DEVELOPMENT OF MAINTENANCE PRACTICES FOR OREGON F-MIX

Final Report

SPR 371

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SPR PROJECT 371

by

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16. Abstract

Oregon Department of Transportation (ODOT) has been using open-graded F-mix since the 1970's. These porous asphalt concrete mixes have become the pavement-of-choice for rural high-traffic sites statewide, as they promote drainage and reduce hydroplaning, spray and splash. Deformation rutting has also been reduced.

Standard pavement maintenance procedures have been developed for dense-graded mixes, but use of these methods on F-mix diminishes its free-draining attributes and changes noise and ride characteristics. This project was developed to study maintenance practices for F-mix and recommend standardized procedures for Oregon. Unfortunately, no new techniques specific to porous pavements or open-graded friction courses could be identified, so researchers surveyed ODOT maintenance personnel to collect experience and recommendations for best practices for F-mix maintenance. Field monitoring was done on specific maintenance projects over several years.

This report documents the results of the surveys and field evaluation work, and presents recommendations for improving preventative maintenance, corrective surface maintenance, and winter maintenance practices. Also recommendations are provided for documenting maintenance practices using the pavement management system and maintenance management system.

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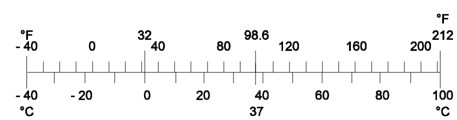
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	Millimeters	Mm
Ft	Feet	0.305	Meters	M
Yd	Yards	0.914	Meters	M
Mi	Miles	1.61	Kilometers	Km
		AREA		
in^2	Square inches	645.2	millimeters	mm^2
ft^2	Square feet	0.093	meters squared	M^2
yd^2	Square yards	0.836	meters squared	M^2
Ac	Acres	0.405	Hectares	Ha
mi^2	Square miles	2.59	kilometers squared	Km^2
		VOLUME		
fl oz	Fluid ounces	29.57	Milliliters	ML
Gal	Gallons	3.785	Liters	L
ft^3	Cubic feet	0.028	meters cubed	m^3
yd^3	Cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	Kg
T	Short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	Millimeters	0.039	inches	in
m	Meters	3.28	feet	ft
m	Meters	1.09	yards	yd
km	Kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	Hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	Grams	0.035	ounces	oz
kg	Kilograms	2.205	pounds	lb
Mg	Megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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DISCLAIMER

F-MIX MAINTENANCE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES/PHOTOS

1.0 INTRODUCTION

1.1 BACKGROUND

The Oregon Department of Transportation (ODOT) began using open-graded F-mix (19 mm) as a surface wearing course in the 1970's. Usage has accelerated since 1989, and in recent years, these mixes have become the pavement-of-choice for rural high-traffic sites statewide. F-mix, typically placed 50 mm thick, is a type of porous pavement that has become popular for several reasons. Its porous nature and open surface texture reduces hydroplaning, spray and splash during western Oregon's wet winters. Use of F-mix has also resulted in reduction of deformation rutting from truck traffic. This is attributed to the aggregate gradation, which results in good aggregate interlock. As another benefit, experience has shown that F-mix pavements are quieter than dense-graded asphalt concrete and portland cement concrete pavements *(Scott et al. 1999)*. European countries routinely use porous pavements to reduce road noise.

Emergency maintenance or corrective maintenance presents a challenge because ODOT asphalt pavement maintenance procedures have been developed for dense-graded mixes, rather than open-graded mixes. Use of traditional dense-graded maintenance procedures destroys the free-draining characteristics of F-mix, and changes noise and ride characteristics. As ODOT's inventory of F-mix pavements ages and wears under traffic, preservation through proper maintenance takes on increasing importance. ODOT has not standardized maintenance practices, resulting in considerable variation in maintenance approaches.

In May, 1997, ODOT contracted with Oregon State University to study F-mix maintenance. Specific questions to be answered include:

1. Are fog seals the best preventive maintenance strategy, and if so, what is the optimum frequency and procedure? Fog-sealing applications have varied widely throughout the state. Although fog seals represent one of the most economical pavement maintenance procedures known, ODOT is uncertain of the benefit.

2. Are better procedures available than those traditionally used for dense-graded asphalt pavements? Surface maintenance procedures traditionally used for dense-graded pavements destroy the drainage characteristics of the F-mix.

3. Can F-mix be obtained in the small quantities required for many repair and patching activities? Excellent patches of F-mix using an open-graded patching material have been made but they are not easy. Obtaining small quantities of F-mix for repair and patching can be difficult.

4. What must be done differently for F-mix to meet the challenges presented by wintertime precipitation: snow, ice, and freezing fog? Winter maintenance of F-mix presents a challenge because it behaves differently than dense-graded pavements in freezing conditions.

