure that they are equally inflated to the correct pressure.

When constructing an aggregate seal, the weather should be warm and dry with no rain forecast within 24 hours. Washington State Department of Transportation specifications require that the air temperature in the shade be at least 60 degrees Fahrenheit before work begins, and other agencies require at least this air temperature or even higher [3.4-3,3.4-8,3.4-9].

Prior to placing an aggregate seal, the existing surface should be patched and leveled. If patching is performed, the patch material must be allowed time to cure prior to sealing. After surface repairs are made, the area should be thoroughly cleaned with a power broom to enhance the bond. The binder is then applied, typically at a rate of 0.35 to 0.45 gallons per square yard, the cover aggregate is placed, normally 30 to 40 pounds per square yard, and a pneumatic-tired roller is used to compact the surface.

The chip spreader should not be allowed to fall behind the distributor. The aggregate needs to be placed immediately after the application of the asphalt, before the emulsion breaks (while it is still brown) to provide uniform wetting of the cover stone and desired aggregate embedment (50 to 70 percent) [3.4-2]. If the asphalt cools, good adhesion between the asphalt and aggregate will not be achieved.

Rolling should start before the emulsion breaks, and must be vigorous enough to create interlock between the chips and to securely embed the aggregate. Rolling should begin at the outer edge and proceed in the longitudinal direction, working towards the center of the road. Each trip should overlap the previous trip by 1/2 the width of the front wheels [3.4-3].

On low volume roads a chip seal is usually opened to traffic immediately; however, on high-speed roads, traffic control is essential to prevent early chip seal failure. A fog seal is sometimes applied after the chip seal is placed to improve the appearance and help with chip retention.

When constructing a cape seal, the chip seal is laid as described above. After the chip seal has cured, the loose cover stone is removed. Then the slurry is applied to fill the voids between the cover stone. [3.4-2]

3.4.6.6 Cost. A Canadian study conducted in 1985 found that chip seals cost an average of $0.72 per square yard in U.S. dollars [3.4-11]. A publication by the U.S. Army Corps of Engineers estimated an average U.S. cost of $0.54 per square yard for chip seals when applied as a maintenance activity, and $1.96 in 1984 dollars per square yard when used as a rehabilitation activity [3.4-4]. A recent article in Better Roads magazine estimates chip seals cost between $1 and $3 per square yard [3.4-8]. Chip seals with asphalt-rubber binders were reported in the literature to cost roughly twice as much as those with asphalt cement binders [3.4-12].

A report published by the Washington Department of Transportation estimated the cost of chip seals at $17,900 per mile (approximately $1.27 per square yard) [3.4-13].

The results of a questionnaire distributed as part of this study found that Washington cities spend between $5000 and $13,373 per mile ($0.36 to $0.95 per square yard) to place a chip seal, with an average of $8000 per mile. Washington counties reported that chip seals placed in conjunction with minor pre-repair work cost between $5500 and $11,000 per mile ($0.39 to $0.78 per square yard) to place, with an average cost of $8099 per mile. The counties reported that a chip seal placed in conjunction with preleveling work cost $8000 to $20,000 per mile ($0.57 to $1.42 per square yard) to place, with an average of $11,896 per mile.

3.4.6.7 Estimated Performance Period. Chip seal life was estimated at 5 years for projects in New Brunswick, Canada [3.4-11], 5 years in Florida [3.4-14], and 3 to 6 years in the U.S. as an average [3.4-8]. A Washington Road Jurisdiction study assumed an 8 year cycle for placing bituminous surface treatments and thin overlays [3.4-15]. Respondents from Washington Counties that responded to a recent questionnaire distributed as part of this study predicted that chip seals placed after minor pre-repair work last 2 to 11 years, with 6.4 years the average. Counties estimated that chip seals placed in conjunction with preleveling last 5 to 12 years, with 9 years the average life expectancy. Washington cities predicted chip seals would last would last 3 to 10 years, with an average chip seal life expectancy of 7 years.

The AASHTO Design Manual estimates that a chip seal using unmodified asphalt will perform well for 3 to 6 years when applied to pavements receiving low and moderate traffic volumes, and a chip seal using rubberized asphalt will last 3 to 8 years under the same traffic levels [3.4-6]. Pavement life was reported to be significantly shortened when chip seals are applied to high-volume traffic roads.

Asphalt-rubber chip seals have the potential to provide longer service life than conventional chip seals in the following situations [3.4-16]:

1. The pavement exhibits alligator cracks or random cracks at less than 8 feet intervals.
2. The chip seal is used for maintenance on a low-volume facility where a conventional chip seal would oxidize and crack due to lack of use.
3. The traffic level on the facility is such that a conventional chip seal could not withstand the high traffic volume.

3.4.7 Open-Graded Friction Courses

3.4.7.1 Definition. Open-graded friction courses are porous surface mixes with a large amount of voids.

3.4.7.2 Purpose. Open-graded friction courses are designed to drain water off the pavement surface by providing a very open porous structure in the mixture. The rapid removal of water reduces the potential for hydroplaning and hence wet weather accidents. They are used primarily to improve skid resistance, minimize hydroplaning, minimize the spray from tires, and lower tire noise.

3.4.7.3 Materials. For best performance, the coarse aggregate used in an open-graded friction course should be completely crushed, have a low abrasion loss, and have a high resistance to polishing. Traprock and slag are suitable aggregates. A special open gradation of the aggregate is needed with a large reduction in the amount of aggregates in the middle fraction (No. 100 to No. 40 sieve). Some fine aggregate is needed, as is mineral filler. Asphalt and cement grades AC-10, AC-20, AC-40 (85-100, 60-70, and 40-50 pen., respectively) and AR-40 and AR-80 have been recommended as binders. Some agencies also prefer to add an anti-stripping agent to the mix. [3.4-20]

3.4.7.4 Equipment. Placing the open-graded friction course is carried out by using conventional equipment, i.e., a paver equipped with a vibratory screed. A steel drum roller can be used to compact the mix.

3.4.7.5 Procedure. The porous friction course should be placed on a good structural surface free of potholes. After the surface has been cleaned and dried, a heavy tack coat is placed on the pavement. Strict gradation control should be provided during construction, and mix temperatures should be monitored very closely. The thickness laid is normally 5/8 to 3/4 inch.

3.4.7.6 Estimated Performance Period. The AASHTO Design Manual estimates that a porous friction course will last 3 to 7 years under low to moderate traffic [3.4-6].

3.4.8 Rejuvenators

Rejuvenators are used to restore pavement performance believed to have been lost as the bituminous binder ages, along with the sealing of surface openings caused by weathering and temperature cycling. Many rejuvenation techniques depend mainly on softening the bituminous binder. These must be used carefully since the advantages may not outweigh the disadvantages. However, some materials, such as sprayed-on elastomer emulsions, result in a favorable modification to the binder composition, not just surface course stiffness.

Most rejuvenators are proprietary materials and thus it is difficult to determine expected performance of these materials. Promotional literature claims unqualified success. Any product used for bituminous pavement rejuvenation should comply with the following recommendations [3.4-19]:

1. It must be easily applied, and provide quick penetration to a depth such that significant modification of the pavement surface layer can take place.
2. The material should be compatible with aged bitumens and produce beneficial modification to the road which outweigh any detrimental effects.

3. The total cost should be reasonable for the benefit received.

4. The material should not be hazardous to apply, nor result in environmental contamination.

In order for a rejuvenator to be effective, it must penetrate into the asphalt. If it does not penetrate, the asphalt is not softened and the surface will become slick - especially in wet weather. It has been reported that rejuvenators will not be effective if the voids in the total mixture (VTM) are below 7 to 8 percent, since sufficient permeability is not present to allow the rejuvenator to penetrate the surface [3.4-17].

Excess rejuvenator should be sanded and removed if it remains on the surface after 24 to 48 hours [3.4-18]. Also, rejuvenators should not be applied to pavement surfaces with a large amount of asphalt near the surface, such as slurry seals or surface treatments [3.4-18].

Only one Washington agency that completed this study's questionnaire reported using rejuvenators. This county reported that the beneficial effects of rejuvenators last 1 to 3 years. A few Oregon agencies reported using rejuvenators, and they estimated that rejuvenators last 4 years, with an average cost of $0.16 per square yard. The AASHTO Design Manual estimates that rejuvenators have a 1 to 3 year service life under low and moderate traffic levels [3.4-6].

3.5 CRACK SEALING

3.5.1 Definition

Crack sealing involves cleaning asphalt pavement cracks and placing a sealant material to seal the cracks.

3.5.2 Purpose

When cracks in asphalt concrete pavements are adequately sealed and maintained, surface noncompressibles are rejected from the cracks, oxidation of the asphalt binder at crack faces is reduced, and the infiltration of surface water into the underlying base and subgrade is minimized. Crack sealing will reduce raveling and further deterioration of the asphalt concrete at the crack face, reduce weakening of the base and subgrade layers due to infiltrating water, and prevent noncompressibles from restricting crack closure during warm weather.

3.5.3 Appropriate Crack Sealing Applications

The Federal Highway Administration Pavement Rehabilitation Manual [3.5-1] suggests the following criteria be used for crack sealing:

1. Nonworking cracks less than 1/8 inch wide should not be routed or crack sealed. These cracks generally do not penetrate through the surface and should not pose a source of deterioration to the pavement. If there are many small cracks, consider sealing the entire area with a slurry seal, chip seal, or overlay. The practice of sealing tight non-working cracks by pouring a sealant over them is of little or no value, and may cause a skidding problem.
2. Cracks between 1/8 inch to 3/4 inch wide should be sealed. These cracks should only be routed when sidewalls have deteriorated, or if they are thermal cracks. Thermal cracks undergo large movements with temperature changes, and need a crack sealant reservoir to accommodate the strain developed during these movements [3.5-2]. A

blocking medium may be used in the routed cracks to preserve the desired shape factor.

3. Cracks greater than 3/4 inch wide with spalling should be repaired with a patch.

Crack sealing can only be effective as long as the sealant prevents the intrusion of water. It cannot be effective when the pavement integrity has failed. Therefore, pavements with alligator cracking or extensive cracking should not be crack sealed. Crack sealing has been used as a surface preparation activity prior to placing an overlay to limit further general deterioration of the crack walls after the overlay has been placed.

3.5.4 Materials

Crack sealant materials should have the following properties [3.5-3]:

- o the ability to penetrate into the crack at low ambient air temperatures;
- o flexibility at low temperatures;
- o flow resistance at high service temperatures;
- o adhesion to asphaltic concrete;
- o cohesive failure resistance;
- o resilience or elasticity;
- o low temperature elongation at high rate of strain;
- o good ductility under conditions of low temperature;
- o reasonable cure time;
- o weathering resistance; and
- o workability.

These properties are important for several reasons. Sealants that lose cohesiveness as they harden are more susceptible to tensile failure, and sealants which have low adhesiveness will separate from the sidewall soon after placement. Non-durable sealants will blister, harden, and crack in a relatively short time.

There are three basic classifications of sealants based on their physical characteristics and degree of temperature susceptibility modification: unmodified asphalts, asphalt-rubber, and polymer-modified asphalts. Unmodified asphalts include various grades of asphalt cement, emulsified asphalts, cutback asphalts, and asphalts that contain various types of mineral or fibrous fillers. Asphalt-rubber is a mixture of paving grade asphalt cement and between 15 to 30 percent granulated reclaimed crumb rubber and particles. One study recommended that 18 percent plus or minus 1 percent rubber by weight be used, since this provides a good sealant with substantially reduced material warm-up time and reduced equipment clogging [3.5-3]. Polymer-modified asphalt hot-poured sealant materials are compounded with asphalt cements, plasticizers, and various types of polymers and other ingredients [3.5-4].

Two basic sealant classifications with respect to mode of application exist: cold-pour and hot-pour. Cold-pour sealants are applied by pouring at ambient temperatures. Cold-pour sealants cure or set up as the fluidizing medium evaporates. Hot-pour sealants must be melted and then heated before being applied.

Use a quality product to seal cracks. Crack preparation and traffic control costs are generally the largest part of the cost in a resealing project. Using life cycle cost analysis, sealants with the longest life (even with higher initial costs) may be the most cost effective.

3.5.5 Equipment

Equipment used in crack sealing operations includes sealant melters (tarpots, sealant melters with oil heat transfer systems, and sealant melters using hot air as the heat transfer medium), sealant applicators (wands and hoses, pour pots, squeegees, band-aid squeegees), and crack preparation equipment (routers, air lances, wire brushes, and hot compressed air lances).

Crumb rubbers and most of the high-ductility materials have insulating characteristics, and need specially built sealant melter units with controlled heat transfer to properly obtain the higher temperatures required for application. Certain types of rubbers may be easily damaged if overheated. Closely regulated temperature control of both the product and the heat transfer medium are required. [3.5-5]

3.5.6 Procedure

Crack sealing involves several steps which are discussed below.

1. If necessary, route the crack to obtain a shape factor (depth to width ratio) of 1 to 2 [3.5-1].
2. Clean the cracks well. They need to be free of dust, dirt, loose aggregate, vegetation, and moisture to ensure that adequate bonding is achieved. Several different methods are used for cleaning the cracks. Wire brushing may clean the crack of most debris, but may not remove the dust which can inhibit the bond between the crack wall and sealant. Back-pack blower units do not have enough pressure to clean the cracks adequately, and thus are not recommended for this purpose. Compressed air will usually provide a clean face for bonding in dry cracks that are relatively clean and at least 1/2 inch wide. Equipment that combines high pressure with heat is very effective. This equipment delivers a high-velocity, heated air stream which dries and cleans the crack. In addition, the asphalt surface is heated and the asphalt binder softened to aid the bonding of the sealant. Hot compressed air equipment should improve the bonding achieved in cold or moist pavements. [3.5-3]
3. Place backing material, if required, to obtain desired shape factor.

4. Do not place sealant unless the pavement is dry and the temperature is at least 45 degrees F and rising [3.5-1].

5. Pour sealant material into crack and fill it completely. Pour slightly above the pavement surface and if necessary, smooth sealant tight to the surface with a squeegee.

6. Blotting material may need to be applied prior to allowing traffic to cross recently-poured material, especially when the ambient temperature is greater than 70 degrees F.

It should be noted that routing to widen and shape cracks is a controversial procedure. Proponents claim routing is necessary to achieve the proper reservoir shape needed for the sealant to perform well, especially in thermal cracking situations. Opponents claim it is a costly, time-consuming portion of crack sealing, which is often ineffective. When routing is not required, savings of 15 to 30 percent can be realized [3.5-3]. Routing may cause a fracture or weakening of the sidewall and a subsequent sealant failure. Routing opponents claim that 10 to 20 percent of the cracking is commonly missed with the router. In one field study, many of the routes in the wheelpaths collapsed, and when sealants failed, pot hole development was higher in the routed sections than the unrouted sections [3.5-5].

3.5.7 Cost

Crack maintenance is costly, time consuming, and very labor intensive. As a class, unmodified asphalts are the least expensive. Asphalt-rubber modified asphalts are more expensive than unmodified asphalts, and the cost of polymer-modified asphalts is highly variable, depending upon the composition of the sealant.

The Federal Highway Administration Pavement Rehabilitation Manual estimated the cost to clean, route, and seal cracks in the range of $0.50 to $0.80 per linear foot when performed by contract and using high quality sealant [3.5-5]. The questionnaire distributed throughout Washington State, as part of this study, found that Washington counties spend between $0.29 to $0.50 per linear foot, with an average reported value of $0.40 per linear foot, to crack seal. Washington cities estimated that crack sealing with rubberized material cost between $0.40 to $0.91 per linear foot, with an average of $0.65 per linear foot.

3.5.8 Estimated Performance Life

Unmodified asphalts have a high degree of temperature susceptibility. In addition, they have little or even negative resilience values. Because of these properties, unmodified asphalt sealants tend to experience tracking in warm weather and may crack easily in cold weather. They will permit penetration of noncompressible materials into sealed cracks, and suffer from bond and adhesion failure. Generally, the useful life of these sealants has been reported as less than one year [3.5-4] to 1 to 2 years [3.5-1].

Asphalt-rubber sealants have improved temperature susceptibility characteristics and higher elasticity than the unmodified asphalt sealants. Properly formulated asphalt-rubber sealants can provide an effective and lasting seal for many types of cracks in all but the coldest of climates. Some agencies report a performance life of 7 years for asphalt-rubber sealants, but the average life is 3 to 5 years [3.5-3]. There are different types of asphalt-rubber sealants, and their performance lives vary.

Polymer-modified asphalt hot-poured sealant materials have a high degree of temperature susceptibility modification, and thus greatly improved performance when compared with unmodified asphalt sealants. These sealant materials are very promising but long-term performance data are still needed. There are a variety of these sealant materials available, and each type should be evaluated separately.

Washington cities that responded to a questionnaire distributed as part of this study reported that crack sealing using rubberized material lasts 2 to 6 years, with an average of 5.1 years. The cities reported that sealing with materials that are not rubberized last 1 to 5 years, with an average expected life of 3.7 years. Counties reported that crack sealing (unidentified sealant types) last 3 to 10 years, with an average expected life of 5.4 years.

3.6 ASPHALT PAVEMENT RECYCLING

3.6.1 Definition

Asphalt pavement recycling is the reuse of an existing asphalt pavement through surface recycling, cold-mix recycling, or hot-mix recycling. The Federal Highway Administration provided the following definitions in an 1987 recycling report [3.6-1]:

1. Asphalt Pavement Surface Recycling - The re-working in-place of the surface of an asphalt pavement to a depth of less than about two inches by any of the suitable machinery available. This operation is a single- or multi-step process that may involve the use of added materials, including aggregate, modifiers, or asphalt mixtures (virgin or recycled).
2. Cold-Mix Asphalt Pavement Recycling - The reuse of untreated base materials and/or asphalt concrete pavement that is either processed in-place or at a central plant with the addition of asphalt emulsions, cutbacks, portland cement, lime and/or other materials as required to achieve desired mix quality, followed by placement and compaction.
3. Hot-Mix Asphalt Pavement Recycling - The removal of more than the top inch of an asphalt pavement with or without removal of underlying pavement layers (e.g., untreated base materials) that is processed by sizing, heating, and mixing in a central plant with additional components such as aggregate, bitumen, or recycling agents and then relaid and compacted according to standard specifications for conventional hot mixtures (e.g., asphalt concrete base, binder, and asphalt concrete leveling or surface course).

3.6.2 Purpose

Recycling is used to improve pavement performance and correct noted deficiencies. Recycling provides conservation of materials (aggregate, binder, energy), preservation of road geometrics, energy conservation, protection of the environment, and often reduced costs. Recycling is particularly advantageous when only one lane is distressed, since just that lane can be repaired without affecting the adjacent lanes. Each recycling option, and its appropriate repair applications, is described individually in the following sections.

3.6.3 Surface Recycling

3.6.3.1 Definition. Surface recycling is a process in which the pavement surface is reworked or removed to a depth of less than 2 inches. In the literature reviewed, surface recycling is divided into two basic processes. One process involves heating, scarifying, remixing, and repaving the recycled material in a continuous process. This process is called hot surface recycling. The other process is a cold or hot pavement removal process normally using planer or milling equipment. While pavement removal is not technically part of a surface recycling process, the removed material can be recycled in a separate operation. [3.6-2]

3.6.3.2 Purpose. Surface recycling, in broad terms, can be used to correct several pavement distresses, including: raveling and weathering, non-load associated cracking, bleeding, low skid resistance, rutting, corrugations, and poor drainage profile. In addition, surface recycling reduces reflection cracking and promotes the bond between old pavement and overlays. It can also be used to eliminate feathering when placing a new overlay. For residential and low-volume traffic situations, surface recycling options are often sufficient. In all cases, surface recycling is only appropriate if the pavement structure is intact, since structural adequacy is not increased in the process. The appropriate application of each surface recycling process will be described below.

The major purpose of cold and hot milling is to remove surface deterioration and irregularities. In addition, skid problems can be corrected, drainage cross-slopes can be maintained, and the bond between the old pavement and new overlay can be improved through surface milling. The removed material can be used for unstabilized base courses or recycled (in-place or plant) into stabilized base and surface courses.

Cold planing is used primarily to remove corrugations, to reduce rutting, and to remove improperly designed or constructed surface treatments [3.6-3]. The material that is removed is often reused. Today's generation of equipment tends to be evolving more towards milling machines, since they physically cut the surface of the road, whereas earlier planing machines scraped the surface. Often, in the more recent literature reviewed, cold milling and cold planing are referred to synonymously.

Heater planers have been used to remove localized instability; to correct low and medium rutting if it is developing in the asphalt concrete layer; to correct bleeding, raveling, and low skid areas; to remove localized surface deformities such as corrugations; and, to remove material to reduce feathering of the overlay along gutters.

Hot surface recycling can be used for a number of corrective actions, including correction of gradation deficiencies, correcting asphalt content (too much or too little), and correcting asphalt properties. In addition to the five uses listed for heater planers, heater scarifiers are suited to sealing and rejuvenating oxidized or cracked surfaces which may have material deficiencies as well as cracking, and producing a strong bond between the old pavement and the new overlay. [3.6-2]

3.6.3.3 Materials. When heater scarifiers are used, additional materials may be added, such as aggregate and/or modifiers. Modifiers normally include rejuvenating agents and soft asphalts. It is desirable to select the amount of modifier that restores the desired consistency, either viscosity or penetration to the asphalt. A slightly softer consistency than normally selected has proven beneficial in reducing reflective cracking when the scarification precedes an overlay. [3.6-2]

3.6.3.4 Equipment. There are many different types of surface recycling equipment. Each will be discussed briefly below.

3.6.3.4.1 Cold Millers. Cold millers are equipped with rotating drums lined with tungsten-carbide-tipped cutting teeth that grind the pavement.

3.6.3.4.2 Cold Planers. Cold planers are normally motor graders with hardened steel blades.

3.6.3.4.3 Heater Planer. Heater planers use heating units that precede the planer, or single pieces of equipment that can both heat and plane the pavement. After the top surface of the pavement is heated, it is then bladed off the underlying pavement.

3.6.3.4.4 Heater Scarifier. Heater scarifiers heat and scarify the surface. Immediately following the heater a series of carbide-tipped steel blades mounted on springs or air bags scarify the heated surface to the desired depth. The equipment may be self-contained single units or multiple-unit paving trains. It is usually limited to a depth of 3/4 inch to 1 inch in a single pass. The equipment required for heater-scarifier surface recycling is heater-scarifier, roller, distributor truck and usually a paver.

3.6.3.4.5 Hot Millers. Hot milling equipment heats the pavement surface and then mills or grinds the surface down to a depth of about 1 to 2 inches. It has not been used extensively in the United States.

3.6.3.5 Procedure. The procedure normally followed when the different surface recycling methods are used will be presented under separate sections below.

3.6.3.5.1 Cold Milling. The action of cold milling is produced by carbide tipped cutter bits mounted on a revolving drum. The arrangement of bits on the cutting drum produces a pattern on the milled surface, which can provide a very skid resistant surface. However, if the aggregates used are low skid resistant quality, the milled surface can polish rapidly. The quality and roughness of the surface texture is dependent on the forward velocity of the miller; the rotational velocity of the cutter drum; type, spacing and arrangement of teeth; and the grade control [3.6-2]. A uniform texture should be produced throughout the project. The surface millings can be recycled through a cold or hot mix process and reused as a base course or surface course material depending on their quality. Cold-milled bituminous pavement surfaces may experience raveling if not overlaid or sealed, and a cold-milled surface has a rough texture which may give undesirable ride qualities due to excessive noise [3.6-4].

3.6.3.5.2 Cold Planing. A motor grader with hardened steel blades is usually used by local governments during the summer to remove material. The material that is removed is often reused. [3.6-3]

3.6.3.5.3 Heat Planing. Heater planers heat about the top inch of the pavement, which is then bladed off. The excess material can be used in other recycled mixes. The most common heating systems are either radiant-heat emitters or open-flame burners. They are enclosed by a hood that directs the heat onto the pavement.

3.6.3.5.4 Hot Surface Recycling. The hot surface recycling operation includes performing a laboratory analysis of the materials; preparing, heating, and scarifying the surface; adding additional materials, if required; placing and compacting a thin overlay and making final adjustments to manholes and drainage structures. In order for heater-scarifiers to work, the pavement should have at least 3 inches of an asphalt mixture and the surface aggregates should not be larger than 1 inch. The equipment is not suitable for steep and curving roads. [3.6-1]

Preparation of the pavement prior to heater scarification during hot surface recycling includes cleaning the pavement surface. Grease, excess crack-pouring materials, or oily substances should be removed, since surface heaters used to preheat the pavement can cause air pollution problems in these cases. If there is free asphalt on the surface or heavy fog seals, sand, slurry, or chip seals, this will usually need to be removed also to assure compliance with air pollution regulations [3.6-5].

The depth of scarification is a critical element. The deeper the scarification, the better will be the finished product. Once the material has been heated and scarified, a rejuvenating agent may be sprayed on the hot mixture before it is screeded and compacted. Aggregate problems for the top inch can be corrected by adding more aggregate.

3.6.3.6 Cost. Surface recycling is the least expensive of the recycling options. In general terms, one report estimated that the cost of surface recycling is approximately one half that of a conventional 1 inch thick asphalt concrete overlay [3.6-7]. The Oregon Department of Transportation reported in a recent publication that surface recycling with a chip seal results in a 24 percent cost savings, and surface recycling without a chip seal results in a 70 percent cost savings, when compared to reconstruction or placement of an overlay with virgin material [3.6-1].

The specific data pertaining to surface recycling costs were very limited. The representative cost for heat scarifying was estimated at $0.90 per square yard in a 1984 report [3.6-8]. A document prepared by the Seattle Engineering Department in 1987 provided a bid price of $2.15 per square yard for heater-scarification.

One Washington county that completed this study's questionnaire provided a cost estimate for surface recycling with a seal coat of $2.84 per square yard. One Washington city reported that surface recycling with an overlay cost $15 per square yard.

3.6.3.7 Estimated Performance Life. All surface recycling projects vary greatly with respect to performance. The type of project, method used, experience of the construction personnel, and many other factors all influence the performance of the final product. A recent national survey found that agencies expect hot surface recycling projects to last 11 years on the average [3.6-8]. One Washington county reported that surface recycling with a seal lasts 7 years, and a Washington city estimates that surface recycling with an overlay last 17.5 years. One Oregon agency estimated that surface recycling lasts 10 years.

3.6.4 Cold-Mix Asphalt Pavement Recycling

3.6.4.1 Definition. Cold-mix asphalt recycling is a process in which reclaimed asphalt pavement materials (RAP), new aggregate and/or reclaimed aggregate materials (RAM), or both, are mixed with new asphalt and/or recycling agents to produce cold-mix base mixtures. The mixing may be done at a central plant or in place, and the process does not require the addition of heat. Cold recycling can also involve the reworking of foundation materials and roadways without surfaces. [3.6-1]

3.6.4.2 Purpose. In-place recycling is used to correct surface deficiencies (mixture problems, distresses), correct base deficiencies (gradation, moisture concentrations, density), to reduce or eliminate reflection cracking, and to improve skid resistance and ride quality. When pavement deterioration is so bad that the conventional overlay thickness required is not economical or is prohibited by existing grades, cold-mix recycling should be considered.

3.6.4.3 Equipment. The equipment used in cold recycling is basically the same that is used for conventional stabilization procedures and therefore is readily available. The only special equipment required is that needed to properly size the bound material prior to stabilization. Surface break up can be accomplished with road graders equipped with scarifier teeth rather than blades, bulldozers with ripper teeth pulled behind, and pulverization equipment. Sizing can be accomplished with rippers (hammermill, open grid rollers) and pulverizers. Blade mixers, rotary mixers, and travel plant mixers can all be used for mixing. Standard compaction equipment for compacting cold mix asphalt material is used.

3.6.4.4 Materials. Asphalt cement, cutbacks, and emulsions have all been used in cold-mix recycling. The Asphalt Institute considers AC-2.5, AR-1000, and 200-300 pen asphalt cements and medium or slow-setting emulsified asphalts, which meet either ASTM D977 or ASTM D2397 requirements, appropriate for cold-mix recycling [3.6-9]. One report recommends that due to the limited experience in using emulsified asphalt in a cold-mix recycling process, emulsions should only be used on low volume roadways, on expressway shoulders, and as a base material. Another publication reported that foamed asphalt provided satisfactory initial performance as a binder material. This report stated that foamed asphalt has an advantage over asphalt cement because it can be used at lower temperatures, and an advantage over emulsions because it does not need curing time [3.6-10]. When deciding which type and grade or asphalt cement or emulsified asphalt to use, first consider the type and grade that is performing satisfactorily on local projects with aggregate gradations and traffic conditions similar to those on the project under study. The decision must consider usage of the completed pavement, environmental conditions at the pavement location, type of equipment available, aggregate type, subgrade firmness, and construction operations. Consider the properties of the asphalt, consistency, and curing or setting rate.

Available stabilizers for use in cold recycling include lime, portland cement, and fly ash in combination with lime, portland cement, and flue dust. The choice of stabilizer depends on the characteristics of the soils or aggregates. If new aggregate is needed to correct the gradation of the reclaimed aggregate material or to increase the thickness of the recycled pavement, its quality should not be less than that of the reclaimed aggregate material. Not all water is compatible with emulsified asphalt, and it should be tested before use.

3.6.4.5 Procedure. There are six basic steps in the construction of a cold recycled asphalt pavement. These are:

1. preliminary work (field sampling, laboratory analysis, and additive selection),
2. pavement removal and size reduction,
3. addition of new asphalt/recycling agent and mixing,

4. spreading and aeration,
5. compaction and curing, and
6. application of wearing surface.

The pavement to be recycled should be sampled to determine the properties existing in the materials that will be recycled in each layer. The laboratory analysis is crucial in producing an acceptable recycled mixture. A thorough laboratory analysis should consist of additive selection, gradation analysis, and mix design.

The road surface and/or base is broken up to a specified depth. Ripping/scarifying and cold milling are common methods which may be used to break the pavement. Scarifying is inexpensive, but the depth of the rip is hard to control, and the pieces must be further sized to produce the final gradation. The broken-up material can be further reduced in size in-place or hauled to a central plant location for crushing. Cold milling directly reduces the pavement to desired particle size.

Mixing uniformly distributes the asphalt material through the recycled asphalt pavement, old granular base and new aggregate, if used. The mixing operation consists of determining the additive rate, mixing, and spreading. The material may be mixed in-place. The pulverized material is windrowed, the stabilizer is added, and the material is mixed using blade mixers, rotary mixers, or travel plant mixers. The material can also be transported and mixed cold at a plant. The choice of mixing techniques will depend upon the equipment available, the type of asphalt used, and the degree of uniformity required.

Mixtures that do not require aeration may be spread to the required thickness immediately after mixing. The material must be properly compacted using normal compaction procedures for a cold mix asphalt material. A delay in initial rolling may be necessary for cold-mix recycling, especially with dense-graded mixes. Rolling seals the pavement as it reduces the voids in the mix. If done prematurely, it retards evaporation of the water in the mix and greatly extends the time required for the mix to reach required density. The mix must also be allowed to develop sufficient cohesion to support the rollers.

If delayed too long, compaction will be difficult and in some cases the developing asphalt-aggregate bond will be irreversibly broken. A surface layer of some form must then be placed to keep air and water from intruding into the mat. [3.6-9]

The Kansas Department of Transportation has discovered that their cold-recycled pavements:

1. exhibit less reflective cracking if the existing mat is left as thin as possible while still being thick enough to form a solid base for equipment, and
2. in dry Western Kansas, performs better with minimal amounts of emulsion or rejuvenator added to the new mix [3.6-11].

3.6.4.6 Cost. In general terms, the literature reviewed reported that significant savings may be realized when recycling is used, rather than asphalt overlays, to repair secondary roads. As the distance new materials must be hauled increases, the cost advantage of recycling increases significantly. About half of the cost of recycling lies in the new binder or recycling agent used to restore the properties of the reclaimed pavement material [3.6-12].

One Oregon agency that completed the study's questionnaire estimated that cold-recycling costs $6.80 per square yard to complete. The Kansas Department of Transportation reported that conventional cold-recycling to a depth of 4 inches plus a 3/4 inch hotmix overlay is $31,000 per two lane mile (approximately $2.20 per square yard), with the 4 inch cold-recycling alone costing $15,000 per two lane mile ($1.06 per square yard), and a 4 inch cold-recycle plus chip seal costing $22,500 per two lane mile ($1.60 per square yard) [3.6-11]. The Pennsylvania Department of Transportation reported that 3 inches of recycled base costs $4.09 per square yard, versus $5.80 per square yard for virgin material [3.6-13]. The New Mexico Department of Transportation found that the cost savings between cold-recycling and conventional overlays averaged between $2.34 and

$3.88 per square yard, with an average cost of in-situ cold-recycling of $0.70 per square yard - inch [3.6-14].

<u>3.6.4.7 Estimated Performance Life.</u> The performance of cold-mix recycling is difficult to quantify, since each project is unique. A recent national survey found that cold in-place recycling was expected to last 9 years [3.6-8]. An Oregon agency that completed our questionnaire estimated that cold recycling lasts 20 years.

3.6.5. Hot Mix Recycling

<u>3.6.5.1 Definition.</u> Hot mix recycling is a process in which reclaimed asphalt pavement materials (RAP), reclaimed aggregate materials (RAM), or both, are combined with new aggregate and/or asphalt, and/or recycling agents, in a central plant blending and mixing operation. The finished product is a hot-mix asphalt base, binder, or surface course.

<u>3.6.5.2 Purpose.</u> Hot mix recycling can provide significant structural improvements, treatment for all types and degrees of pavement distress, elimination of reflection cracking, skid resistance improvement, and improvement of ride quality.

<u>3.6.5.3 Materials.</u> During hot mix recycling, rejuvenating agents, additional new and/or reclaimed aggregate, and new asphalt cement may be added to the mix. Asphalt binders in salvaged asphalt mixtures are often brittle and have undesirable properties which need to be modified before reuse. Rejuvenating agents are organic materials with chemical and physical characteristics selected to restore aged asphalt to desired specifications. It is normally more desirable to use a softer asphalt without the use of any other rejuvenating agent, if possible [3.6-2]. New low viscosity or high penetration asphalt cement will serve two purposes: increase the total asphalt content to meet requirements of mixture, and blend with aged asphalt to yield asphalt meeting specifications. The combination of salvaged asphalt with new asphalt should provide a blend with viscosity or penetration equal to that commonly used in conventional asphalt mixes [3.6-15].

Antistripping additives, such as hydrated lime, should be considered when a moisture susceptible salvaged mix is used [3.6-15]. New aggregates may be added to meet gradation requirements, satisfy skid requirements, meet air quality requirements, meet thickness requirements, improve mix properties, and to maintain required mix proportions.

3.6.5.4 Equipment. Much of the same equipment used for pavement removal and sizing in cold recycling can be used in hot mix recycling. Batch plants and drum mixers have been used to recycle the salvaged materials. Plants specially designed for hot mix recycling are also available. Conventional equipment is used for laying and compacting the hot mix recycled materials.

Historically, it was not acceptable to use 100 percent reclaimed asphalt concrete material into recycled mixtures due to air pollution problems. Microwave heating has recently been used in an attempt to overcome this limitation. [3.6-16]

3.6.5.5 Procedure. The recycling operation involves the following activities: preliminary evaluation (field sampling and laboratory analysis); removal of existing asphalt pavement; preparation of reclaimed pavement for hot-mix recycling, stockpiling, and crushing; processing the blend of old and new materials in a hot-mix plant; and, placing the recycled material.

The preliminary evaluation includes a distress survey and a drainage survey to establish the types and probable causes of distress. Field sampling is used to characterize the project. A sufficient quantity of materials must be collected for mix design tests and structural tests. Different aggregates and asphalt quantities should be examined to select optimum values. Laboratory analysis includes: extraction and recovery of asphalt cement and aggregate, examination of asphalt cement properties, selection of a modifier, examination of aggregate properties, and development of a suitable mix design.

Material preparation includes full or partial-depth removal of the pavement and reduction of the asphaltic concrete to the appropriate size. The material can be sized in place and hauled to a plant, or it can be removed from the site and crushed at the central plant. In-place removal and sizing can be done using milling machines, heater-planers, and on-grade pulverizers. Sizing at a central plant can be accomplished with conventional crushing and screening equipment.

The material is then reprocessed by feeding the sized, salvaged material through a hot mix plant with the addition of virgin aggregate, salvaged base aggregate, virgin asphalt cement, and a modifier. Three types of central plant hot processing are used: direct flame heating, indirect flame heating, and aggregate superheating. [3.6-6]

The recycled material is then re-layed as a base, binder, or surface course. Conventional equipment and procedures have been used for laying and compacting hot mix recycled materials. The mixtures should be compacted to a density of 92 to 97 percent of the Rice theoretical maximum density [3.6-15].

3.6.5.6 Cost. Cost depends on many factors: availability and cost of aggregate, availability and cost of asphalt cement, and the presence of necessary equipment and experienced operators. The Washington Department of Transportation found that the bid price of asphalt concrete where recycled planing materials were used offers an average 34 percent cost advantage over new asphalt concrete paving based on 1982 production [3.6-17]. Another study found that the U.S. average cost savings when comparing recycled mix to virgin mix ranged from 1 to 40 percent. In this study, Washington State showed an 18 percent savings [3.6-1].

3.6.5.7 Estimated Performance Life. The Washington Department of Transportation had completed 24 hot-mix recycling projects as of January, 1985. The two initial projects, built in 1977 and 1978, are performing well. The others are still relatively young, but early performance data are promising. Pavement performance resulting from hot mix recycling in Washington State has been comparable with new asphalt concrete paving. [3.6-17]

3.7 PATCHING

3.7.1 Definition

Asphalt patching involves filling holes in the pavement surface, either produced by deterioration or purposely made by maintenance forces, with bituminous patching materials.

3.7.2 Purpose

Patching is used to correct damaged pavement areas, including those exhibiting potholes, failed patches, edge cracking, rutting, fatigue cracking, raveling, bleeding, depressions, and upheaval [3.7-1,3.7-2]. In general, patching is needed when the surface of the pavement becomes too rough for the safe passage of traffic.

3.7.3 Materials

Bituminous patching mixtures need to have the following properties in order to perform well [3.7-1]:

1. Stability - to resist shoving and rutting,
2. Cohesiveness - to adhere to the holes,
3. Resistance to Water Action - to prevent stripping,
4. Durability - to resist deterioration and disintegration due to traffic and weather,
5. Workability (if stockpiled) - to allow easy handling, shoveling, and compaction, and
6. Storageability (if stockpiled) - to allow long storage periods while still retaining workability.

Bituminous patching materials may be separated into three major categories: hot mixes, cold mixes (stockpiled), and recycled pavement materials. In addition to these categories, various modifiers have been added to conventional patching materials, and many proprietary materials are also available.

3.7.3.1 Hot Mix. Hot-laid patching mixtures (excluding cold stockpiled materials which are reheated prior to placing) are produced in hot mix plants. These materials are generally considered the most desirable for patching, since they contain quality aggregate, strong bitumen binder, and are accurately proportioned. Since hot mix asphalt plants normally close during the winter or periods of no construction, the use of this material may be seasonally limited. When hot mix is available, the typical truck load obtained necessitates patching many potholes to use up the mix before the mix has cooled to the point when proper compaction can no longer be achieved.

It is possible to use hot mix year round. Small portable mix-plants designed for small jobs and maintenance operations, which are equipped with a small dryer and pugmill, can be used to prepare hot mix during any season [3.7-3]. Other agencies order hot mix asphalt concrete that meets their specifications in the fall before the hot mix asphalt plants close. The hot mix is tailgate spread in a layer 6 to 8 inches thick on a relatively clean paved area. After the hot mix has cooled, it is broken up and stockpiled under cover. Hot boxes or small portable recycling equipment are then used to heat this stockpiled asphalt concrete for patching. In the summer, these same hot boxes keep asphalt concrete picked up at the plant hot all day and even overnight, eliminating the waste caused by a load of asphalt that has cooled below specifications [3.7-4].

All the literature reviewed supports the contention that hot mix is the preferred material to use during the warm months. However, there is a wide range in the reported performance of hot mix as a patch material in cold, wet weather. A Value Engineering Study, cited in an Ohio Department of Transportation report, found that reheated hot mix performed well in cold, wet weather installations [3.7-5]. Likewise, a New Jersey study found that conventional hot-mix asphalt outperformed the standard cold-mix patching material [3.7-6]. However, the Ohio Department of Transportation found that hot-mix patching material is not suitable for their cold, wet weather patching conditions [3.7-5]. A Pennsylvania study found that, when using plant-mixed, cold, stockpiled patching mixtures compacted by mechanical means, after two winters 70 percent of the repairs were rated being in good to excellent condition, and there was no significant difference in the survival rate of repairs made with cold mix or hot mix [3.7-6].

3.7.3.2 Cold Mix. Cold mix materials are usually made with a cutback or emulsified asphalt. A cold mix stockpile is often maintained at local garages and maintenance yards. Mix design is critical for a cold mix to perform properly. However, most local agencies do not have the staff or facilities to develop these mixes, and therefore rely on local batch plants that often sell poor quality cold mix. The heating of stockpiled cold mix prior to placing the patch is considered beneficial. A New Jersey study reported that patching operations where cold mix was preheated lasted 75 percent longer than those placed cold, and an Indiana study found that heating cold mix resulted in improved durability compared with using unheated cold mix [3.7-6].

Old material that has been removed from a paved surface can be reused for patching. It is processed in a portable recycling/patching machine or at a batch plant, because heat is needed to soften the old asphalt and make the mix workable. In addition, the aged asphalt concrete tends to be brittle, so new material is usually blended into the mix. Recycled pavement might be blended with cold mix or a rejuvenator before being used as patch material. [3.7-7]

The Texas State Department of Highways and Public Transportation conducted a study in which fly ash combined with coarse aggregate and polypropylene fibers was studied as a potential material for the rapid repair of wet asphaltic concrete. It is a temporary repair lasting from one to three years. [3.7-8]

Roll roofing material is being investigated as a substitute for conventional skin patching. Although the application of roll roofing costs more than skin patching, superior performance may be obtained for limited applications. It is a viable alternative for skin patching when excessive multi-directional traffic movement is present and during cold weather at primary locations for potential pothole development. [3.7-9]

3.7.3.3 Binders. Hot mix patching materials achieve workability through heat, so the binders in these mixes need to be stiff and provide good durability. Usually, asphaltic cements are used for this purpose. AC-20 (60 to 70 pen), AC-10 (85 to 100 pen), and AC-5 (120 to 150 pen) are the grades most commonly used [3.7-1]. High float emulsions have also been used for these hot patching mixtures.

Stockpiled patching mixtures need binders that are resistant to moisture damage in the stockpile, workable during transport and placement, and stable after placement. The binder should have low temperature susceptibility, shear thin during working, and cure rapidly after placement without excessive hardening. [3.7-6]

Liquid bituminous binders are used in cold mix patch materials. Medium-curing cutbacks, MC-250 and MC-800, are the most commonly used. The thicker grade (MC-800) can be used in the fall and spring, and the thinner grade in the winter. The primary advantages of the cutback asphalts are their relative simplicity of use and low cost. The main disadvantage is their potential for air pollution. Medium and slow-curing asphalt emulsions and cationic emulsions have been used, but these are often not very workable. High float emulsions, HFE-150 and HFE-300, have been used successfully. In fact, one research effort found that certain high-float medium-set emulsion binders performed demonstrably better than other binders [3.7-6].

A recent research study evaluated various materials to rate their effectiveness as potential cold mix binder modifiers. Plastics, elastomers, reclaimed tire rubber, and polymeric fibers were analyzed. Consideration was given to the addition of these modifiers to conventional medium-curing cutback asphalt cements, anionic and cationic emulsions, and high-float emulsions. The study found that the most successful binders were those based on the HFMS-2 emulsion. The MC-800 modified with latex showed very poor performance. The butyl-modified high-float emulsion, especially with the addition of fibers, was found to have the characteristics necessary to produce a mix with significantly improved performance and to be a cost-effective replacement for conventional cutbacks or emulsions. [3.7-6]

3.7.3.4 Aggregates. The aggregates used in patching mixtures are very important. They should be clean and have good resistance to abrasion and stripping. Angular, rather than rounded, aggregate is recommended. Crushed stone is recommended by some agencies, required by others. Dense-graded aggregates, which result in highly stable and durable patching mixtures, are typically used for hot mixes.

In a cold mix, resistance to pushing and shoving under traffic must be developed primarily by the interlocking of the aggregate particles. Cold mixes should contain crushed angular particles and a maximum of 1 to 2 percent passing the No. 200 sieve; the maximum aggregate size must be less than 1/2 inch. Limiting the amount of fine dust and the maximum aggregate size optimizes workability. Crushed angular particles are required to produce stability under traffic. A gradation that is relatively open provides sufficient space for the thick binder films that contribute to workability and water resistance. [3.7-6]

3.7.3.5 Tacking and Sealing Materials. Tacking materials are normally rapid curing cutbacks (RC-70, 250). They should be applied at about 0.10 gallons per square yard [3.7-7]. If too much is applied it will lead to shoving, or bleeding, and premature patch failure. Rapid setting emulsions set too quickly to be used for tacking, but medium setting and slow setting emulsions (MS-1, SS-1, 1h, and CSS-1, 1h) are acceptable. If the tack coat is asphalt emulsion, enough time should be allowed for the emulsion to break and most of the water to dry out before the patch-mix is placed. A cutback asphalt should be given time to penetrate and cure before the patch mix is placed. [3.7-3]

The most desirable sealing materials include rapid set emulsions (RS-1, 2 and CRS-1, 2). Medium set emulsions (MS-1, CMS-1) are acceptable, but less desirable. Slow set emulsions are not acceptable for sealing. Rapid cure and medium cure cutbacks have been used for sealing. [3.7-7]

3.7.4 Equipment

Four types of equipment are needed for effective pothole patching [7]:

1. Cleaning, tacking and sealing equipment;
2. Hole preparation equipment;
3. Mix equipment; and
4. Compaction equipment.

Brooms, brushes, spray cans, rags, and torches can be used for cleaning, tacking, and sealing. An air compressor with a sprayer would be useful for blowing debris from the hole and for drying. A pavement breaker (jackhammer) is the best tool for squaring a hole and making vertical sides. Some breakers are hydraulically driven by a gasoline engine and some require a portable air compressor. A chisel point with one flat side is recommended. A power saw should not be used unless there is no other way to make the vertical sides, since it will leave a surface which is too smooth.

Mix equipment includes recyclers, stockpile heaters, and hot boxes. Most portable recycling machines are designed to be towed and can be brought near the holes being patched. Stockpile heaters can be set up at a central maintenance yard and used like a miniature asphalt plant. The mix is then loaded into trucks with hot boxes and delivered to the work site. Hot boxes can be little more than insulated boxes, or they may have their own heat source.

Vibrating plate or vibrating roller compactors are the most suitable compaction devices. Some authorities dislike the use of vibratory plates for patch compaction, stating that they are inefficient and time-consuming [3.7-1]. The next most effective compactor, after vibrating plate and vibrating roller compactors, is the heavy "static" or non-vibrating steel wheel rollers for larger potholes. If other types of compactors are used (such as hand tampers), place the hot material in 1 to 2 inch lifts and take extra care to properly compact the patch. Compacting with truck tires alone is not recommended except under extreme emergency conditions. This type of compaction usually leaves the patch undercompacted, which will cause the mixture to rapidly shove out of the hole or to depress under traffic.

Equipment is available which partially automates the patching process. One such piece of equipment, the Patchmaster, was evaluated by King County in 1988 [3.7-10]. This equipment allows patching year-round. It heats the damaged pavement until it can be broken loose with a rake. Asphalt rejuvenator and new asphalt are then added and mixed in with the existing material. A rejuvenator is applied again and some sand is placed over the surface. The area is then compacted. This equipment apparently works well when used for the appropriate repairs. It is not suitable for making repairs involving on-going damage to the pavement base course, and is limited in the size of patch it can handle. It is not cost-effective to use this type of equipment to repair isolated potholes that require relatively long travel times.

Towed-type pavers or spreader boxes, and motor patrol graders can all be used for overlay paving. On small paving jobs, a tow-behind paver or spreader box is often the most convenient and economical placement method. Steel-wheeled, vibratory, and pneumatic-tired rollers are the most common compactors types used during overlay patching.

The Oregon Department of Transportation has found that inlay patching, using a planer, is effective. In small repairs less than 4 feet wide, the inlay repair area is ground out using a small cold planer equipped with a conveyor. The machines use a cutter head 14 to 20 inches wide. Full lane width repairs are done in the same manner using full-sized equipment, such as 78-inch cold planers and full-width commercial pavers. [3.7-11]

3.7.5 Procedure

There are seven basic steps that should be followed when constructing a patch:

1. Mark the patch boundaries,
2. Cut the patch boundaries,

3. Clean and repair the foundation,
4. Apply tack coat,
5. Fill hole with material,
6. Compact the material, and
7. Edge seal.

The boundaries are marked with chalk or paint and should include all deteriorated areas plus a safety margin of about 12 inches. These boundaries can be changed if cutting and removal expose more deterioration than was expected. When cutting the patch boundaries, sound vertical sides around the patch must be left. Full-depth saw cutting is not recommended because is produces a side wall that is too smooth for good bonding. Partial-depth saw cutting with breakout works well. A cutting tool is used to remove bituminous material.

The patch area must be thoroughly cleaned to provide a surface to which the tack and patch material can bond. Water, rocks, and dust must all be removed. Brooming alone is inefficient. Compressed air should be followed by brooming. The material at the bottom of the open patch should be reworked, dried out, recompacted, or removed if it is wet, loose, soft, or disturbed. Some reworking and recompaction should be standard procedure. The goal is to provide an adequate foundation for the new asphalt concete material. The Washington State Department of Transportation Maintenance Manual states that in all cases, the surfacing materials (gravel base, crushed surfacing) and pavement must be replaced in depths at least equal to the original design or by additional depth of asphalt concrete compacted in lifts of 1 to 3 inches [3.7-12].

A tack coat may be used to provide a bond between old and new surfaces. There is controversy with respect to the advisability of using a tack coat with cold mix patches. Some reports state that cold mix should never be tacked, since the solvents in the tack will soften the cold mix, increase shoving and promote stripping [3.7-1]. Other authorities, including the Washington State Department of Transportation, recommend that all types of patching material should be tacked [3.7-7, 3.7-12]. When tack coats are applied, they should be low-pressure sprayed or brushed onto the patch area. They should never be poured. A thin uniform coating is needed, and excess application of tack coat material must be avoided.

The patching material must not be allowed to segregate when being placed, so it should be dumped rather than raked or thrown into place. Segregation of the fine and coarse aggregate particles can greatly affect compaction. According to the Washington State Maintenance Manual, Class B asphalt should be compacted in lifts of no more than 3 inches thick to obtain optimum patch life. After the material has been placed, it should be tamped around the patch edges and corners.

Compaction is the most critical step in placing a patch. Letting traffic compact the mix is unacceptable except in grave emergencies. An undercompacted mix will ravel, shove, or compact and leave a depression. When compacting a patch, pinch the material into the hole by rolling the edges first. Next, roll the center of the patch, moving outward toward the edges with each pass. The roller must rest on the patch mix and not on the old pavement. If a hot mix is being used, the mix temperature should be watched carefully. Control tests need to be run with the compaction equipment being used to determine the number of coverages required to achieve adequate density. Traffic must be kept off the patch until it is cool enough to handle loading without marking or deformation.

Edge sealing is done to keep water out of the joint between the pavement and patch. A layer of fine sand can be used to blot the seal. An Indiana study found that tacking and sealing were detrimental when using unheated and heated cold mix because they contributed to patch failures such as rutting, shoving, and bleeding resulting from poor application control and excessive use of tack material [3.7-6].

The patching method described above involves removing and replacing damaged material, often referred to as "dig-out" patching. Another repair method, referred to as "overlay" patching, may be utilized when an area is too large to be economically repaired by hand or with a small crew. This process involves covering the defective area with an overlay of a suitable material to renew the surface, seal the defective area, and stabilize the affected pavement [3.7-12]. Typically, overlay patches are applied in areas of pavement failure or wear problems rather than areas with a base or subgrade problem. The overlay material is typically asphalt concrete Class B or Class G.

Prior to overlay patching, all loose asphalt should be removed and replaced. Any deep ruts, depressions, or swells must be repaired or preleveled, and all cracks should be cleaned and sealed. Before placing the overlay patch, the surface must be dry and free of loose rocks, sand, dust, oil, and grease.

A tack coat is placed on the clean and dry surface, typically at a rate of 0.02 to 0.08 gallons per square yard [3.7-12]. The asphalt is placed, and rolling should begin as soon as the material is laid. It is important to make the initial breakdown passes at least 4 inches away from the edges of the mat [3.7-18]. Traffic should be kept off the patch until it has had sufficient time to cure.

3.7.6 Cost

Total patching costs include equipment costs, personnel expense, material costs, future maintenance costs, user costs, and traffic control expenses. It is difficult to quantify the cost of patching, since a wide range in reported costs exists due to differences in materials and procedures being used. In general terms, pothole patching (cold mix) has been shown to cost five times as much annually as a one-time permanent patch [3.7-14]. A value engineering analysis showed that permanent repair would save an estimated 70 percent of a maintenance budget [3.7-15].

One research document reported the following patching costs in 1984 dollars [3.7-13]:

Shallow patching:	$16.20 per square yard
Deep patching:	$44.12 per square yard (hand placed)
	$32.30 per square yard (machine-placed)
Skin patching:	$9.79 per square yard (hand placed)
	$3.17 per square yard (machine placed)

The estimated cost in a 1988 report of various patch mixes were [3.7-6]:

Unmodified MC-800:	$30.00 per ton
MC-800 with fibers:	$35.00 per ton
MC-800 with latex:	$40.22 per ton
Unmodified HFMS-2:	$40.22 per ton
HFMS-2 with butyl:	$41.66 per ton
HFMS-2 with butyl and fibers:	$46.66 per ton
HFMS-2 with latex:	$40.61 per ton

Agencies within Washington State that completed the questionnaire distributed during this project provided widely varying cost estimates for the different patch types. The extreme range in cost estimates is probably due to a wide variety of patching methods, equipment, and material types. The cost ranges reported by these agencies are provided below:

1. Pothole patching cost between $14 to $150 per ton.
2. Skin patches were reported to cost $40 to $100 per ton.
3. Partial depth patching costs ranged from $58 to $122 per ton.
4. Full depth patching ranged from $46 to $230 per ton.

3.7.7 Estimated Performance Life

It has been reported in the literature that patch performance depends on the following factors:

- o material quality (aggregate and asphalt),
- o conditions of storage and handling,
- o weather conditions,
- o shape and size of patch,
- o patch location in reference to traffic,
- o preparations prior to patching,
- o construction effort, and
- o specifications and procurement practices.

A value engineering study conducted in 1976 indicated that a patch repaired with a "dump and run" procedure has a serviceable life of 1 month, and, on an annualized basis, a direct agency cost of $308 per ton [3.7-14]. According to that study, a properly compacted repair made by cutting out the deteriorated pavement will last more than 12 months and has an annualized cost per ton of $65 per ton. A more recent study shows that the uniform annual cost of repairing a pothole correctly, including manpower, material, and equipment, is about $100 per ton, whereas the "dump and run" procedure costs about $310 per ton [3.7-16].

In Washington State, results from questionnaires distributed as part of this study revealed the following:

- o Typical pothole patching, involving little hole preparation and cold mix material which is typically compacted with truck tires, can be expected to last 1 month to three years.
- o Skin patches are predicted to last 1 to 10 years, with a 3.5 year average life expectancy.

- Partial depth patches were reported to 1 to 12 years, with an average life expectancy of 6 years.
- Full depth patches have been found to last 1 to 15 years, with 8.5 years being the average.

Repair longevity is the secret to a cost-effective procedure since repeated repairs cost almost as much as the initial repair. Material costs were found to constitute less than 10 percent of the total cost of repair when the correct procedure was used [3.7-6].

3.8 ASPHALTIC OVERLAYS

3.8.1 Definition

An asphaltic overlay consists of the application of asphalt concrete to an existing pavement.

3.8.2 Purpose

Overlays are used to correct many pavement surface and structural deficiencies. The surface deficiencies include poor skid resistance, excess roughness, inadequate surface drainage, and climate-related deterioration. In many cases an overlay is used to correct structural failure. The primary load-associated distresses resulting from a structural deficiency include alligator cracking and rutting. The type of overlay needed for each pavement depends on the function of the overlay and the type and condition of the existing pavement. Each variation is most effective when used in specific applications.

3.8.3 Presentation

In this section, two types of overlays will be discussed: thick (> 1-1/2 inch) overlays and thin (< 1-1/2 inch) overlays. In addition, various techniques available for retarding reflection cracking of pavement overlays will be reviewed.

3.8.4 Thick Asphaltic Overlays

3.8.4.1 Definition. A thick overlay is an application of 1-1/2 or greater inches of asphalt concrete to an existing pavement.

3.8.4.2 Purpose. A thick overlay is needed when the existing pavement has experienced structural distress, such as rutting and/or alligator cracking. The overlay must arrest the structural deterioration of the pavement and provide sufficient structure to resist fatigue from future loadings.

3.8.4.3 Materials. Asphalt concrete overlays are assumed to be constructed with a high type asphaltic concrete type mix made with a dense-graded aggregate and an asphalt cement. Polymer-modified asphalts, manganese-modified asphalts, and asphalts with fillers or fibers incorporated into the mix, have all been used to improve the performance of an overlay.

The tack coats are often asphalt emulsions SS-1, SS-1h, CSS-1, and CSS-1h because they can be diluted safely with an equal amount of clean fresh water. The diluted emulsion tack coat is applied at the rate of 0.05 to 0.15 gallons per square yard [3.8-1].

3.8.4.4 Equipment. A paving machine, box, or grader is required to place an overlay. Trucks, brooms, hand tools, and rollers are also required.

3.8.4.5 Procedure. First, the existing pavement must be examined to determine the amount of treatment and/or repair which must be conducted prior to placing the overlay. The structural adequacy of the existing pavement, the distress exhibited by the existing pavement, the thickness of the overlay, other constraints, and costs must all be considered when determining how much pre-overlay work to perform.

If the pavement is failing in fatigue due to traffic loadings, then additional surface thickness may correct the problem and give the desired life extension. However, if the cause of the deterioration lies beneath the surface, the distress can be repaired prior to overlaying or sufficient thickness can be added to the overlay to protect the weakened areas in the lower layers. If the distressed areas are localized, it may not be economical to place a thicker overlay just to protect these areas. However, it also may not be economical to repair all the distressed areas. Some combination of increased thickness and full-depth patching is usually required. [3.8-2]

There are several practices currently being utilized by highway agencies prior to an overlay project. These include

1. crack sealing,
2. filling potholes,
3. patching,
4. leveling courses,
5. cold milling, or
6. combinations of these practices.

Potholes are often filled or patched. Ruts are filled with leveling courses or removed through cold milling. Moderately and severely distressed areas are often patched. Cold milling is useful for removing highly oxidized material from the existing surface, promoting bonding between the overlay and the existing surface, and leveling rutted pavements. [3.8-3]

When repairs are completed, the surface to be overlaid must be thoroughly cleaned. A thin tack coat of asphalt is then applied to ensure uniform and complete adherence of the overlay. Lack of uniform thin-tack-coat coverage may result in slippage of the surface layer. After the pavement has been repaired and cleaned, the tack coat and overlay should be placed without delay. Compaction must proceed immediately after the asphalt is placed. If the asphalt cools too much prior to rolling, adequate compaction will not be achieved.

3.8.4.6 Cost. The Federal Highway Administration's publication, "Price Trends for Federal-Aid Highway Construction," Calendar Year 1986, reports the following average prices for asphalt concrete pavement construction in dollars per ton in place:

Idaho:	28.99
Oregon:	27.39
Washington:	26.74

One research effort reported that the cost of a 2 inch overlay in Washington was $5.77 per square yard (approximately $81,224 per two lane mile) in 1984 dollars [3.8-4]. A Washington Department of Transportation publication in 1986 reported that structural overlays cost $166,200 per mile on the average in Washington [3.8-5].

Cities and counties within Washington State that completed the questionnaire distributed as part of this study estimated that a thick overlay cost between $22 to $60 per ton (approximately $50,000 to $152,000 per two lane mile for a 3 inch overlay).

3.8.4.7 Estimated Performance Life. In a study by the Washington Legislative Committee on Transportation, a 15 year performance period was used for structural overlays to maintain the road system, and a period of 12 years if the system were to improve [3.8-6]. The cities and counties within Washington State that completed the questionnaire predicted that thick overlays would last 5 to 20 years, with 13 years being the average life expectancy.

3.8.5 Thin Overlays

3.8.5.1 Definition. A thin overlay is an application of less than 1-1/2 inches of asphalt concrete to an existing pavement.

3.8.5.2 Purpose. Surface deficiencies, including poor skid resistance, inadequate surface drainage, excess roughness, and climate related deterioration, may be corrected with a minimum thickness overlay.

3.8.5.3 Equipment, Materials, and Procedure. The materials, equipment, and procedure are basically the same as described previously for the construction of thick overlays.

3.8.5.4 Cost. One publication reported that in 1984 the cost of an 1-1/2 inch overlay in Washington was $4.98 per square yard (approximately $70103 per two lane mile) [3.8-4]. The Washington Department of Transportation estimated in 1986 that the cost of a thin overlay is $92,900 per mile [3.8-5]. Cities and counties within Washington State that completed the questionnaire distributed during this study estimated that a thin overlay costs $22 to $100 per ton (approximately $20,000 to $85,000 per two lane mile for a 1 inch thick overlay).

3.8.5.5 Estimated Performance Life. In a document produced by the Washington Legislative Transportation Committee, an 8 year cycle was used for bituminous surface treatments [3.8-6]. The cities and counties within Washington State that completed the questionnaire estimated that a thin overlay would last between 3 to 15 years, with 9 years being the average expected life expectancy.

3.8.6 Minimizing Reflection Cracking in Asphalt Pavement Overlays

Reflective cracks are fractures in the overlay which result from movement of cracks in the underlying pavement layers. These cracks are caused by vertical and horizontal movements of the pavement that has been resurfaced. Both traffic and/or environmentally related loads are responsible for reflection cracking. Without some form of prevention or reduction of these reflective cracks, early deterioration of an overlay may occur.

No comprehensive design procedure has yet been proven to prevent the problem of reflection cracking (except recycling), but there are treatments available to delay the problem. The five methods found to be the most successful in delaying reflection cracking in AC overlays are [3.8-7]:

1. Thicker overlays.
2. Low-viscosity asphalts (200 - 300 penetration) used in AC overlays and interlayers.

3. Heater-scarifier remix of the old surface covered with a new AC overlay.

4. Asphalt-rubber interlayers such as the SAMI construction process.

5. Certain fabric interlayers used over fatigue cracked pavements but not over thermally cracked pavements.

The success of each technique is influenced by traffic, climate, condition of roadway prior to treatment, pavement preparation, the experience with the technique, and whether the cracking was due to fatigue or temperature. Each method will be discussed, with particular emphasis placed on the use of fabrics.

3.8.6.1 Increased Overlay Thickness. One research effort concluded that a minimum two-inch overlay is needed when the underlying AC pavement has alligator cracking. A minimum of three inches is required when the underlying pavement has block cracking, and a minimum of 3-1/2 inches is required for an AC overlay over an AC pavement with cement treated bases. Note, these thickness are for retarding reflection cracking, and may not meet structural needs. [3.8-7]

3.8.6.2 Low Viscosity AC Interlayers and AC Overlays. A significant factor in retarding reflection cracking is the viscosity of the asphalt binder at the time it is placed. The temperature susceptibility of this asphalt, the climate surrounding it, the amount used, and its ability to resist hardening all affect the rate of crack progression through an AC mat. By using the lowest possible viscosity asphalt with slow aging characteristics, some agencies have retarded reflection cracking.

3.8.6.3 Heater-Scarifier Remix. In this process, 3/4 to 1 inch of the existing pavement is heated and then scarified or loosened. A rejuvenating agent or soft asphalt is added, and the material is recompacted. An asphalt overlay is then placed. The purpose of using the heater-scarifier process in the upper portion of the pavement is to eliminate the wide cracks caused by spalling and to provide a narrower crack beneath the overlay.

Manufacturers' estimated service life and annual cost in 1980 for heater scarification and rejuvenation followed with a 1-1/2 inch asphalt-concrete overlay was 3 to 6 years at an annual cost of $0.65 per square yard [3.8-9].

3.8.6.4 Asphalt-Rubber Interlayers. Asphalt-rubber stress absorbing membrane interlayers (SAMI) have been used to retard reflection cracking. The interlayer functions as a soft interfacial layer that dissipates the stresses caused by the crack movement entirely within the interlayer. The SAMI is constructed using asphalt-rubber covered with aggregate. This forms a membrane interlayer about 0.35 to 0.50 inch thick. The SAMI is then covered with an AC surface course. Asphalt-rubber stress relieving layers have worked effectively when placed over flexible pavements exhibiting fatigue and longitudinal cracking [3.8-2], but have not performed well when placed over those exhibiting transverse thermal cracking [3.8-8].

Manufacturers' estimated service lives and annual costs for a 1-1/2 inch asphalt-concrete overlay with an asphalt-rubber interlayer is 6 to 10 years with an annual cost of $0.42 per square yard [3.8-9].

3.8.6.5 Fabrics. Fabrics may be woven or non-woven synthetic fabrics made of polypropolene, polyester, fiberglass, nylon, or combinations of these materials. Fabrics serve one or two mutually exclusive purposes in overlays: reinforcing or strain relieving. In order to reinforce, a fabric must have a modulus more than 5 times larger than that of the surrounding asphaltic concrete. If these conditions are met, and a thick enough overlay is placed, reflection cracks will be turned to travel horizontally below the fabric. In strain relieving fabric layers, the cracking reflects through overlay directly without breaking the fabric. The crack is delayed in its growth by the intermediate layer. The effectiveness of strain-relieving fabrics is dependent upon the amount of asphalt tack coat that can be applied without causing bleeding of the pavement surface. Reinforcing fabrics have a better chance at delaying reflection cracks for a long period of time than do strain-relieving fabrics. All fabrics are much more effective against horizontal movement than shear displacement. [3.8-12]

The following general conclusions with respect to the use of fabrics are emerging from field studies [3.8-8]:

1. Fabrics are most effective in reducing the rate of reflective cracking when thick overlays are used and are ineffective when used with thin overlays on asphalt concrete pavements exhibiting transverse temperature related cracks,
2. Fabrics are most effective in reducing the rate of reflective cracking when differential movements are small (alligator cracking, closely spaced block cracking, etc.),
3. Fabrics are most effective in reducing the rate of reflective cracking when climates are warm,
4. Fabrics are most effective when they are placed on top of an asphalt concrete leveling course rather than on the existing cracked pavement, and
5. Fabrics are not effective substitutes for overlay thickness, and a minimum thickness of 1/2 the thickness of the existing asphalt pavement should be considered if the rate of reflection cracking is to be controlled. A minimum thickness of 1-1/2 inches should be used to prevent slippage and to provide effective moisture barriers.

It has not been documented whether cracks which have reflected through pavement overlays which contain fabrics are less severe and require less maintenance. Also, the benefits of asphalt saturated fabrics in retarding penetration of water have been recognized by some agencies, but the results have not been quantified.

3.8.6.5.1 Fabric Materials [3.8-8]. The most commonly used fabric in overlay applications is nonwoven and composed of either polypropolene or polyester.

Research has shown that fabrics with a somewhat fuzzy surface next to the asphalt tack offer more resistance to slippage under tires of construction equipment than smoother surfaced fabrics. Thick absorbent fabrics which hold comparatively large quantities of asphalt exhibit greater resistance to cracking during fatigue tests. Fabrics which exhibit free shrinkage in excess of 5 percent upon exposure to 300 degrees Fahrenheit for 30 minutes have been linked to hairline cracks in the overlay. A fabric weight of 4 ounces per square yard is the minimum weight recommended for use with overlays.

Grade AC-10 is recommended for fabric tack coats in moderate to low temperature environments and AC-20 is recommended for high temperature environments. In general, use the same grade that is used in the overlay mixture. Emulsified asphalt has been successfully used as a tack, but since they develop bond strength more slowly than asphalt cement, fabric debonding on windy days has occurred. Emulsified asphalts are suitable to secure overlaps at construction joints. Never use cutback asphalts as tack because they are damaging to most synthetic fabrics.

3.8.6.5.2 Equipment. The tack coat is normally applied by asphalt distributors such as those which are conventionally used for chip seals. A small tractor rigged for handling fabric rolls can be used for fabric placement. The fabric can be placed manually but this is not recommended except for small projects. Pneumatic rolling immediately after applying fabric will maximize adhesive strength and shear resistance, and minimize its disruption by traffic, construction equipment, or wind [3.8-12].

3.8.6.5.3 Procedure [3.8-8]. The first step in placing a fabric prior to an overlay involves surface preparation. Potholes and other areas of localized severe distress should be patched prior to placement of the fabric and overlay. If hot mix is used to patch these areas, complete this procedure at least 30 days before the asphalt shot is scheduled, and if cold patch material is used, allow 60 days minimum. If raveling is severe, fill depressions with slurry seal about 30 days prior to application of fabric. Fill cracks > 1/4 inch with crack sealing material. If severe bleeding is present, remove excess asphalt with heater-planer or cold milling machines or heat surface and roll-in hot aggregate. If rutting or corrugations > 3/4 inch are present, remove them with heater planer or cold milling machine. Remove grass and debris build-up from the pavement edges and patch any raveled edges. Make sure that the proper drainage is maintained. Finally, clean the surface immediately prior to asphalt shot. All mud or other foreign matter must be removed by sweeping thoroughly with a power broom, and the entire area should be flushed with clean water, if necessary, and allowed to dry.

The preferred method of application is to place a leveling course first and place the fabric on top. Fabrics perform better when treated in this manner. The tack coat should be reduced in this case and should be sprayed on both the leveling course and on the fabric once it is placed.

Tack coat distribution should be performed such that relatively long shot lengths are utilized. Insufficient asphalt tack can result in failures due to slippage at the fabric interface, and excessive tack can migrate to the pavement surface due to the action of traffic and appear as flushing in the wheelpaths. As the fabric is rolled onto the asphalt tack coat, it must be aligned and smoothed to remove wrinkles and folds. Folds that result in a triple thickness must be cut with a knife and lapped. A 4 to 6 inch overlap is suggested at all longitudinal and transverse fabric joints. It is desirable to apply additional asphalt tack at these locations to insure proper saturation and bonding. For this purpose, emulsified asphalt can be applied using a brush or mop. The fabric is then rolled or brushed into the tack coat. Do not expose the installed fabric unnecessarily to traffic and the elements. An asphalt concrete overlay can be placed over a fabric using conventional equipment and techniques. Since polypropylene begins to melt at 300 degrees Fahrenheit, watch the paving mix temperature if this material is being used. If in-place density specifications are met, heat and rolling will have taken place to allow for fabric saturation.

Some specific recommendations have been made with respect to the use of fabrics and asphalt rubber interlayers to minimize reflective cracking in overlays in geographical regions within the United States [3.8-10]. The recommendations pertinent to Washington State are presented below:

1. Eastern Washington: Place fabric or interlayer with a 3 to 4 inch minimum overlay thickness.
2. Western Washington: Place fabric or interlayer with a minimum 2 inch overlay thickness.
3. When using engineering fabric, all cracks larger than 1/8 inch should be sealed.
4. When using asphalt rubber interlayer, all cracks larger than 1/4 inch should be sealed. The thickness of the SAMI should range from 0.35 to 0.75 inches.

3.8.6.5.4 Cost. In a report published in 1984, the cost range for a conventional fabric with tack coat is $0.65 to $1.50 per square yard, in place [3.8-8]. New Hope, Minnesota estimates the cost for a 1-1/2 inch overlay with a geotextile fabric to be $5.50 to $6.50 per square yard, with patching, milling where required, fabric installation, bituminous leveling all included [3.8-13]. The fabric alone cost them $0.75 to $0.80 per square yard. The only cost information provided by an agency completing the questionnaire distributed as part of this study was from a Western county. This county reported that using a fabric increases the overlay cost by $14,000 per mile (approximately $0.99 per square yard).

3.8.6.5.5 Estimated Performance Life. Wrinkles, bubbles, placing fabric directly on old pavement or under a thin (< 1-1/2 inches) overlay, or with too much or too little tack coat cause performance problems. Performance of overlays containing fabrics is primarily dependent upon the following three factors:

1. proper saturation of fabric with asphalt cement,
2. proper bond of saturated fabric to old pavement, and
3. proper bond of saturated fabric to overlay.

3.9 ASPHALT ADDITIVES

3.9.1 Definition

Asphalt additives are materials which are added to the asphalt cement to improve the properties of the asphalt cement and asphalt concrete.

3.9.2 Purpose

Some of the reported benefits for the different additives are [3.9-1]:

1. increased strength;
2. reduced temperature susceptibility;
3. improved durability;
4. improved stripping resistance;
5. improved abrasion resistance;
6. reduced rutting;
7. increased elasticity, adhesion, and cohesion;
8. retarded reflective cracking; and
9. increased stability.

3.9.3 Types

Additives reviewed during this literature survey can be classified into the following types:

1. polymers,
2. metal complexes,
3. sulfur,
4. fillers, and
5. fibers.

In broad terms, polymers and metal complexes improve the properties of asphalt cement; fillers and fibers reinforce the mixture; and sulfur is a partial or complete replacement for asphalt.

3.9.4 Polymers

Polymers can be divided into several categories based upon their physical and chemical characteristics. Thermoplastic polymers soften upon heating and when cooled regain their original consistency. They form a tough, rigid, three dimensional network resistant to deformation. These polymers exhibit quick early strength under loading, but may fracture with strain. Plastomeric asphalt modifiers include ethyl-vinyl-acetate (EVA), polyethylene/polypropylene, ethylene propylene (EPDM), and polyvinyl chloride (PVC). A few commercial examples of thermoplastic polymers are Accorex, Solar Laglugel, Asphadur, and Novophalt [3.9-2]. Various improvements have been reported through the use of thermoplastic polymer additives, including increased resistance to permanent deformation and increased dynamic stiffness, increased strength, and reduced penetration [3.9-1].

Thermoset polymers can be heated and made to flow under stress only once. They include pure natural rubbers, synthetic rubbers, and reclaimed rubbers. Rubbers are elastomers, which resist permanent deformation by stretching and recovering their shape quickly when the deforming force is removed. Such polymers add very little strength to the asphalt until they are stretched, but their tensile strength increases with elongation. Elastomers used for asphalt modification include styrene-butadiene-styrene block copolymers (SBS), styrene-isoprene-styrene block copolymers (SIS), styrene-butadiene rubber latexes (SBR), polychloroprene latex, and natural rubber latex [3.9-2].

Natural rubbers are limited by cost and availability. Synthetic rubbers of the SBR and neoprene types are used primarily as latex emulsions. Commercial examples used for asphalt pavement applications include Styrelf, Tex-Crete, and UltraPave. Reclaimed rubber, obtained from scrap tires, is used in SAM's and SAMI's to control reflective cracking. Commercial products using reclaimed rubber include Plus-Ride, Over-Flex, Rosphalt, and Arm-R-Shield.

Specific binder and mix properties can be controlled by selecting the proper polymer modifier. Elastomers give a more resilient, flexible pavement, while plastomers result in mixes with higher stabilities and stiffness moduli. Most polymer systems provide reduced temperature susceptibility, improved low temperature flexibility, and better tensile properties to the binder. Modified asphalt concrete exhibits varying degrees of reduced rutting, longer fatigue life, increased stripping resistance, higher stiffness and Marshall stabilities at high temperatures, and improved resistance to cracking [3.9-2].

Polymer additives have been used in chip seals, fog seals, sand seals, slurry seals, and cold patching applications. In chip seals polymer modified emulsions have helped with increasing early chip retention and decreasing long term chip loss under traffic [3.9-2]. The incorporation of polymer used in a cold-mix binder allows the use of more open aggregate gradations. The greater tensile strength of polymer binders helps to prevent the migration and raveling normally associated with these open mixes when used for patching applications [3.9-2]. Polymer modified slurry seals are gaining acceptance. Natural rubber latex has been the primary polymer source for this application. The use of polymer additives typically increases the mix cost by $3 to $10 per ton, but the cost ranges widely depending on the product used.

3.9.5 Metal Complexes

A metal complex is a chemical compound composed of a metal ion linked to any variety of organic compounds. Several manganese compounds have been utilized as asphalt modifiers.

Low concentrations of asphalt-soluble manganese compounds improve the strength and stability of asphalt concrete as measured by indirect tensile, Marshall stability, and unconfined compression tests [3.9-3]. It is possible to obtain much higher stabilities with manganese-modified AC-5, AC-10, or AC-20 grade asphalts without the mixing and placement difficulties that would occur if a very high-viscosity asphalt cement were used.

In general, manganese modification is not recommended for thin overlays because of the increased potential for cracking caused by having a stiffer surface layer over a lower-strength and more flexible base [3.9-3]. It does provide improved strength for full-depth asphalt concrete construction and improves stabilities where only poor-quality aggregates are available at a reasonable cost. A representative commercial product increases the mix cost by $3.25 per ton [3.9-1].

3.9.6 Sulfur-Extended Asphalt

The major purpose for replacing asphalt with sulfur has been to reduce asphalt usage without sacrificing performance. In general, sulfur-extended asphalt (SEA) pavements are performing as well as asphalt control sections in all climates and under all types of traffic loading. SEA pavements have been successfully constructed using conventional mixing, paving, and compaction equipment in Washington State.

Given the 1987 cost of elemental sulfur compared with that of asphalt, the use of SEA is difficult to justify because no significant improvement in pavement performance attributable to the incorporation of sulfur was found [3.9-4]. Unless the price of asphalt cement rises substantially with respect to the price of elemental sulfur, the production of SEA paving mixtures is not currently economical in the State of Washington [3.9-5].

3.9.7 Carbon Black Filler

The reported benefits resulting from the use of carbon black include increased abrasion resistance, decreased temperature susceptibility, increased moisture resistance, increased ultraviolet radiation protection, and inhibition of oxidation. To date, the performance of asphalt mixes modified with carbon black has been satisfactory, but the added cost ($3.50 to $10.75 per ton of hot mix) has not been justified [3.9-1].

3.9.8 Fibers

Polyester and polypropylene fibers are widely used in asphalt paving applications. Synthetic fibers incorporated into an asphalt concrete overlay mix will often reduce reflective cracking, especially in colder climates. Reflective cracking is reduced because the fibers re-distribute the strain in the overlay immediately above the crack. Instead of a single crack reflecting upward, the fibers cause the crack to branch out, expending the energy in driving several cracks upward through the overlay at a slower rate [3.9-6].

Several precautions need to be taken when mixing and placing a fiber-modified mix. Mix temperatures should not exceed 290 degrees Fahrenheit when polypropylene fibers are used, since they will melt at these temperatures. Fibers in asphalt pavement are useful only if they are discreet, uniformly distributed fibers. To accomplish this they are cut very short, because in the very short mixing time used for hot mix and cold mix, long fibers would not mix discreetly or uniformly [3.9-7].

The Oregon State Department of Transportation has noted frequent occurrences of balling during the use of fibrous mixes. Balls of fibers can mar and tear the surface of the pavement. They are believed to occur because of the short time the fibers were in the mixing chamber before asphalt was added. This agency has found that a mix approach using a pre-separation blower to separate fibers and accelerate them into the aggregate freefall area prior to pugmill mixing improves fiber distribution [3.9-8]. Another agency found that blending the fibers with preheated aggregates in a mid-drum feed for about 25 seconds before being coated with asphalt decreased the occurrence of balling [3.9-9].

When placing a fiber-modified mix, extra care should be taken. Incorporation of fibers increases the air void content when compactive effort remains constant, so mixtures with fibers will require more compactive effort than a mixture without fibers [3.9-6].

The City of Columbus, Ohio uses polypropylene fibers in asphalt mixes to help stabilize its pavements against rutting and shoving from heavy bus axle loads. The fibers increase the cost of the mix by about $10 per ton in place, but the City has found that the increased cost of the fibers has been more than offset by subsequent reduced maintenance costs [3.9-10].

Experimentation is currently underway involving the use of glass fiber reinforcement in conjunction with an asphalt polymer to minimize reflection cracks in an asphalt overlay. The system reviewed is a combination of high tensile strength, high modulus woven glass fiber fabric, and an asphalt polymer with properties designed for use with the glass fabric. The asphalt polymer adheres to the old road, the glass fiber reinforcement, and the new overlay. It protects the glass fiber reinforcement, acts as a stress relieving membrane, and transfers the stresses to the reinforcement. The glass fiber reinforcement distributes the stresses over the width of the repair to a level below the fracture point of the overlay. It is a spot repair system and each crack is repaired individually. The cracks must be clean and dry. The asphalt polymer is melted and heated to 375 degrees Fahrenheit. The fabric is cut to the length of the crack. Molten asphalt polymer is poured over the crack and spread with a squeegee. The glass fiber reinforcement is placed over the crack while the asphalt polymer is still molten. Then, more molten asphalt polymer is poured over the glass fiber reinforcement and squeegeed. The repaired crack can be exposed to traffic or overlaid in about 30 minutes. The test results reported in this source were very positive. [3.9-11]

CHAPTER 4.0

FEASIBLE ALTERNATIVES

4.1 BACKGROUND

To facilitate the selection of cost-effective asphalt pavement maintenance and repair techniques for use within Washington State, an extensive list of potential techniques was prepared during this phase of the project. The potential techniques and materials included in this list were then reviewed to determine which alternatives are feasible at this time. The results of this analysis were used during the final project phase to develop a prioritized repair list for use by Washington agencies.

4.2 POTENTIAL ALTERNATIVES

Information obtained from the completed questionnaires (Chapter 2.0) and the literature review (Chapter 3.0) was used to prepare a list of potential asphalt pavement repair methods and materials. The list, presented in Table 4-1, contains techniques and materials currently used within Washington State, and additional alternatives being used throughout the nation. It includes widely accepted repair methods, as well as new or experimental techniques and materials.

4.3 UNFEASIBLE ALTERNATIVES

The next step in developing a list of feasible alternatives involved analyzing all the potential repair methods and materials, and determining which techniques are appropriate for use within Washington State. Only obviously unsuitable potential repair alternatives were eliminated from further consideration. The following items were considered sufficient justification for identifying a repair alternative as unfeasible:

1. Poor performance,
2. Unjustified cost,

3. Special equipment requirements,
4. Limited material availability,
5. Repair difficulty,
6. Limited experience/experimental status,
7. Excessive energy consumption,
8. Safety concerns, and
9. Adverse environmental impacts (noise and pollution).

Table 4-2 provides a list of repair alternatives and materials which are not considered feasible at this time for use within Washington State. The justification for the removal of an alternative or material from further consideration is also provided in this table.

In some situations, repair methods were found to be appropriate only for rural, low-volume applications. In other cases, the increased expense of some rapid-repair techniques was justified in city, high traffic-density situations, but not for rural applications. Also, some specialized equipment, specially-trained operators, and unusual materials are currently only available to select cities or geographical regions. Where possible, these situations were identified in Table 4-2. However, each agency will need to review Table 4-2, and determine whether any of the repair alternatives listed should be eliminated due to the agency's individual constraints.

4.4 FEASIBLE ALTERNATIVES

After eliminating potential repair methods and materials which were considered impractical at this time, a list of feasible repair methods was compiled. This list is presented in Table 4-3, which is organized to show which repair types are appropriate for specific repair situations. Table 4-4 summarizes the distress severity level definitions used in this analysis.

Certain repair techniques are effective when the pavement distress is localized, whereas others are only cost-effective if the distress is extensive. Other repair techniques can only be effectively applied when the identified distress is not load-associated. Also, some repair methods are not successful when applied under high traffic volume conditions. These situations are identified when possible in Table 4-3.

Drainage is not referred to in Table 4-3. However, any pavement repair project must include a determination of whether drainage is adequate or whether some additional drainage work is required. Special additives or materials are not specifically identified in this list, except in the case of binder-modified chip seals. The appropriate preparatory work required prior to initiating a specific repair is not contained in Table 4-3, either. For example, the patching and crack sealing recommended prior to placing an overlay is not listed. Chapter 3.0 should be referred to in order to obtain specific information on appropriate additives and correct repair procedures.

4.5 DISCUSSION

It was important at this stage to address the issue of what distress types can be effectively treated with each repair method. In this study, a feasible alternative is defined as one that repairs the existing distress and prevents its recurrence. The questionnaire results (presented in Chapter 2.0) revealed that viable repair methods are occasionally being applied in the wrong situations. For example, seal coats are being used by some Washington State agencies as a permanent repair for extensive alligator cracking. If the mechanism which is causing the distress is not treated, the distress will continue to develop and increase in severity. The objective of this project was to provide a list of effective, long-term solutions to correct pavement problems.

4.6 SUMMARY

Periodically, all alternatives should be reevaluated, since conditions which currently limit or promote the use of a given method or material may change in the future. Material and equipment availability, energy constraints, repair efficiency and cost, etc. are all subject to change. In addition, repair alternatives which are presently being tried on an experimental basis may prove through field trials to be feasible solutions.

Table 4-1. Potential Repair Methods and Materials

Repair Method	Associated Special Materials
Burn	
Cape Seal	Polymer Modified Asphalt High-Float Emulsions
Chip Seal	Polymer Modified Asphalt High-Float Emulsions
Crack Seal	Polymer Modified Asphalt Filler Modified Asphalt
Fog Seal	Polymer Modified Asphalt High-Float Emulsions
Grind	
Mill	
Open-Graded Surface Course	Polymer Modified Asphalt
Thin Overlay	Polymer Modified Asphalt Metal Complex Modified Asphalt Sulfur Modified Asphalt Filler Modified Asphalt Glass Fiber Modified Asphalt
Thick Overlay	Polymer Modified Asphalt Metal Complex Modified Asphalt Sulfur Modified Asphalt Filler Modified Asphalt Glass Fiber Modified Asphalt
Patch	Filler Modified Asphalt Polymer Modified Asphalt Fabrics Roll Roofing Material Cold Mix Binders: Butyl Modified High Float Emulsions Fly Ash Cement combined with Coarse Aggregate and Polypropylene Fibers
Plane	
Prelevel with Asphalt Treated Base and Apply Seal Coat	

Table 4-1. Potential Repair Methods and Materials (Continued)

Repair Method	Associated Special Materials
Reconstruct	
Recycle	Stabilizers Foamed Asphalt Polymer Additives Rejuvenating Agents Antistripping Additives Microwave Heating Waste Roofing Material
Reflection Cracking Retardants	Fabric Asphalt-Rubber Interlayer Low Viscosity AC Interlayer or Overlay Heater-Scarifier Remix
Rejuvenator	Elastomer Emulsions
Sand	
Sand Seal	Polymer Modified Asphalt
Shoulder Correction	
Slurry Seal	Polymer Modified Asphalt

Table 4-2. Eliminated Repair Methods/Materials

Eliminated Alternative	Justification
"Throw and Go" pothole patching	Poor performance
Crack sealing with unmodified asphalt	Poor performance
Manganese modified asphalt in thin overlays	Poor performance
Chip seals with unmodified asphalt on high-volume roads	Poor performance
Rejuvenators used on roads with existing seal coats	Poor performance
Slurry seals on high volume roads	Poor performance/Cost
Sulfur-extended asphalt (SEA)	Cost
Carbon-black modified asphalt	Cost
Patching with roll roofing material except in areas with excessive multi-directional traffic movement and during cold weather at primary locations for potential pothole development.	Cost
Recycling in some locations[1]	Equipment availability
Fiber modified asphalt in some locations[1]	Equipment availability
Glass fiber modified asphalt	Experimental status
Cold-mix recycling using emulsified cement	Experimental status
Recycling waste roofing material	Experimental status

[1] Feasibility depends upon equipment availability in each area.

Table 4-3. Feasible Repair Methods

Distress Type	Repair Action	Severity Level
Alligator Cracking	Crack Seal[1]	L
	Patch	L, M, H (Localized)
	Rubberized Chip Seal[1]	L
	ATB[2] + Seal Coat	M, H (Low Volume)
	Surface Recycle[3]	M, H
	Full Depth Recycle	H
	Thick Overlay	H
	Reconstruct	H
Bleeding	Apply Heat & Roll Sand	M, H
	Burn	M, H
	Burn + Sand Seal	M, H
	Burn + Chip Seal[4]	M, H
	Burn + Slurry Seal	M, H (Low Volume)
	Burn + Thin Overlay	H
	Surface Recycle	H
	Patch	H (Localized)
	Reconstruct	H
Block Cracking	Crack Seal	L, M, H
	Rejuvenator	L
	Chip Seal[4]	L, M
	Patch	H (Localized)
	Slurry Seal	L (Low Volume)
	Thin Overlay	H
	ATB[2] + Seal Coat	M, H (Low Volume)
	Surface Recycle	H
	Full Depth Recycle	H
	Reconstruct	H
Corrugation	Patch	M, H (Localized)
	Grind, Mill, Or Plane	M, H (Low Volume)
	Grind, Mill, Or Plane + Overlay/Chip Seal	M, H
	Prelevel + Thin Overlay	H
	ATB[2] + Seal Coat	M, H (Low Volume)
	Surface Recycle	M, H
	Reconstruct	H

[1] Temporary Repair
[2] Asphalt Treated Base
[3] Only appropriate if problem in surface course, and not base or subgrade.
[4] Need modified binder for high traffic volume applications.

Table 4-3. Feasible Repair Methods (Continued)

Distress Type	Repair Action	Severity Level
Depression	Patch	M, H
	Prelevel + Thin Overlay	H
	ATB[1] + Seal Coat	M, H (Low Volume)
	Full Depth Recycle	H
	Reconstruct	H
Edge Cracking	Crack Seal	L, M, H
	Patch	M, H
	Shoulder Seal[2]	L
	Prelevel + Seal Coat	M, H
	Thin Overlay	H
	Surface Recycling	H
Lane/Shoulder Drop-Off	Add Aggregate & Grade	M, H
	Level Off Shoulder & Chip Seal	M, H
	Patch	L, M, H (Localized)
Longitudinal/Transverse Cracking	Rejuvenator[2]	L
	Crack Seal	L, M, H
	Patch	H (Localized)
	Chip Seal[3]	L, M
	Slurry Seal[2]	L (Low Volume)
	Surface Recycle[4]	M, H
	ATB[1] + Seal Coat	M, H (Low Volume)
	Thin Overlay[4]	H
	Thick Overlay	H
	Full Depth Recycle	H
	Reconstruct	H
Patching and Utility Cut	Crack Seal	M
	Patch	H (Localized)
	ATB[1] + Seal Coat	M, H (Low Volume)
	Overlay	H
	Full Depth Recycle	H
	Reconstruct	H
Polished Aggregate	Grind, Mill, or Plane	N.A. (Low Volume)
	Slurry Seal	N.A. (Low Volume)
	Open Graded Course	N.A.
	Chip Seal[3]	N.A.
	Sand Seal	N.A.
	Surface Recycle	N.A.
	Thin Overlay	N.A.

1 Asphalt Treated Base
2 Temporary Repair
3 Need modified binder for high traffic volume applications.
4 Only appropriate if distress is not load-associated.

Table 4-3. Feasible Repair Methods (Continued)

Distress Type	Action	Repair Severity Level
Potholes	Patch	L, M, H (Localized)
	ATB[1] + Seal Coat	L, M, H (Low Volume)
	Thick Overlay	L, M, H
	Full Depth Recycle	L, M, H
	Reconstruct	L, M, H
Rutting	Patch	M, H (Localized)
	Grind, Mill, or Plane	M, H (Low Volume)
	Grind, Mill, or Plane + Thin Overlay/Chip[3]	M, H
	Surface Recycle[2]	M, H
	Prelevel + Thin Overlay	M, H
	ATB[1] + Seal Coat	M, H (Low Volume)
	Thick Overlay	H
	Full Depth Recycle	H
	Reconstruct	H
Shoving	Patch	M, H (Localized)
	Surface Recycle	H
	Reconstruct	H
Slippage Cracking	Crack Seal	L, M
	Patch	M, H (Localized)
	Full Depth Recycle	H
	Reconstruct	H
Swell	Patch	M, H (Localized)
	ATB[1] + Seal Coat	M (Low Volume)
	Grind, Mill, or Plane	M, H
	Full Depth Recycle	H
	Reconstruct	H
Weathering and Raveling	Patch	H (Localized)
	Fog Seal	L
	Rejuvenator	L
	Sand Seal	L, M
	Slurry Seal	L, M (Low Volume)
	Open Graded Course	M, H (Low Volume)
	Chip Seal[3]	M, H
	ATB[1] + Seal Coat	L, M (Low Volume)
	Surface Recycle	H
	Thin Overlay	H
	Reconstruct	H

[1] Asphalt Treated Base
[2] Appropriate only if problem in surface layer, and not base or subgrade.
[3] Need modified binder for high traffic volume applications.

Table 4-4. Distress Severity Level Definitions

In Accordance With U.S. Army CERL Technical Report M-294

Distress Type	Severity	Definition
Alligator Crack	L	Fine, longitudinal hairline cracks running parallel to each other with none or only a few interconnecting cracks. The cracks are not spalled.
	M	Development of light alligator cracks into a pattern or network of cracks that may be lightly spalled.
	H	Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic.
Bleeding	L	Bleeding has only occurred to a very slight degree and it is noticeable only during a few days of the year. Asphalt does not stick to shoes or vehicles.
	M	Asphalt sticks to shoes and vehicles during only a few weeks a year.
	H	Bleeding has occurred extensively and considerable asphalt sticks to shoes and vehicles during at least several weeks of the year.
Block Cracking	L	Blocks are defined by low-severity cracks.
	M	Blocks are defined by medium-severity cracks.
	H	Blocks are defined by high-severity cracks.
Corrugation	L	Corrugation causes low-severity ride quality.
	M	Corrugation causes medium-severity ride quality.
	H	Corrugation causes high-severity ride quality.

Table 4-4. Distress Severity Level Definitions (Continued)

Distress Type	Severity	Definition
Depression	L	1/2 to 1 inch maximum depth of depression.
	M	1 to 2 inch maximum depth of depression.
	H	More than 2 inch maximum depth of depression.
Edge Cracking	L	Low or medium cracking with no breakup or raveling.
	M	Medium cracks with some breakup and raveling.
	H	Considerable breakup or raveling along the edge.
Lane/Shoulder Drop-Off	L	Difference in elevation is 1 to 2 inches.
	M	Difference in elevation is 2 to 4 inches.
	H	Difference in elevation is > than 4 inches.
Longitudinal & Transverse Crack	L	Nonfilled crack < 3/8 inch wide, or filled crack of any width if filler in satisfactory condition.
	M	Nonfilled crack 3/8 to 3 inches, or nonfilled crack of any width up to 3 inches surrounded by light and random cracking, or filled crack of any width surrounded by light random cracking.
	H	Any crack filled or nonfilled surrounded by medium- or high-severity random cracking, or nonfilled cracks over 3 inches, or a crack of any width where a few inches of pavement around the crack is severely broken.
Patching	L	Patch is in good condition and satisfactory. Ride quality is rated as low severity or better.
	M	Patch is moderately deteriorated and/or ride quality is rated as medium severity.
	H	Patch is badly deteriorated and/or ride quality is rated as high severity. Patch needs replacement soon.

Table 4-4. Distress Severity Level Definitions (Continued)

Distress	Type	Severity Definition
Polished Aggregate	N.A.	The degree of polishing should be significant before it is included in the condition survey and rated as a defect.
Potholes	L	Average pothole diameter is 4 to 8 inches and the pothole depth is 2 inches or less; or, average pothole diameter is > 8 to ≤ 18 inches, and the pothole depth is 1/2 to 1 inch.
	M	Maximum pothole depth is 1/2 to 1 inch, and the average diameter is > 18 to ≤ 30 inches; or, maximum pothole depth is > 1 to 2 inches, and the average diameter is > 8 to ≤ 18 inches; or, the maximum pothole depth is > 2 inches and the average diameter is 4 to ≤ 18 inches.
	H	Average pothole diameter is > 18 to ≤ 30 inches, and the maximum depth is > 1 inch.
		Note: If the pothole is > 30 inches in diameter, the area should be determined in square feet and divided by 5 square feet to find the equivalent number of holes. If the depth is ≤ 1 inch, they are considered medium severity. If the depth is > 1 inch, they are considered high severity.
Rutting	L	Mean rut depth is 1/4 to ≤ 1/2 inch.
	M	Mean rut depth is > 1/2 to ≤ 1 inch.
	H	> 1 inch.
Shoving	L	Shove causes low-severity ride quality.
	M	Shove causes medium-severity ride quality.
	H	Shove causes high-severity ride quality.

Table 4-4. Distress Severity Level Definitions (Continued)

Distress	Type	Severity Definition
Slippage	L	Average crack width is < 3/8 inch.
	M	Average crack width is 3/8 to 1.5 inches, or the area around the crack is broken into tight fitting pieces.
	H	Average crack width is > 1.5 inches, or the area around the crack is broken into easily removed pieces.
Swell	L	Swell causes low-severity ride quality.
	M	Swell causes medium-severity ride quality.
	H	Swell causes high-severity ride quality.
Weathering & Raveling	L	Aggregate or binder has started to wear away. In some areas, the surface is starting to pit.
	M	Aggregate and/or binder has worn away. The surface texture is moderately rough and pitted.
	H	Aggregate and/or binder has been considerably worn away. The surface texture is very rough and severely pitted. The pitted areas are less than 4 inches in diameter and less than 1/2 inch deep; pitted areas larger than this are counted as potholes.

CHAPTER 5.0

RECOMMENDATIONS

5.1 BACKGROUND

The final phase of this research project involved prioritizing the list of feasible alternatives presented in Chapter 4.0. The prioritized list can be used by Washington cities and counties to help them select the most appropriate repair alternatives to correct a specific problem. In addition, the legal definitions of what constitutes "maintenance" activities and what constitutes "construction" activities were addressed. These definitions have an impact on which funding sources an agency may utilize to finance a given repair, and may determine whether the road must be brought up to current design and safety standards when the repair is performed.

5.2 PRIORITIZED FEASIBLE REPAIR ALTERNATIVES

5.2.1 Prioritization Process

An extensive list of potential repair methods and materials was presented in Chapter 4.0. This list was reviewed during the previous project phase to determine which alternatives are feasible at this time. The feasible alternatives were then organized according to appropriate application situations and presented in Table 4-3.

During this final project phase the identified feasible alternatives available to correct each distress were prioritized. The main criteria used to prioritize repair methods were cost and service life. The life and cost values were obtained from the questionnaire results when available, from the information gathered during the literature review, and from WSDOT documents.

The life and cost estimates used in this analysis correspond to repairs performed with the correct materials and procedures, as presented in Chapter 3.0. The effectiveness of any repair will depend upon many factors, including:

1. skill and care with which work is performed,
2. quality of materials,
3. environmental conditions,
4. traffic, and
5. other work performed concurrently.

5.2.2 Results

Tables 5-1 and 5-2 summarize the results of the prioritization process, for low and high traffic volumes, respectively. Localized and extensive distress are presented individually. It was necessary to divide the tables in this manner because as these conditions change, the appropriate solutions also change.

5.2.3 Discussion

Obviously, cost and service life are not the only items an agency should consider when selecting a repair method. Many additional factors and constraints must be evaluated in order to select the best repair alternative. This study did not directly consider all the factors and constraints which affect the decision-making process, because these will be unique for each repair situation an agency encounters. Table 5-3 summarizes the factors which may affect an agency's repair method selection.

An added complication in the selection process is that a feasible rehabilitation alternative may encompass more than one repair technique. Many projects exhibit several types and severities of distress and thus require the application of several different repair methods. Tables 5-1 and 5-2 provide prioritized repair lists for correcting individual repair types. When multiple distresses are present, each agency will have to consider their unique conditions and constraints when selecting appropriate repair method(s).

In addition, each agency needs to consider whether the road requiring repair is scheduled for major work (such as an overlay) in the next few years. Different repair alternatives will be selected if the goal is to provide stop-gap maintenance until major work is performed, rather than to provide long-term distress correction.

5.2.4 Recommendations

The purpose of the prioritized lists presented in Tables 5-1 and 5-2 is to provide general guidance pertaining to the selection of a repair method to correct an identified pavement deficiency. The goal is not to dictate which repair alternatives an agency can utilize in a given situation, but to provide insight into which alternatives are considered appropriate and cost-effective for use within Washington State. It is hoped that repair alternatives have been identified in Tables 5-1 and 5-2 for further consideration which might otherwise be overlooked by an agency.

Whichever repair method is ultimately selected, it is very important to use the proper materials and methods. A repair method incorrectly applied, or made with inadequate materials, will probably do more harm than good. It will certainly be a waste of scarce maintenance dollars. Chapter 3.0 contains information pertaining to successful repair techniques and materials.

5.3 "MAINTENANCE" VERSUS "CONSTRUCTION" ACTIVITIES

5.3.1 Problem Statement

In addition to selecting cost-effective pavement repair techniques, agencies with roadway jurisdiction are faced with another challenge. Agencies must determine whether the selected repair techniques are considered to be maintenance activities, or whether they constitute construction activities. During this phase of the project, the legal aspects of "maintenance" versus "construction" as currently defined were evaluated. The ramifications of these definitions were considered, and recommendations pertaining to the modification of these definitions were made.

5.3.2 Current Legal Definitions

In order to adequately address the maintenance/construction issue, several documents were reviewed to locate current definitions. The documents reviewed include the following:

1. Local Agency Guidelines (LAG);
2. Washington Accounting Code (WAC);
3. Budgeting, Accounting, Reporting System for Counties and Cities and Other Local Governments (BARS Code);
4. Revised Code of Washington (RCW);
5. Route 2000 - Washington Road Jurisdiction Study;
6. Development of the State Highway Priority Array (WSDOT), and an associated internal WSDOT document; and
7. FHWA Pavement Policy for Highways.

The first four documents were used to obtain the legal definitions which apply to repair activities performed by Washington cities and counties. The next two documents were reviewed to obtain further information from previous Washington State Department of Transportation studies which addressed this issue. The last publication was reviewed to determine the Federal perspective concerning the definitions when applied to work receiving Federal-aid. A copy of the pertinent sections from each document are provided in Appendix C.

According to the Route 2000 study, the cities and counties are not entirely consistent in their definition of maintenance and construction. This study cites the following key differences:

1. Some cities and counties report all contracted work as construction, including those which should be included under maintenance activities.
2. Some cities and counties report all overlays (including those averaging three or more inches in depth) as maintenance, even though they add structural strength to the pavement.

A description of what exactly constitutes construction can be found in the BARS Code and LAG. The LAG definitions are important, because the BARS Code states that the LAG contains the complete definitions of maintenance and construction for accounting purposes. The BARS Code further specifies that maintenance does not include repair, restoration, or rehabilitation (3-R) activities, and that these activities should be coded as construction.

A summary of the relevant LAG definitions, contained in full in Appendix C, follows:

5.3.2.1 Construction. The building of a street, a portion of a street, or a facility that did not previously exist.

5.3.2.2 Improvement. Betterment in traffic service without major changes in the original construction. This includes widening, signals, illumination, curbs, gutters, drainage, sidewalks, and other items which add value to the facility.

5.3.2.3 Repair. Replacement or rebuilding of a facility which is worn out, destroyed, or damaged. Repair includes overlays which are 0.06 foot thick or thicker.

5.3.2.4 Maintenance. Work directed toward preservation of the existing roadway and related appurtenances for safe and efficient operation. Any surface treatments less than 0.06 foot thick, crack sealing, etc., are considered to be maintenance and are not 3-R activities.

__5.3.2.5 New Construction.__ The building of a new roadway or structure on substantially new alignment, or the upgrading of an existing roadway or structure by the addition of one or more lanes. If 50 percent or more of the project length involve alignment changes, the project is new construction. The following type of project is not classed as new construction, and the 3-R standards apply:

Modernization of an existing street or road by resurfacing, widening lanes, adding shoulders, or adding turn lanes at intersections.

__5.3.2.6 Rehabilitation.__ Similar to "Restoration" except the work may include reworking or strengthening the base or sub-base, recycling or reworking existing materials to improve their structural integrity, adding under-drains, improving or widening shoulders.

__5.3.2.7 Repair.__ Replacement or rebuilding of a facility which is worn out, destroyed, or damaged. Repair includes overlays 0.06 foot thick or thicker.

__5.3.2.8 Restoration.__ Work performed on pavement or bridge decks to render them suitable for resurfacing. This may include supplementing the existing roadway by increasing surfacing and paving courses to provide structural capability, and widening up to a total of 10 feet.

__5.3.2.9 Resurfacing.__ The addition of a layer or layers of paving material to provide additional structural integrity, improved serviceability, and rideability.

__5.3.2.10 3-R.__ Resurfacing, Restoration, and Rehabilitation.

5.3.3 Discussion

There are two separate issues that must be addressed when discussing the categorization of repair activities. The first issue pertains to whether performing a specific repair activity requires the agency to bring the road in question up to current standards. The second issue concerns which funding and labor sources are available to perform repair activities. These issues will be presented separately.

5.3.3.1 Upgrading to Current Design Standards. One ramification of the definitions presented in Appendix C pertains to whether performing a specific repair activity requires the agency to bring the road in question up to current standards. With respect to cities, the RCW states that the governing body of the several municipalities must apply the uniform design standards adopted under RCW 35.78.030 to all new construction on major arterial and secondary arterial streets and to reconstruction of old such streets as far as practicable. Pertaining to counties, the RCW states that uniform design standards shall apply to all new construction within, and as far as practicable and feasible to reconstruction of old roads comprising the county primary road system.

While other road classifications, other than the major and secondary arterials, and primary county road system, are not specifically mentioned in the RCW, the Washington State Auditor's Office predicted that from a liability viewpoint, the same requirements regarding upgrading a road to current design standards would exist for access roads, too. Also, the phrase "as far as practicable" is subject to interpretation.

Due to budget constraints, the requirement to upgrade a road to current design standards if work classified as construction is performed simply prohibits in many situations the use of any repair activity defined as "construction". Maximizing the benefits of limited fiscal resources precludes the development of all roads to "design standards" for their functional classification.

In addition to the monetary issue, several agencies have expressed concern over the liability aspect of the definitions. If an accident occurs, and it can be proven that a repair activity defined as construction was performed, but the road was not upgraded to current standards at that time, the agency with road jurisdiction could be liable.

Concerning state highways, an internal WSDOT document pertaining to the State Highway Priority Array states that seals and thin overlays (1R) do not require the road to be brought to geometric standards or for any mandatory work elements to be performed. Resurfacing and restoration (2R) do not require the road to be brought to geometric standards, however minimal safety work must be performed. Resurfacing, restoration, and rehabilitation (3R) must meet minimum geometric standards and must enhance roadside safety.

5.3.3.2 Permissible Funding and Labor Sources. The second issue involves the rules governing the financing of street improvement, and the role the distinction between maintenance and construction plays in determining available funding. The funding sources which are available for a repair are often controlled by whether the activity is termed maintenance or construction. Some funding sources restrict the use of their money to activities defined as maintenance, whereas others are targeted only for construction. In addition, the use of day labor is restricted in some situations.

LAG defines how cities and towns can use state gasoline tax monies. The 6.92 Percent Program (Street or Road Fund) can be used for any street or road purpose, including maintenance. The 4.61 Percent Program (Arterial Fund) can be used for preliminary engineering, right of way, construction, improvements, and repair of arterials and city streets. Cities with a population less than 15,000 may also use these funds for maintenance.

The RCW states that the Rural Arterial Trust Account can be used for the construction and improvement of county major and minor collectors in rural areas, the construction of replacement bridges funded by the federal bridge replacement program on access roads in rural areas, and for those expenses of the board associated with the administration of the rural arterial program. The Motor Vehicle Fund may be used for construction, alteration, repair, improvement, or maintenance of county roads and bridges, etc. The Urban Arterial Trust Account can be used for the construction and improvement of city arterial streets and county arterial roads within urban areas, for expenses of the transportation improvement board, or for the payment of principal or interest on bonds issued for the purpose of constructing or improving city arterial streets and county arterial roads within urban areas, etc.

The use of day labor by counties is addressed in the RCW and WAC. Title 136 of WAC states that for the purposes of implementing the requirements of RCW relative to day labor construction work, the following definitions shall apply:

1. Construction - the building of a new road facility or improvement of an existing facility to a higher geometric or structural standard.
2. Day labor construction - construction work performed by personnel carried on the county payroll using county owned, leased or rented equipment.

WAC also states that the BARS shall be used for all county road department budgeting, accounting and reporting. The BARS Code in turn refers to the LAG, which contains the final definitions of repair categories. RCW sets limits on the amount which may be spent on any county road to be constructed or improved by day labor. All construction work to be performed at a cost in excess of these limits must be performed by contract.

An internal WSDOT document pertaining to the State Highway Priority Array discusses which types of funding are available for different activities when applied to state highways. According to this document, seals, thins overlays, resurfacing, and restoration work are eligible for state funds only. Resurfacing, restoration, and rehabilitation (3R) work is eligible for Federal funds.

The FHWA 1989 "Pavement Policy for Highways" established a national policy for identifying work eligible for federal-aid funding. The FHWA uses a performance specification to determine whether work is eligible or not for federal funding. Rehabilitated pavement projects on interstate, other principal arterials, and other freeways and expressways must provide at least an eight-year performance period. A five-year minimum performance period may be used for all other routes. State funds must be used for maintenance work on federal-aid highways. When the policy refers to rehabilitation, it means resurfacing, restoration, and rehabilitation (3R) work undertaken to restore serviceability and to extend the service life of an existing facility.

5.3.4 Recommendations

The overall objective of each city and county agency should be to obtain an optimum combination of expenditure for maintenance and rehabilitation to get the best possible value for total available funds. However, because the required funding is not usually available, various maintenance and rehabilitation alternatives, including deferral of the work, should be considered for each need and their cost and benefit implication analyzed. Maintenance and rehabilitation expenditures should be programmed simultaneously to avoid incompatibilities in an operational sense and to approach a truly optimum allocation of available funds.

Trying to draw a definitive boundary between maintenance and construction/rehabilitation activities is difficult, if not impossible. Because of current definitions, many city and county agencies are not selecting pavement repair activities based on which provide the most cost-effective solutions to their problems, but are selecting repair methods based on which "category" they lie under. This approach leads to an inefficient use of available funds. For example, Klickitat County personnel reported that very little overlaying has been performed in recent years, due to funding limits and day labor constraints associated with construction funding. They feel a partial solution to inadequate funding would be to allow overlays to a depth that is realistic under the maintenance definition. If the definitions were revised in this manner, Klickitat County would utilize a cold-mix pugmill at a substantial savings.

A potential solution to this problem is to create a general road preservation category. Rather than defining repair activities as maintenance, preventive maintenance, rehabilitation, construction, etc., all these activities would be considered together. This general category would allow city and county agencies to perform life cycle cost analysis to determine which repair activity in each case is most cost-effective.

A general preservation category would also allow each agency to take full advantage of local resources. For example, Klickitatt County could use its pugmill in producing overlays of sufficient thickness to be useful in maintaining their road system. While a change in definitions will not provide any additional funding to city and county agencies, it will permit them to select the most cost-effective methods for maintaining their roads.

5.4 SUMMARY

The main objective of this research project was to provide cities and counties in Washington State with a document outlining the best methods and materials available to rehabilitate the asphalt pavements under their jurisdiction. In conjunction with this work, the delineation between "maintenance" and "construction" was also addressed.

The study was divided into the following major activities:

1. an evaluation of the asphalt pavement repair techniques and materials used by agencies in this and other states, through the distribution of a questionnaire;
2. an extensive literature review on asphalt pavement rehabilitation techniques;
3. development of recommendations pertaining to asphalt pavement rehabilitation in Washington State; and
4. an investigation concerning the present legal definitions of "construction" and "maintenance" activities.

A review of the completed questionnaires distributed during this study yielded the following information:

1. The distress types causing the most concern within Washington are alligator cracking, edge cracking, lane-shoulder drop-off, patching, potholes, and weathering and raveling.
2. Only a few alternatives are considered by most Washington agencies to repair pavements, namely chip seals, overlays, and patching.
3. Some repair methods are being applied inappropriately, such as the use of a fog seal to correct alligator cracking.
4. Many repair procedures being undertaken by Washington agencies involve the use of poor materials, or are not being performed in the most effective manner possible. For example, patching is often not being performed well. Also, in some cases very little, if any, pre-repair work is being performed prior to placing chip seals or overlays.
5. Fabrics and modified asphalts are performing well in Washington.
6. There is confusion in Washington with respect to the construction versus maintenance issue, and it is of considerable concern to many agencies.
7. Available funds are not sufficient to correct existing pavement deficiencies, and many smaller agencies are feeling overwhelmed.

The literature review performed during this study provided very useful information. A comparison of the state-of-the-art repair procedures and materials identified in the literature to those being utilized within Washington State revealed areas where local agencies can improve repair performance.

After the questionnaires had been compiled, and the literature review completed, an extensive list of potential repair techniques was prepared. The potential techniques and materials included in this list were then reviewed to determine which alternatives are feasible at this time. Finally, the resultant lists of feasible repair alternatives were prioritized.

The purpose of the prioritized lists is to provide general guidance pertaining to the selection of a repair method to correct an identified pavement deficiency. Very few techniques are identified in these lists which will be unfamiliar to local agencies. However, if the prioritized lists are compared to the questionnaire responses, it can be seen that many repair alternatives are being applied inappropriately and ineffectively within Washington State.

The legal definitions of maintenance and construction as currently defined were evaluated. It was found that confusion exists among the agencies concerning the definitions, and that in some situations the definitions significantly restrict the ability of an agency to utilize limited road funds effectively. It is recommended that modifications be made to these definitions to enable agencies with Washington to optimize the use of available maintenance and construction funds.

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Alligator Cracking	Localized	Low	1. Crack Seal 2. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Crack Seal 2. Chip Seal 3. Patch
		Medium	1. Surface Recycle[1] 2. ATB[2] + Seal 3. Patch
		High	1. Surface Recycle[1] 2. ATB[2] + Seal 3. Full Depth Recycle 4. Thick Overlay 5. Reconstruct
Bleeding	Localized	Low	No Action
		Medium	1. Patch 2. Heat & Roll Sand 3. Burn
		High	1. Patch 2. Heat & Roll Sand 3. Burn
	Extensive	Low	No Action
		Medium	1. Burn + Sand Seal 2. Burn + Chip Seal 3. Burn + Slurry Seal
		High	1. Burn + Sand Seal 2. Burn + Chip Seal 3. Burn + Slurry Seal 4. Surface Recycling 5. Burn + Thin Overlay 6. Reconstruct

[1] Appropriate if problem in surface course, and not in the base or subgrade.
[2] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Block Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Slurry Seal 2. Rejuvenator 3. Crack Seal 4. Chip Seal
		Medium	1. Chip Seal 2. ATB[1] + Seal Coat 3. Crack Seal
		High	1. Surface Recycle 2. ATB[1] + Seal Coat 3. Thin Overlay 4. Full Depth Recycle 5. Reconstruct
Corrugation	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Thin Overlay/ Chip Seal 2. Grind, Mill, or Plane 3. ATB[1] + Seal Coat 4. Surface Recycle
		High	1. Surface Recycle 2. ATB[1] + Seal Coat 3. Prelevel Course + Thin Overlay 4. Grind, Mill, or Plane + Thin Overlay 5. Grind, Mill, or Plane 6. Reconstruct

[1] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Depression	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. ATB[1] + Seal Coat 2. Patch
		High	1. ATB[1] + Seal Coat 2. ATB[1] + Thin Overlay 3. Full Depth Recycle 4. Reconstruct
Edge Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Shoulder Seal 2. Crack Seal
		Medium	1. ATB[1] + Seal Coat 2. Crack Seal
		High	1. ATB[1] + Seal Coat 2. Thin Overlay 3. Surface Recycle
Lane/Shoulder Drop-Off	Localized	Low	No Action
		Medium	No Action
		High	1. Patch

[1] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Lane/Shoulder Drop-Off	Extensive	Low	No Action
		Medium	1. Add Aggregate + Grade 2. Level Shoulder + Chip Seal
		High	1. Level Shoulder + Chip Seal 2. Add Aggregate + Grade
Longitudinal & Transverse Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Crack Seal 2. Chip Seal 3. Slurry Seal 4. Rejuvenator
		Medium	1. Chip Seal 2. Crack Seal 3. Surface Recycle[1] 4. ATB[2] + Seal Coat[1]
		High	1. Surface Recycle[1] 2. ATB[2] + Seal Coat[1] 3. Thin Overlay[1] 4. Thick Overlay 5. Full Depth Recycle 6. Reconstruct

[1] Appropriate if problem is non-load associated.
[2] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Patching	Localized	Low	No Action
		Medium	1. Crack Seal 2. Patch
		High	1. Patch 2. Crack Seal
	Extensive	Low	No Action
		Medium	1. ATB[1] + Seal Coat 2. Crack Seal
		High	1. ATB[1] + Seal Coat 2. Overlay 3. Full Depth Recycle 4. Reconstruct
Polished Aggregate	Localized	N.A.	No Action
	Extensive	N.A.	1. Sand Seal 2. Chip Seal 3. Slurry Seal 4. Open Graded Course 5. Grind, Mill, or Plane 6. Surface Recycle 7. Thin Overlay
Potholes	Localized	Low	1. Patch
		Medium	1. Patch
		High	1. Patch

[1] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Potholes	Extensive	Low	1. ATB[1] + Seal Coat 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
		Medium	1. ATB[1] + Seal Coat 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
		High	1. Full Depth Recycle 2. Reconstruct 3. Thick Overlay 4. ATB[1] + Seal Coat
Rutting	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch 2. ATB[1] + Seal Coat 3. ATB[1] + Thin Overlay 4. Grind, Mill, or Plane 5. Grind, Mill, or Plane + Thin Overlay/Chip 6. Surface Recycle
		High	1. ATB[1] + Seal Coat 2. ATB[1] + Thin Overlay 3. Grind, Mill, or Plane 4. Grind, Mill, or Plane + Thin Overlay/Chip 5. Surface Recycle 6. Thick Overlay 7. Full Depth Recycle 8. Reconstruct

[1] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Shoving	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Surface Recycle 2. Reconstruct
Slippage Cracking	Localized	Low	1. Crack Seal
		Medium	1. Patch 2. Crack Seal
		High	1. Patch
	Extensive	Low	1. Crack Seal
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct 3. Patch
Swell	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane 2. ATB[1] + Seal Coat
		High	1. Grind, Mill, or Plane 2. Full Depth Recycle 3. Reconstruct

[1] Asphalt Treated Base

Table 5.1. Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Weathering & Raveling	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	1. Sand Seal 2. Fog Seal 3. Rejuvenator 4. Slurry Seal 5. ATB[1] + Seal Coat
		Medium	1. Sand Seal 2. Chip Seal 3. Slurry Seal 4. Open Graded Course 5. ATB[1] + Seal Coat
		High	1. Chip Seal 2. Thin Overlay 3. Open Graded Course 4. Surface Recycle 5. Reconstruct

[1] Asphalt Treated Base

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Alligator Cracking	Localized	Low	1. Crack Seal 2. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Crack Seal 2. Patch
		Medium	1. Surface Recycle[1] 2. Patch
		High	1. Surface Recycle[1] 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
Bleeding	Localized	Low	No Action
		Medium	1. Patch 2. Heat & Roll Sand 3. Burn
		High	1. Patch 2. Heat & Roll Sand 3. Burn
	Extensive	Low	No Action
		Medium	1. Burn + Chip Seal[2]
		High	1. Burn + Chip Seal[2] 2. Surface Recycling 3. Burn + Thin Overlay 4. Reconstruct

[1] Appropriate if problem in surface course, and not in the base or subgrade.
[2] Modified binder required for high traffic volumes.

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Block Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Crack Seal 2. Chip Seal[1]
		Medium	1. Chip Seal[1] 2. Crack Seal
		High	1. Surface Recycle 2. Thin Overlay 3. Full Depth Recycle 4. Reconstruct
Corrugation	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Thin Overlay/ Chip Seal 2. Surface Recycle
		High	1. Surface Recycle 2. Prelevel Course + Thin Overlay 3. Grind, Mill, or Plane + Thin Overlay 4. Reconstruct
Depression	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch

[1] Modified binder required for high traffic volumes.

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Depression	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct
Edge Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Shoulder Seal 2. Crack Seal
		Medium	1. Crack Seal
		High	1. Thin Overlay 2. Surface Recycle
Lane/Shoulder Drop-Off	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Add Aggregate + Grade 2. Level Shoulder + Chip Seal
		High	1. Level Shoulder + Chip Seal 2. Add Aggregate + Grade

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Longitudinal & Transverse Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Crack Seal 2. Chip Seal[1] 3. Rejuvenator
		Medium	1. Chip Seal[1] 2. Crack Seal 3. Surface Recycle[2]
		High	1. Surface Recycle[2] 2. Thin Overlay[2] 3. Thick Overlay 4. Full Depth Recycle 5. Reconstruct
Patching	Localized	Low	No Action
		Medium	1. Crack Seal 2. Patch
		High	1. Patch 2. Crack Seal
	Extensive	Low	No Action
		Medium	1. Overlay 2. Crack Seal
		High	1. Overlay 2. Full Depth Recycle 3. Reconstruct
Polished Aggregate	Localized	N.A.	No Action
	Extensive	N.A.	1. Chip Seal[1] 2. Surface Recycle 3. Thin Overlay

[1] Modified binder required for high traffic volumes.
[2] Appropriate if problem in surface course, and not in the base or subgrade.

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Potholes	Localized	Low	1. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Full Depth Recycle 2. Thick Overlay 3. Reconstruct
		Medium	1. Full Depth Recycle 2. Thick Overlay 3. Reconstruct
		High	1. Full Depth Recycle 2. Reconstruct 3. Thick Overlay
Rutting	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch 2. Grind, Mill, or Plane + Thin Overlay 3. Surface Recycle
		High	1. Grind, Mill, or Plane + Thin Overlay 2. Surface Recycle 3. Thick Overlay 4. Full Depth Recycle 5. Reconstruct
Shoving	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Shoving	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Surface Recycle 2. Reconstruct
Slippage Cracking	Localized	Low	1. Crack Seal
		Medium	1. Patch 2. Crack Seal
		High	1. Patch
	Extensive	Low	1. Crack Seal
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct 3. Patch
Swell	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Thin Overlay
		High	1. Full Depth Recycle 2. Reconstruct
Weathering & Raveling	Localized	Low	No Action
		Medium	No Action
		High	1. Patch

Table 5-2. Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Weathering & Raveling	Extensive	Low	1. Sand Seal 2. Fog Seal 3. Rejuvenator
		Medium	1. Sand Seal 2. Chip Seal[1]
		High	1. Chip Seal[1] 2. Thin Overlay 4. Surface Recycle 5. Reconstruct

[1] Modified binder required for high traffic volumes.

Table 5.3. Repair Selection Factors and Constraints

SELECTION FACTORS
pavement condition,
shoulder condition,
subgrade condition,
pavement design,
geometric design,
materials and soils properties,
traffic volume and load,
climatic conditions,
drainage conditions,
riding quality,
deflection data (when available),
maintenance history,
cause of distress, and
safety considerations.

SELECTION CONSTRAINTS
project funding,
traffic control problems,
minimum desirable life of rehabilitation,
geometric design problems,
utilities,
clearances,
right-of-way,
time of year,
weather,
available materials and equipment,
contractor expertise and manpower,
reliability,
constructibility,
maintainability,
duration of construction, and
agency policies.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials.
Alligator Cracking	series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading.
ARC	asphalt-rubber concrete, where asphalt-rubber is used as the binder in hot-mixed dense graded asphalt concrete.
Asphalt Additive	material added to asphalt cement to alter properties of asphalt cement and asphalt concrete.
Asphalt Aggregate Surface Treatment	sequential applications of asphalt and stone chips which can be made either singly or in repetitive layers.
Asphalt Cement	straight refined asphalt.
Asphalt Concrete	high quality hot mixture of asphalt cement and well-graded, high quality aggregate, compacted into a uniform, dense mass.
Asphalt Emulsion	suspension of asphalt in water.
Asphalt Overlay	one or more courses of asphalt construction on an existing pavement.
BARS Code	Budgeting, Accounting, and Reporting System for Counties and Cities and Other Local Governments.
Block Cracking	interconnected cracks that divide the pavement into approximately rectangular pieces; caused mainly by shrinkage of the asphalt concrete and daily temperature cycling and not by traffic loads.
Bump	small, localized, upward displacement of the pavement surface.
Cape Seal	chip seal topped with a slurry seal.
Carbon Black Filler	submicrometre-size particles of carbon black dispersed into paving-grade asphalts.
Chip Seal	application of asphalt followed with an aggregate cover.

Choke	a sand or manufactured 1/4"-0 that is applied after the primary cover stone to fill surface voids, to prevent rock turning, and to serve as a blotter.
Cold Milling	use of carbide cutting teeth mounted on a rotary drum to chip off as much as 3 to 4 inches of asphalt concrete surface.
Cold-Pour Sealant	sealant material applied at ambient temperatures.
Cold-Mix Recycling	reuse of untreated base materials and or asphalt concrete pavement that is either processed in-place or at a central plant.
Construction Seal	fog seal placed on a new asphalt concrete surface.
Corrugation/Washboarding	series of closely spaced ridges and valleys occurring at fairly regular intervals, with the ridges perpendicular to the traffic pattern.
Cutback Asphalt	asphalt that is dissolved in a petroleum solvent.
Depression/Birdbath	localized pavement surface area with elevation slightly lower than that of the surrounding pavement.
Edge Cracking	cracks that are parallel to and usually within 1 to 2 feet of the outer edge of the pavement.
Elastomer	polymer which resists permanent deformation by stretching and recovering its shape quickly when the deforming force is moved.
FHWA	Federal Highway Administration.
Flushing/Bleeding	film of bituminous material on the pavement surface which creates a shiny/glasslike, reflecting surface that usually becomes quite sticky.
Fog Seal	application of a dilute emulsion without an aggregate cover.
FRA	fiber reinforced asphalt.
Hot-Mix Recycling	removal of greater than the top inch of asphalt pavement that is processed by sizing, heating, and mixing in a central plant with additional components.
Hot-Pour Sealant	sealant material which must be melted and heated before application.

HRIS	Highway Research Information Service.
IRRD	International Road Research Documentation.
LAG	State Aid Organization's Manual of Local Agency Guidelines.
Lane/Shoulder Drop-Off	difference in elevation between the pavement edge and the shoulder.
Leveling Course	asphalt aggregate mixture of variable thickness used to eliminate irregularities in the contour of an existing surface prior to superimposed treatment or construction.
Long. & Trans. Cracking	longitudinal cracks are parallel to centerline; transverse cracks are approximately perpendicular to centerline.
Metal Complex	chemical compound composed of a metal ion linked to any variety of organic compounds.
Open-Graded Friction Course	application of asphalt and aggregate designed to drain water off pavement surface by providing an open, porous structure in the mixture.
Patching	area of pavement which has been replaced with new material to repair the existing pavement.
Plastomer	polymer which forms a tough, rigid, three dimensional network resistant to deformation.
Polished Aggregate	surface aggregate which has become smooth to the touch.
Polymer	very large molecule made by chemically modifying many smaller molecules to one another in long chains or clusters.
Pothole	small, bowl-shaped depression in the pavement surface.
RAM	reclaimed asphalt pavement materials.
RAP	reclaimed aggregate materials.
RCWA	Revised Code of Washington Annotated.
Recycling	re-use, usually after some reprocessing, of a material that has already served its first intended purpose.

Reflection Cracks	cracks in asphalt overlay which reflect the crack pattern of the pavement underneath.
Rejuvenator	material used to restore pavement performance believed to have been lost as the bituminous binder ages.
Rubber-Modified Asphalt	blend of asphalt cement and rubber.
Rutting	surface depression in wheel paths.
Sag	small, abrupt, downward displacement of the pavement surface.
SAM	stress absorbing membrane.
SAMI	stress absorbing membrane interlayer, used to reduce reflection cracking prior to overlaying.
Sand Seal	spray application of emulsion followed by a sand cover aggregate.
SEA	replacement of a significant portion (typically 20 to 40%) of conventionally used asphalt with elemental sulfur.
Seal Coat	sprayed asphalt treatments, with or without cover aggregate, and asphalt-aggregate mixtures.
Shoving	permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading.
Slippage Cracking	crescent-shaped cracks created when breaking or turning wheels cause the pavement surface to slide or deform.
Slurry Seal	mixture of a specially graded aggregate and a diluted asphalt emulsion.
Surface Recycling	re-working in-place of asphalt pavement surface to a depth less than 2 inches.
Surface Treatment	application of asphalt and/or aggregate to a roadway surface, usually less than 1 inch thick, which improves or protects the surface characteristics of roadway.
Swell	upward bulge in pavement surface.
Tack Coat	light application of asphalt between an existing pavement and an overlay.
TLIB	Transportation Libraries.

TRIS	Transportation Research Information Services.
WAC	Washington Accounting Code.
Weathering & Raveling	wearing away of the pavement surface caused by the loss of asphalt or tar binder and dislodged aggregate particles.

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APPENDIX A. SAMPLE QUESTIONNAIRE

Your participation in this study is greatly appreciated. Please return the enclosed questionnaire by October 15, 1989 to:

Pavement Consultants Incorporated
Attention: Margaret Broten, Project Engineer
9500 Roosevelt Way N.E., Suite 300
Seattle, Washington 98115

If you have any questions, please do not hesitate to contact Margaret Broten at 206-523-9796.

Name: ______________________________

Title: ______________________________

City/County: ______________________________

Phone Number: ______________________________

Lane Miles Under Your Jurisdiction: ______________________________

Annual Maintenance Budget: ______________________________

1. Please estimate the percentage of the asphalt concrete and/or bituminous surface treatment pavements in your area which exhibit the following distress types, using the scale shown below. Place an asterisk (*) by the distress types which cause you the most maintenance/rehabilitation headaches.

   1 = 0 - 20%
   2 = 20 - 40%
   3 = 40 - 60%
   4 = 60 - 80%
   5 = 80 - 100%

   __ Alligator Cracking (fatigue cracking, a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading)

   __ Weathering and Raveling (wearing away of the pavement surface caused by the loss of asphalt or tar binder and dislodged aggregate particles)

   __ Transverse and Longitudinal Cracking (longitudinal cracks are parallel to the pavement's centerline or laydown direction; transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of laydown)

   __ Rutting (surface depression in the wheel paths)

   __ Potholes (small, bowl-shaped depressions in the pavement surface)

   __ Corrugation/"Washboarding" (series of closely spaced ridges and valleys occurring at fairly regular intervals, with the ridges perpendicular to the traffic pattern)

   __ Patching (area of pavement which has been replaced with new material to repair the existing pavement)

1. Continued

- __ Flushing/Bleeding (film of bituminous material on the pavement surface which creates a shiny/glasslike, reflecting surface that usually becomes quite sticky)
- __ Edge Cracking (cracks that are parallel to and usually within 1 to 2 feet of the outer edge of the pavement)
- __ Slippage Cracking (crescent-shaped cracks produced when braking or turning wheels cause the pavement surface to slide or deform)
- __ Depressions/"Birdbaths" (localized pavement surface areas with elevations slightly lower than those of the surrounding pavement)
- __ Swells (upward bulges in the pavement's surface)
- __ Polished Aggregate (the surface aggregate is smooth to the touch)
- __ Block Cracking (interconnected cracks that divide the pavement into approximately rectangular pieces; caused mainly by shrinkage of the asphalt concrete and daily temperature cycling and not by traffic loads)
- __ Lane/Shoulder Drop-Off (difference in elevation between the pavement edge and the shoulder)
- __ Shoving (permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading)

2. For each distress type, please list <u>all</u> the maintenance/repair actions you would consider completing to correct each problem. If you would ignore the distress type, please identify with DN ("Do Nothing"). If your pavements do not exhibit a distress type, please mark with NA. Feel free to identify different repair actions for pavements exhibiting only localized distressed areas versus those showing extensive distress. If you wait to repair a certain distress until it reaches a certain level (for example, no crack sealing is performed until the cracks are > 1/4"), please identify the cut-off level.

DISTRESS TYPE	EXTENT	PROPOSED ACTION(S)
Alligator Cracking	Localized	
	Extensive	
Weathering and Raveling	Localized	
	Extensive	

2. Continued

DISTRESS TYPE	EXTENT	PROPOSED ACTION(S)
Transverse and Longitudinal Cracking	Localized	
	Extensive	
Rutting	Localized	
	Extensive	
Potholes	Localized	
	Extensive	
Corrugation/ Washboarding	Localized	
	Extensive	
Patching	Localized	
	Extensive	
Flushing/ Bleeding	Localized	
	Extensive	
Edge Cracking	Localized	
	Extensive	

2. Continued

DISTRESS TYPE	EXTENT	PROPOSED ACTION(S)
Slippage Cracking	Localized	
	Extensive	
Depressions/ "Birdbaths"	Localized	
	Extensive	
Swells	Localized	
	Extensive	
Polished Aggregate	Localized	
	Extensive	
Block Cracking	Localized	
	Extensive	
Lane/Shoulder Drop-Off	Localized	
	Extensive	
Shoving	Localized	
	Extensive	

Comments:

3. Please complete the questions pertaining to each of the repair/maintenance activities listed below. If you do not perform a repair activity, mark it NA.

Crack Sealing

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Full-Depth Patch

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Partial-Depth Patch

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

3. Continued

Skin Patch

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Pothole Filling

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Thin Overlays (<1.5 inches)

Repair Steps (including surface preparation activities):

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

3. Continued

Thick Overlays (>1.5 inches)

Repair Steps (including surface preparation activities):

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Rejuvenator

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Fog Seal (dilute emulsion without an aggregate cover)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

3. Continued

Construction Seal (fog seal placed on new surfaces)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Sand Seal (application of asphalt followed by sand cover)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Slurry Seal (mixture of graded aggregate and asphalt emulsion)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

3. Continued

Chip Seal (application of asphalt followed with aggregate cover)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Cape Seal (chip seal topped with a slurry seal)

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Hot-Mix Recycling

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

3. Continued

Cold-Mix Recycling

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Surface Recycling

Repair Steps:

Materials and Equipment Used:

Estimated Repair Cost:

Estimated Repair Life:

Performed In-House or Contracted Out:

Additional Repair Techniques Not Listed

4. Please attach any material and construction specifications which you use during asphalt pavement repair projects.

5. What pavement management system are you currently using, if any?

6. When more than one repair action is available to repair a given distress type, what criteria do you use in order to determine which repair approach to utilize?

   a) For example, is the cheapest alternative in terms of initial cost always selected, or do you use life-cycle cost analysis in making a decision?

   b) Are user-costs calculated (such as traffic delays, safety, etc.)? If so, how?

   c) Do the repair approaches used vary according to road classifications (rural (07, 08, 09), urban (15, 16, 17, 19) and federal)?

7. How do you decide when to repair a distress using short-term maintenance techniques (crack sealing, skin patches, etc.) and when to perform full-scale rehabilitation, such as reconstruction or a thick overlay?

8. Please list the repair actions you define as maintenance and the repair actions you define as rehabilitation/construction under the appropriate headings below:

Maintenance Activities	Rehabilitation/Construction Activities

9. What criteria did you use to answer question 7 (for example, local, state or federal guidelines; cost of the activity; repair life; etc.)

10. If you are aware of any asphalt pavement repair projects which have been conducted in your area involving new techniques, materials, or equipment, please describe below. In particular, we would like to know the potential benefit of using such a new method or material, any special equipment or expertise that is required to successfully implement such a repair, and the predicted service life of the repair. Please list any contact persons and phone numbers regarding these projects if available. If new materials were involved, such as an asphalt additive, please attach relevant specifications.

APPENDIX B. QUESTIONNAIRE RESULTS

Table B-1. Occurrence of Pavement Distress

Washington Counties

Percent of Pavements Exhibiting a Distress Type

Distress Type	0-20%[1] E	W	T	20-40%[1] E	W	T	40-60%[1] E	W	T	60-80%[1] E	W	T	80-100%[1] E	W	T	Problem[2] E	W	T
Alligator Crack	33	100	62	22	0	12	22	0	13	11	0	6	12	0	7	33	29	31
Bleeding	78	86	81	22	14	19	0	0	0	0	0	0	0	0	0	0	0	0
Block Crack	67	100	81	22	0	12	11	0	7	0	0	0	0	0	0	0	0	0
Corrug-ation	89	86	88	11	14	12	0	0	0	0	0	0	0	0	0	0	0	0
Depres-sions	45	86	62	33	14	25	0	0	0	11	0	6	11	0	7	11	0	6
Edge Crack	0	57	25	56	43	50	11	0	6	11	0	6	22	0	13	44	29	38
Lane-Shld. Drop-Off	43	75	56	35	0	19	22	25	25	0	0	0	0	0	0	22	0	13
Patching	34	57	44	33	43	37	11	0	6	0	0	0	22	0	13	22	14	19
Polished Aggregate	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potholes	67	71	68	11	29	19	0	0	0	0	0	0	22	0	13	22	0	13
Rutting	45	57	50	22	14	19	11	29	19	11	0	6	11	0	6	0	0	0
Shoving	89	100	94	0	0	0	0	0	0	11	0	6	0	0	0	11	0	6
Slippage Crack	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Swells	78	100	88	11	0	6	0	0	0	11	0	6	0	0	0	0	0	0
Trans. & Long. Crack	44	86	62	0	14	6	44	0	25	12	0	7	0	0	0	0	0	0
Weather & Ravel	78	57	69	0	29	12	11	14	13	11	0	6	0	0	0	0	14	6

[1] Percent of counties identifying the distress type as occurring on this percentage of their pavements.

[2] Percent of counties naming the indicated distress type as causing major maintenance concerns.

Table B-2. Occurrence of Pavement Distress

Washington Cities

Percent of Pavements Exhibiting a Distress Type

Distress Type	0-20%[1]			20-40%[1]			40-60%[1]			60-80%[1]			80-100%[1]			Problem[2]		
	E	W	T	E	W	T	E	W	T	E	W	T	E	W	T	E	W	T
Alligator Crack	29	50	42	14	20	18	43	20	29	0	0	0	14	10	12	14	40	29
Bleeding	86	100	94	0	0	0	14	0	6	0	0	0	0	0	0	14	0	6
Block Crack	72	90	82	14	10	12	14	0	6	0	0	0	0	0	0	0	0	0
Corrug-ation	100	90	94	0	10	6	0	0	0	0	0	0	0	0	0	0	10	6
Depres-sions	71	80	76	29	10	18	0	0	0	0	0	0	0	10	6	0	0	0
Edge Crack	72	80	76	0	10	6	14	10	12	14	0	6	0	0	0	0	10	6
Lane-Shld. Drop-Off	71	70	71	29	30	29	0	0	0	0	0	0	0	0	0	0	0	0
Patching	43	70	59	14	30	24	29	0	12	0	10	6	14	0	6	14	0	6
Polished Aggregate	100	90	94	0	10	6	0	0	0	0	0	0	0	0	0	0	0	0
Potholes	58	80	70	14	10	12	14	10	12	0	0	0	14	0	6	14	30	24
Rutting	71	90	82	0	10	6	29	0	12	0	0	0	0	0	0	0	0	0
Shoving	86	90	88	14	10	12	0	0	0	0	0	0	0	0	0	0	0	0
Slippage Crack	86	100	94	14	0	6	0	0	0	0	0	0	0	0	0	0	0	0
Swells	71	100	88	29	0	12	0	0	0	0	0	0	0	0	0	0	0	0
Trans. & Long. Crack	43	60	53	14	40	29	29	0	12	0	0	0	14	0	6	14	10	12
Weather & Ravel	72	70	71	14	30	23	14	0	6	0	0	0	0	0	0	14	10	12

[1] Percent of cities identifying the distress type as occurring on this percentage of their pavements.

[2] Percent of cities naming the indicated distress type as causing major maintenance concerns.

Table B-3. Potential Repair Actions

Washington Counties

Distress Type	Distress Extent	East Repair Action	West Repair Action
Alligator Crack	Localized	Patch Prelevel Chip Seal Seal Coat Crack Seal Do Nothing	Patch Prelevel Chip Seal Seal Coat Fog Seal Overlay
	Extensive	Overlay Reconstruct Patch Rebuild and Seal Patch & Chip Seal Patch & Seal Coat	Overlay Patch and Overlay Patch Seal Coat Patch, Place Fabric, Overlay Chip Seal
Bleeding	Localized	Do Nothing Seal Coat Sand	Do Nothing Seal Coat Sand Overlay Chip Seal
	Extensive	Sand Seal Coat	Sand Seal Coat Overlay Chip Seal
Block Cracking	Localized	Do Nothing Crack Seal Chip Seal	Do Nothing Patch Seal Coat
	Extensive	Crack Seal Chip Seal Crack Seal and Seal Coat Crack Seal and Chip Seal	Seal Coat Overlay Prelevel and Seal Do Nothing

Table B-3. Potential Repair Actions (Continued)

Washington Counties

Distress Type	Distress Extent	East Repair Action	West Repair Action
Corrugation	Localized	Do Nothing Prelevel and Seal Scarify Surface, Mix with Base, Resurface	Do Nothing Prelevel & Overlay Prelevel
	Extensive	Patch & Chip Seal Prelevel and Seal Scarify Surface, Mix with Base, Resurface Overlay Reconstruct and Chip Seal	Prelevel & Overlay
Depressions	Localized	Do Nothing Prelevel Patch and Seal Patch	Do Nothing Prelevel Patch and Seal Patch
	Extensive	Prelevel & Overlay Prelevel & Chip Overlay Reconstruct Patch Prelevel and Seal	Prelevel Overlay
Edge Crack	Localized	Patch Crack Seal Chip Seal Prelevel	Patch Patch and Seal Prelevel Prelevel and Chip Seal
	Extensive	Patch Patch and Seal Prelevel and Overlay Widen Shoulder Prelevel and Seal	Patch Overlay Outer Edge Prelevel Patch & Prelevel Extend Shoulder Prelevel and Seal

Table B-3. Potential Repair Actions (Continued)

Washington Counties

Distress Type	Distress Extent	East Repair Action	West Repair Action
Lane/Shoulder Drop-Off	Localized	Do Nothing Patch Add Rock	Rebuild Shoulder Patch Add Rock Fabric and Prelevel
	Extensive	Do Nothing Seal Coat Add Rock Grade Shoulder Widen Shoulder Remove and Replace	Add Rock Rebuild Shoulder Prelevel Prelevel and Seal
Patching	Localized	Crack Seal Seal Coat Patch	Do Nothing Prelevel Patch Prelevel & Overlay
	Extensive	Patch Crack Seal & Prelevel Overlay Overlay & Chip Seal	Prelevel Patch and Overlay Overlay (w/ or wo Fabric)
Polished Aggregate	Localized	Do Nothing Chip Seal Seal Coat	Do Nothing Chip Seal
	Extensive	Do Nothing Chip Seal Seal Coat	Do Nothing Chip Seal Overlay
Potholes	Localized	Do Nothing Patch	Patch and Overlay Patch (w/ or w/o Fabric)
	Extensive	Patch Patch and Seal Patch & Chip Seal	Patch Reconstruct Patch and Seal Coat Patch and Overlay

Table B-3. Potential Repair Actions (Continued)

Washington Counties

Distress Type	Distress Extent	East Repair Action	West Repair Action
Rutting	Localized	Do Nothing Prelevel Seal Coat Prelevel & Seal Patch and Chip	Do Nothing Prelevel Prelevel & Overlay Prelevel & Chip Seal
	Extensive	Do Nothing Rebuild and Chip Patch and Seal Prelevel & Overlay Patch Overlay Prelevel Prelevel and Seal	Prelevel & Chip Seal Prelevel with Fabric Prelevel and Seal Prelevel & Overlay
Shoving	Localized	Do Nothing Remove & Restore Patch	Do Nothing Patch Prelevel
	Extensive	Do Nothing Patch Repave Remove and Replace	Do Nothing Prelevel
Slippage Crack	Localized	Do Nothing Patch Crack Seal	Do Nothing Patch Crack Seal Patch With Fabric
	Extensive	Crack Seal and Chip Seal Reconstruct Seal Coat	Do Nothing Prelevel Patch & Prelevel Patch With Fabric
Swells	Localized	Do Nothing Patch	Do Nothing Patch
	Extensive	Do Nothing Patch Rebuild Patch and Seal	Do Nothing Patch Plane

Table B-3. Potential Repair Actions (Continued)

Washington Counties

Distress Type	Distress Extent	East Repair Action	West Repair Action
Transverse & Longitudinal Crack	Localized	Do Nothing Seal Cracks Chip Seal	Do Nothing Seal Cracks Chip Seal Patch & Seal Coat
	Extensive	Seal Cracks Seal Cracks & Chip Seal	Overlay Chip Seal Seal Coat Overlay w/ Fabric Prelevel & Overlay
Weather & Ravel	Localized	Do Nothing Chip Seal Seal Coat	Do Nothing Chip Seal Seal Coat Patch Prelevel
	Extensive	Do Nothing Seal Coat Reconstruct	Prelevel Seal Coat Prelevel and Patch Cold Mix Patch & Seal Chip Seal Overlay Patch, Place Fabric, Overlay

Table B-4. Potential Repair Actions

Washington Cities

Distress Type	Distress Extent	East Repair Action	West Repair Action
Alligator Crack	Localized	Do Nothing Patch Rejuvenator	Do Nothing Patch Chip Seal Crack Seal Patch w/ Fabric Overlay
	Extensive	Overlay Overlay w/ Fabric Reconstruct Patch & Overlay Patch	Overlay Overlay w/ Fabric Reconstruct
Bleeding	Localized	Sand	Do Nothing Sand
	Extensive	Sand	Do Nothing Sand Chip Seal Slurry Seal Seal Coat
Block Cracking	Localized	Do Nothing Crack Seal	Do Nothing Crack Seal Patch
	Extensive	Do Nothing Overlay Reconstruct Crack Seal	Do Nothing Overlay Reconstruct Reconstruct w/ Fabric
Corrugation	Localized	Do Nothing	Do Nothing Patch
	Extensive	Do Nothing Reconstruct	Overlay Reconstruct Grind

Table B-4. Potential Repair Actions (Continued)

Washington Cities

Distress Type	Distress Extent	East Repair Action	West Repair Action
Depressions	Localized	Do Nothing Patch	Do Nothing Shim
	Extensive	Do Nothing Patch Overlay	Do Nothing Remove & Replace Overlay Reconstruct Grind & Overlay Prelevel & Overlay
Edge Crack	Localized	Chip Seal Patch Build Shoulder Overlay Crack Seal	Do Nothing Patch Shoulder Repair Remove & Repair Crack Seal
	Extensive	Patch Chip Seal Overlay	Patch Overlay Outer Edge Remove & Repair Overlay w/ Fabric Overlay Do Nothing
Lane/Shoulder Drop-Off	Localized	Do Nothing Patch Add Rock	Rebuild Shoulder Patch Add Rock
	Extensive	Do Nothing Patch	Add Rock Rebuild Shoulder Overlay Patch
Patching	Localized	Do Nothing Patch Patch and Seal	Do Nothing Patch
	Extensive	Patch and Seal Patch Reconstruct Overlay	Do Nothing Patch Overlay (w/ or wo Geotextile) Scarify & Overlay

Table B-4. Potential Repair Actions (Continued)

Washington Cities

Distress Type	Distress Extent	East Repair Action	West Repair Action
Polished Aggregate	Localized	Do Nothing	Do Nothing
	Extensive	Do Nothing	Do Nothing Chip Seal Slurry Seal
Potholes	Localized	Do Nothing Patch Patch & Seal	Patch
	Extensive	Patch Patch and Seal Reconstruct	Patch Patch & Overlay Reconstruct Patch & Overlay w/ Fabric Scarify & Overlay
Rutting	Localized	Do Nothing Patch	Do Nothing Patch
	Extensive	Do Nothing Reconstruct Overlay Grind	Grind and Overlay Overlay w/ Fabric Overlay Reconstruct
Shoving	Localized	Do Nothing	Do Nothing Patch Grind
	Extensive	Do Nothing Reconstruct	Do Nothing Reconstruct Grind & Overlay
Slippage Crack	Localized	Do Nothing	Do Nothing Patch
	Extensive	Do Nothing	Remove & Replace
Swells	Localized	Do Nothing	Reconstruct Patch
	Extensive	Do Nothing Patch Reconstruct	Reconstruct

Table B-4. Potential Repair Actions (Continued)

Washington Cities

Distress Type	Distress Extent	East Repair Action	West Repair Action
Transverse & Longitudinal Crack	Localized	Do Nothing Seal Cracks Patch	Do Nothing Seal Cracks
	Extensive	Do Nothing Crack Seal Reconstruct Patch and Overlay Overlay Chipe Seal	Overlay w/ Fabric Crack Seal Crack & Chip Seal Crack Seal & Overlay Overlay
Weather & Ravel	Localized	Do Nothing Patch Overlay	Do Nothing
	Extensive	Overlay	Do Nothing Overlay Chip Seal Slurry Seal Grind & Overlay

Table B-5. Estimated Repair Cost and Performance Life*

Washington Counties

Repair Action	East Repair Cost($) Range	East Repair Cost($) Ave.	West Repair Cost($) Range	West Repair Cost($) Ave.	East Repair Life(yr) Range	East Repair Life(yr) Ave.	West Repair Life(yr) Range	West Repair Life(yr) Ave.
Chip Seal + Minor Repair Work	5500-11000mi	8197mi	6000-10000mi	8000mi	5-11	7.1	2-7	5.8
Chip Seal + Preleveling	8000-15000mi	10667mi	10000-20000mi	13125mi	10-12	10.3	5-12	7.6
Crack Seal	.29-.50lf	.40lf	NA	.18lf	3-5	4.3	5-10	6.5
Fog Seal	NA	NA	NA	800mi	NA	NA	NA	NA
PDP[1]	60-122tn	91tn	NA	58tn	4-12	7.0	1-10	5.7
FDP[2]	70-230tn	143tn	NA	87tn	7-15	10.9	1-10	7.1
Skin Patch	40-60tn	50tn	NA	NA	2-10	5.2	1-7	3.3
Pothole Fill	60-78tn	69tn	122-137tn	130tn	0-5	2.2	0-3	1.6
Thin Overlay	39-52tn	46tn	22-60tn	42tn	10-15	11.1	3-12	9.0
Thick Overlay	28-50tn	36tn	22-60tn	38tn	12-20	16.2	5-18	13.0
Surface Recycle + Seal Coat	NA	NA	NA	40000mi	NA	NA	NA	7.0
Rejuvenator	NA	NA	NA	NA	NA	NA	1-3	2.0

* Note: The values in this table reflect a wide range of repair procedures and materials.

[1] Partial Depth Patch

[2] Full Depth Patch

Table B-6. Estimated Repair Cost and Performance Life*

Washington Cities

Repair Action	East Repair Cost($) Range	East Repair Cost($) Ave.	West Repair Cost($) Range	West Repair Cost($) Ave.	East Repair Life(yr) Range	East Repair Life(yr) Ave.	West Repair Life(yr) Range	West Repair Life(yr) Ave.
Chip Seal + Minor Repair Work	NA	7038mi	5000-13373mi	8975mi	3-7	5.0	3-10	8.5
Chip Seal + Preleveling	NA	NA	NA	NA	NA	7.0	NA	NA
Construction Seal	NA	NA	NA	1830mi	NA	NA	NA	NA
Crack Sealing:								
Rubberized	NA	.58lf	.40-.91lf	.71lf	NA	5.0	2-6	5.2
Other	NA	NA	NA	NA	3-5	4.5	1-5	2.9
PDP[1]	NA	74tn	98-100tn	99tn	4-8	6.0	2-10	5.3
FDP[2]	46-74tn	63tn	65-150tn	104tn	7-10	9.3	3-10	7.1
Skin Patch	NA	116tn	60-100tn	80tn	1-5	2.8	1-10	3.9
Pothole Fill	14-109tn	60tn	92-150tn	121tn	1-5	3.1	0-4	2.1
Sand Seal	NA	2500mi	NA	NA	NA	3.0	NA	NA
Slurry Seal	NA	NA	14077-35192mi	24635mi	6-8	7.0	3-10	6.5
Thin Overlay	37-74tn	55tn	28-100tn	56tn	5-10	8.6	3-15	6.8
Thick Overlay	NA	NA	30-35tn	32tn	10-15	13.0	5-15	11.7
Surface Recycle + Overlay	NA	NA	NA	15sy	NA	NA	15-20	17.5

* Note: The values in this table reflect a wide range of repair procedures and materials.

[1] Partial Depth Patch

[2] Full Depth Patch

Table B-7. Maintenance versus Construction Activities

Washington Counties

Repair Activity	% East I.D.[1] As Maintenance	% West I.D. As Maintenance	% East I.D. As Construction	% West I.D. As Construction
Chip Seal	22	33	11	50
Construction Seal	0	0	11	0
Crack Sealing	11	50	0	0
Edge Repair	0	33	0	0
Fog Seal	0	17	0	0
Leveling	11	50	0	0
Patching (All)	100	100	0	0
Reconstruction	0	0	11	17
Recycling	0	0	0	17
Seal Coat	56	50	0	0
Thin Overlay	22	100	11	0
Thick Overlay[2]	0	0	44	83
Work Involving Entire Width/Length	0	0	0	17
Change in Road Width, Grade, Alignment, or Surface	0	0	33	50

1 Identification

2 Definition varied from >3/4" to >2"

Table B-8. Maintenance versus Construction Activities

Washington Cities

Repair Activity	% East I.D.[1] As Maintenance	% West I.D. As Maintenance	% East I.D. As Construction	% West I.D. As Construction
Chip Seal	0	10	0	10
Construction Seal	0	0	0	0
Crack Sealing	29	30	0	0
Edge Repair	0	0	0	0
Fog Seal	0	0	0	0
Grinding	0	0	0	10
Leveling	0	10	0	0
Patching (All)	71	100	0	0
Reconstruction	0	0	57	30
Recycling	0	0	0	0
Seal Coat	29	0	0	0
Thin Overlay	43	10	0	0
Thick Overlay[2]	0	0	14	10
Work Involving Entire Width/Length	0	0	0	10
Change in Road Width, Grade, Alignment, or Surface	0	0	14	10

[1] Identification

[2] Definition varied from >3/4" to >2"

APPENDIX C. MAINTENANCE VERSUS CONSTRUCTION ACTIVITIES

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

STATE AID ORGANIZATION'S MANUAL OF LOCAL AGENCY GUIDELINES

I-2-03 STATE GASOLINE TAX DISTRIBUTED TO CITIES AND TOWNS

.01 General.

Cities and towns receive 11.53 percent of the net motor vehicle fuel tax. The distribution is on the basis of population as determined by the State Office of Financial Management, and in accordance with RCW 46.68.100. The money is distributed in two separate programs.

(a) 6.92 Percent Program: Street or Road Fund.
These funds may be used for any street or road purpose, including maintenance.

(b) 4.61 Percent Program: Arterial Fund. (See .02 and .03, below.)
These funds shall be used for preliminary engineering, right of way, construction, improvement, and repair of arterials and city streets. Cities with a population less than 15,000 may also use these funds for maintenance.

.02 Definitions.

Construction: The building of a street, a portion of a street, or a facility that did not previously exist. It may be on new or existing right of way.

Improvement: Betterment in traffic service without major changes in the original construction. This includes widening, signals, illumination, curbs, gutters, drainage, sidewalks, and other items which add value to the existing facility.

Repair: Replacement or rebuilding of a facility which is worn out, destroyed, or damaged. Repair includes overlays which are 0.06 foot thick or thicker. Crushed surfacing 0.06 foot thick or thicker and covering more than 10 percent of the original surface may be considered repair.

Maintenance: Work directed toward preservation of the existing roadway and related appurtenances for safe and efficient operation. Any surface treatments less than 0.06 foot thick, crack sealing, etc., are considered to be maintenance.

I-5-04 GLOSSARY OF TERMS AND ABBREVIATIONS

Construction - The building of a street, a portion of a street or a facility that did not previously exist. It may be on new right-of-way or on existing right-of-way.

Maintenance - Work directed toward preservation of the existing roadway and related appurtenances as necessary for safe and efficient operation. Any surface treatments less than 0.06 foot thick, crack sealing, etc. are considered to be maintenance and are not 3-R activities.

New Construction - The building of a new roadway or structure on substantially new alignment, or the upgrading of an existing roadway or structure by the addition of one or more lanes. If 50 percent or more of the project length involve vertical or horizontal alignment changes, the project is new construction. The following types of projects are not classed as new construction, and the 3-R standards apply:

* Modernization of an existing street or road by resurfacing, widening lanes, adding shoulders, or adding turn lanes at intersections.
* Temporary replacement of a street or roadway, immediately after the occurrence of a natural disaster or catastrophic failure, to restore the facility for the health, welfare, and safety of the public.

Rehabilitation - Similar to "Restoration" except the work may include reworking or strengthening the base or sub-base, recycling or reworking existing materials to improve their structural integrity, adding under-drains, improving or widening shoulders. Rehabilitation may include acquisition of additional right-of-way.

Repair - Replacement or rebuilding of a facility which is worn out, destroyed, or damaged. Repair includes overlays 0.06 foot thick or thicker. Crushed surfacing placed to 0.06 foot thick or thicker and covering more than 10 percent of the original surface area may be considered repair.

Restoration - Work performed on pavement or bridge decks to render them suitable for resurfacing. This may include supplementing the existing roadway by increasing surfacing and paving courses to provide structural capability, and widening up to a total of 10 feet. Restoration will generally be performed within the existing right-of-way.

Resurfacing - The addition of a layer or layers of paving material to provide additional structural integrity, improved serviceability, and rideability.

3-R - Resurfacing, Restoration, and Rehabilitation.

4.61 Percent Program - "1/2 Cent Gas Tax", "Arterial Fund."

6.92 Percent Program - "Gas Tax", "Road" or "Street Fund" (formerly 6-7/8 Cents Program).

WAC 136-16-022 Day labor limit. The statutory day labor limit shall be computed in the following manner:

(1) When the sum of all construction costs is in excess of four million dollars the day labor limit is eight hundred thousand dollars or fifteen percent of said sum, whichever is greater.

(2) When the sum of all construction costs is in excess of one million five hundred thousand dollars and less than four million dollars the day labor limit is five hundred twenty five thousand dollars or twenty percent of said sum, whichever is greater.

(3) When the sum of all construction costs is in excess of five hundred thousand dollars and less than one million five hundred thousand dollars the day labor limit is two hundred and fifty thousand dollars or thirty five percent of said sum, whichever is greater.

(4) When the sum of all construction costs is less than five hundred thousand dollars the day labor limit shall be two hundred and fifty thousand dollars, unless the legislative authority, by resolution, elects the alternate procedure. When such alternate procedure is chosen, an individual project limit of thirty-five thousand dollars shall apply, and each project shall be administered in accordance with chapter 136-18 WAC.

WAC 136-18-010 Purpose. The laws of the state of Washington RCW 36.77.065 provide that construction on county roads may be done by contract and/or day labor. The purpose of this standard of good practice is to assure that all day labor construction work is accomplished within statutory limitations.

WAC 136-18-020 Definitions. For the purposes of implementing the requirements of RCW relative to day labor construction work, the following definitions shall apply:

(1) Construction - the building of a new road facility or improvement of an existing facility to a higher geometric or structural standard.

(2) Day labor construction - construction work performed by personnel carried on the county payroll using county owned, leased or rented equipment.

(11) Day labor county road project - day labor construction authorized by action of the county legislative authority in those counties where a cumulative dollar limit applies to all day labor construction.

(12) Special day labor county road project - day labor construction which will result in a facility with independent utility, authorized by action of the county legislative authority in those counties where the total construction budget is less than five hundred thousand dollars and the legislative authority has by resolution elected to perform day labor construction in an amount not to exceed thirty-five thousand dollars on any one project. The following types of construction will normally have sufficient independent utility to constitute separate projects within the meaning of RCW 36.77.065:

Type I. Roadway construction - a project which includes units of work or classes of work such as clearing, grading, drainage, base, gravel surfacing, traffic and pedestrian services (except street lighting and electrical traffic control devices), roadside development and ancillary operations.

Type II. High type surfacing - a project which includes units of work or classes of work such as surfaces of light bituminous, road mix, travel gravel plant mix, pug mill mix, hot plant mix and concrete...

WAC 136-24-010 Budget and accounting system.

In accordance with RCW 43.09.200, the state auditor has formulated and prescribed a uniform system of accounting and reporting for all counties. The state auditor has prescribed forms and types of records to be maintained by the county engineers as required by RCW 36-.80-.060 with the advice and assistance of the county road administration board.

The budgeting, accounting, reporting system for counties and cities and other local governments (BARS) shall be used for all county road department budgeting, accounting and reporting beginning with the 1973 budget and its associated accounting and reporting requirements.

WAC 136-100-010 Purpose. Section 19(5), chapter 49, Laws of 1983 1st ex. sess. (the act), provides that the county road administration board (CRABoard) shall administer the rural arterial program (RAP) established by chapter 36.79 RCW. This chapter describes the manner in which the CRABoard will implement the several provisions of the act.

EXPENDITURE/USE SUBSIDIARY ACCOUNTS
Account Definitions

540.00 TRANSPORTATION. This is a major class of services provided by the governmental entity for the safe and adequate flow of vehicles and pedestrians.

542.00 ROAD & STREET MAINTENANCE. The costs of preserving and keeping the right-of-way and each type of roadway, roadway structure and facility as nearly as possible in its original condition as constructed or as subsequently improved, and the operation of roadway facilities and services to provide satisfactory and safe motor vehicle transportation. This account is not to include reconstruction or betterment. A complete definition of maintenance is found in the Local Agency Guideline Manual (LAG), (issued by the WSDOT) Chapter 1, Division 5, Page 6. Note that maintenance does not include (3-R activities) repair, restoration, or rehabilitation which are also defined in the LAG Manual, Ch. 1, Div. 5, Page 6. These activities should be coded as construction 595.xx.

595.00 ROAD & STREET CONSTRUCTION. The costs of any operation which involves improvement of the road/street. A complete definition of construction is found in the Local Agency Guideline Manual (LAG), (issued by the WSDOT) Chapter 1, Division 5, page 4. New construction is defined in Chapter 1, Division 5, Page 7.

35.76.040. Manual of instructions. The state auditor, after consultation with the association of Washington cities and the planning division of the state department of transportation shall prepare and distribute to the cities and towns a manual of instructions governing accounting and reporting procedures for all street expenditures.

35.76.060 Budgets. Expenditures for city and town streets shall be budgeted by each city and town according to the same functional categories prescribed by the state auditor for purposes of accounting and reporting as provided in RCW 35.76.020 and 35.76.030.

35.78.010 Classification of streets. The governing body of each municipal corporation shall classify and designate city streets as follows:

Major arterials, which are defined as transportation arteries which connect the focal points of traffic interest within a city; arteries which provide communications with other communities and the outlying areas; or arteries which have relatively high traffic volume compared with other streets within the city;

Secondary arterials, which are defines s routes which serve lesser points of traffic interest within a city; provide communication with outlying districts in the same degree or serve to collect and distribute traffic from the major arterials to the local streets;

Access streets, which are defined as land service streets and are generally limited to providing access to abutting property. They are tributary to the major and secondary thoroughfares and generally discourage through traffic.

35.78.030 Committee to adopt uniform design standards. The design standards committee shall from time to time adopt uniform design standards fr major arterial and secondary arterial streets.

35.78.040 Design standards must be followed by municipalities - Approval of deviations. The governing body of the several municipalities shall apply the uniform design standards adopted under RCW 35.78.030 to all new construction on major arterial and secondary arterial streets and to reconstruction of old such streets as far as practicable. No deviation from the design standards as to such streets shall be made without approval of the state aid engineer.

36.77.060 Minor projects by day labor. The board may cause any county road to be constructed or improved by day labor in an amount not to exceed twenty-five thousand dollars on one project. This section shall be construed to mean a complete project and shall not be construed to allow or permit the completion of any project by day labor by division thereof into units of work or classes of work. All construction work to be performed at a cost in excess of twenty-five thousand dollars shall be performed by contract as in this chapter provided.

36.77.065 Day labor construction projects or programs - "county road construction budget" defined - Amounts - Violations. The board may cause any county road to be constructed or improved by day labor as provided in this section.

(1) As used in this section, "county road construction budget" means the aggregate total of those costs as defined by the budgeting, accounting, and reporting system for counties and cities and other local governments authorized under RCW 43.09.200 and 43.09.230 as prescribed in the state auditor's budget, accounting, and reporting manual's (BARS) road and street construction accounts 541.00 through 541.90 in effect April 1, 1975: Provided, That such costs shall not include those costs assigned to the preliminary engineering

account 541.11, right of way accounts 541.20 through 541.25, ancillary operations account 541.80, and ferries account 541.81 in the budget, accounting, and reporting manual.

(2) The total amount of day labor construction programs one county may perform annually shall total no more than the amounts determined in the following manner:
(a) Any county with a total annual county road construction budget of four million dollars or more may accumulate a day labor road construction budget equal to no more than eight hundred thousand dollars or fifteen percent of the county's total annual county road construction budget, whichever is greater.
(b) Any county with a total annual county road construction budget over one million five hundred thousand dollars and less than four million dollars may accumulate a day labor road construction budget equal to not more than five hundred twenty-five thousand dollars or twenty percent of the county's total annual county road construction budget, whichever is greater.
(c) Any county with a total annual county road construction budget over five hundred thousand dollars and less than one million five hundred thousand dollars may accumulate a day labor road construction budget equal to two hundred fifty thousand dollars or thirty-five percent of the county's total annual county road construction budget, whichever is greater.
(d) Any county with a total annual county road construction budget less than five hundred thousand dollars may accumulate a day labor road construction budget equal to two hundred fifty thousand dollars: Provided, That any county with a total annual road construction budget of less than five hundred thousand dollars may, by resolution of the board at the time the county road construction budget is adopted, elect to construct or improve county roads by day labor in an amount not to exceed thirty-five thousand dollars on any one project, including labor, equipment, and materials; such election to be in lieu of the two hundred fifty thousand dollar limit provided for in this section, except that any project means a complete project and the division of any project into units of work or classes of work so as to permit construction by day labor is not authorized.

<u>36.79.020 Rural arterial trust account.</u> There is created in the motor vehicle fund the rural arterial trust account. All moneys to be deposited in the motor vehicle fund to be credited to the rural arterial trust account shall be expended for (1) the construction and improvement of county major and minor collectors in rural areas, (2) the construction of replacement bridges funded by the federal bridge replacement program on access roads in rural areas, and (3) for those expenses of the board associated with the administration of the rural arterial program.

<u>36.82.070 Purpose for which road fund can be used.</u> Any money paid to any county from the motor vehicle fund may be used for the construction, alteration, repair, improvement, or maintenance of county roads and bridges thereon and for wharfs necessary for ferriage of motor vehicle traffic, and for ferries, and for the acquiring, operating, and maintaining of machinery, equipment, quarries, or pits for the extraction of materials, and for the cost of establishing county roads, acquiring rights of way therefor, and expenses for the operation of the county engineering office, and for any other proper county road purpose. Such expenditure may be made either independently or in conjunction with the state or any city, town, or tax district within the county.

<u>36.86.080 Application of design standards to construction and reconstruction.</u> Upon the adoption of uniform design standards the board of county commissioners of each county shall apply the same to all new construction within, and as far as practicable and feasible to reconstruction of old roads comprising the county primary road system. No deviation from such design standards as to such primary system shall be made without the approval of the assistant state director of highways for state aid.

47.26.080 Urban arterial trust account - Created in motor vehicle fund - Expenditures from. There is hereby created in the motor vehicle fund the urban arterial trust account. All moneys deposited in the motor vehicle fund to be credited to the urban arterial trust account shall be expended for the construction and improvement of city arterial streets and county arterial roads within urban areas, for expenses of the transportation improvement board, or for the payment of principal or interest on bonds issued for the purpose of constructing or improving city arterial streets and county arterial roads within urban areas, or for reimbursement to the state, counties, cities, and towns in accordance with RCW 47.26.4252 and 47.26.4254, the amount of any payments made on principal or interest on urban arterial trust account bonds from motor vehicle or special fuel tax revenues which were distributable to the state, counties, cities, and towns.

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

PAVEMENT POLICY FOR HIGHWAYS

Published in the Federal Register as a Final Rule on January 13, 1989 (as reported in July 1989 Better Roads).

The new regulation will establish a national policy for the cost-effective design, selection, construction, maintenance, and management of federal-aid highways, and for identifying work eligible for federal-aid funding.

Pavement reconstruction requirements. When the policy refers to reconstruction, it means the construction of the equivalent of a new pavement structure. This usually involves complete removal and replacement of the existing pavement structure and includes new and/or recycled materials.

Pavement rehabilitation requirements. When the policy refers to rehabilitation, it means resurfacing, restoration, and rehabilitation (3R) work undertaken to restore serviceability and to extend the service life of an existing facility. This may include partial recycling of the existing pavement, placement of additional surface materials. It must return an existing pavement, including shoulders, to a condition of structural or functional adequacy.

Eligibility requirements for state receiving federal funds:

Methods and materials used for new and reconstructed pavements must be a cost-effective solution, based on the state's pavement design and type selection processes. Alternate designs must be considered, as well as life-cycle costs supported by sufficient cost and performance data.

Rehabilitated pavement projects on interstate, other principal arterials, and other freeways and expressways - regardless of jurisdiction - must provide at least an eight-year performance period. A five-year minimum performance period may be used for all other routes.

States must perform satisfactory maintenance on federal-aid highways. This must be paid for with state funds. It is not appropriate for a state to let maintenance lapse in order to obtain federal-aid funding for rehabilitation or reconstruction.

There will no longer be a requirement for a minimum 0.75-inch resurfacing thickness. The new eight- or five-year performance period negates the need for this.

ROUTE 2000. WASHINGTON ROAD JURISDICTION STUDY: PHASE II. (November 1988)

Excerpts from Pages 16 - 20.

. . . recommend the following maintenance and construction categories and their definitions for use in this study.

New Construction - complete construction on a new alignment. Includes new structures as required.

Reconstruction - complete reconstruction on essentially the present alignment for a distance of at least 0.3 miles.

Isolated Reconstruction - reconstruction of sections of under 0.3 miles to correct a specific deficiency such as one or two bad curves or excessive grades.

Major Widening - addition of at least one lane to an existing facility. This will include the cost of resurfacing the existing pavement and other incidental minor improvements such as shoulder and/or drainage improvements. Also includes widening of structures as part of the overall widening project.

Minor Widening - provision of additional width which does not increase the number of lanes. Includes other elements as defined for major widening.

Resurfacing, including shoulder improvements - adding an overlay in excess of 3/4" plus any appropriate improvements to shoulders such as adding material to bring them up to grade and/or widening of shoulders and/or reconstruction of shoulders.

Structures - major rehabilitation and strengthening and/or replacement of existing structures undertaken independent of improvements to the roadway.

Construction - includes all base courses and surfacing or surface treatments over 3/4", including shoulders, interchanges, and frontage roads. Also includes curbs, gutters, and sidewalks constructed as part of a base and surface construction contract.

Maintenance - includes patching, repairing, surface treating, joint filling, mudjacking, scarifying, reshaping, replacement of suitable base material, replacement in kind of roadway or shoulder for very short distances, adding aggregate, applying dust palliative, sweeping and cleaning and resurfacing of 3/4" or less. This also includes shoulders and approaches.

DEVELOPMENT OF THE STATE HIGHWAY PRIORITY ARRAY

WSDOT Program Development Office, April, 1985

II. Priority Programming Act

The array is the primary source document used to identify needs for meeting the program objectives of highway Category A and Category B 4R projects. Category "A" projects consist of those improvements necessary to sustain the structural, safety, and operational integrity of the existing non-interstate state highway system. Category "B" 4R projects consist of resurfacing, restoration, rehabilitation and reconstruction on the Interstate system. Priority selection criteria are set forth in RCW Title 47.05 . . .

WSDOT INTERNAL DOCUMENT

Project Categories

Program A
- 1R - Seals and Thin Overlays with Spot Safety
- 2R - Resurface and Restoration State Funded
- 3R - Resurface, Restoration, Rehabilitation
  Eligible for Federal Funding
- 4R - Reconstruction/New Construction

Program B - Interstate Completion
- Interstate 4R

Program C - Major Capacity Improvements
- Reconstruction on New Alignment

Design Standards/Project Scoping/Funding Eligibility

A. 1R - Seals and Thin Overlays

- o No geometric standards
- o No mandatory work elements (spot safety work ok)
- o Resurfacing report required (seek Mats Lab concurrence)
- o SEPA compliance (NEPA possible for permits)
- o State funds only
- o Companion safety project

B. 2R - Resurfacing and Restoration

- o No geometric standards
- o Minimal mandatory safety work
- o Resurfacing report required (seek Mats Lab concurrence)
- o SEPA compliance (NEPA possible for permits)
- o State funds only

C. 3R - Resurface, Restoration and Rehabilitation

- o Must meet minimum geometric standards
- o Must enhance roadside safety
- o Must satisfy Resurfaçing Report Requirements (structural overlay or safety treatment)
- o SEPA and NEPA compliance (mitigation possible)
- o Eligible for Federal Funds

D. 4R - Adds Reconstruction/New Construction (including bridge replacement)

- o Must meet full new construction standards (lanes, shoulders, slopes, ramps, bridges, barriers, etc.)
- o Must meet all current safety standards
- o Must meet full pavement structural requirements
- o All documents require FHWA approval
- o SEPA and NEPA compliance
- o Eligible for Interstate 4R funds