1.2 RESEARCH OBJECTIVES

This research was undertaken to provide a comprehensive study of preventive and corrective maintenance procedures for Oregon F-mix. Specific objectives include:

1. Evaluate the experiences of other public agencies with various maintenance procedures for open-graded pavements.
2. Evaluate the experiences of ODOT maintenance personnel with F-mix maintenance.
3. Propose and field-test recommended F-mix maintenance procedures.
4. Develop a plan for implementing the resulting recommendations.

It should be noted that evaluation of the merits of F-mix pavement versus other pavement choices was **not** an objective of the study. The focus of the study was clearly on effective maintenance strategies for F-mix.

1.3 RESEARCH METHODOLOGY

Originally, seven tasks were envisioned for the study:

Task 1:	Verification of maintenance challenges presented by F-mix
Task 2:	Literature Review
Task 3:	Identification of promising materials and techniques
Task 4:	Field trials
Task 5:	Monitoring test sections
Task 6:	Evaluation
Task 7:	Report

Tasks 1 and 2 progressed as planned. Unfortunately, no new techniques specific to porous pavements or open-graded friction courses could be identified in the literature, from other road maintenance agencies, or from within ODOT. With no new techniques, field trials were not needed to evaluate specific new maintenance practices. Instead, Tasks 3-5 were replaced with an identification of techniques being used by ODOT and an examination of their effectiveness based on the opinions of ODOT maintenance personnel. ODOT's maintenance personnel became the most important source of information. To gather information as comprehensively and efficiently as possible, surveys of ODOT maintenance personnel were performed in 1997, 1999, and 2001. The 1997 and 1999 surveys were mail-in surveys. The 2001 survey was performed by the University of Oregon Survey Research Laboratory utilizing telephone survey techniques.

Since the research did not include field trials where test and control sections of various potential maintenance practices could be evaluated, an implementation plan was not developed. The research findings documented in this final report provide information about F-mix pavement distresses, and current maintenance practices used by ODOT maintenance personnel.

1.4 INTERIM REPORT

A June 1999 interim report documented progress until that time, including the literature review, the canvassing of other road maintenance agencies, and the results of the 1997 survey of ODOT maintenance personnel *(Rogge and Hunt 1999)*. Material in the interim report is reproduced in this final report only when absolutely necessary.

1.5 FINAL REPORT ORGANIZATION

Chapter 2 presents the results of the 1999 and 2001 surveys of ODOT maintenance personnel, with emphasis on the more recent and more effective 2001 survey. Also in Chapter 2, data summarizing pavement condition from ODOT's Pavement Management System is presented. The pavement condition data for F-mix and B-mix pavements provides another source of information regarding the condition of these two pavement types and their associated distresses.

Documentation of common F-mix distresses and of patches and repairs commonly used by ODOT maintenance personnel is presented in Chapters 3 and 4. Several important publications have been reviewed since the interim report and are highlighted as appropriate in Chapters 3 and 4. Overall conclusions based on the totality of information collected during the study are presented, and recommendations are made.

2.0 SURVEY AND PAVEMENT MANAGEMENT SYSTEM DATA

Surveys of ODOT maintenance supervisors were conducted in 1997, 1999, and 2001. The 1997 and 1999 surveys were mail-in surveys and resulted in returns by only 24 and 38 respondents respectively. The response rates for these mail-out, mail-in surveys were 29% for the 1997 survey and 46% for the 1999 survey. To increase the response rate, the July 2001 survey was a telephone survey conducted by the University of Oregon Survey Research Laboratory. It resulted in 78 responses from 83 maintenance supervisors, a 94 % response rate.

The data obtained with the 2001 survey is clearly the most meaningful. It represents the most current information on the collective opinion of 94% of ODOT's maintenance supervisors. For these reasons, analysis of maintenance supervisor surveys concentrates on the 2001 survey. Information from the 1997 and 1999 surveys is included only in summary form as it relates to the 2001 survey. The survey results are discussed in Sections 2.2 – 2.4 of this chapter.

The 2001 survey form is reproduced in Appendix A. Appendix B tabulates the responses to limited choice questions, and Appendix C presents the responses to open-ended questions. Questions addressed four themes:

- Distresses experienced in F-mix pavements;
- Preventive maintenance;
- Effectiveness of surface maintenance techniques employed; and
- Winter maintenance.

In addition to the survey data, ODOT's Pavement Management System (PMS) was used to determine whether the distresses associated with F-mix pavements are more severe than B-mix pavements. The distress surveys in the PMS were based on ODOT's 2001 Pavement Condition Report. The PMS provides values for the following condition indices on pavement segments in the National Highway System (NHS):

- Rut index;
- Fatigue crack index;
- Patching index;
- Raveling index;
- Temperature crack index; and
- Overall Pavement Condition Index.

These values were compared for open-graded asphalt concrete and for dense-graded asphalt concrete for pavements in the National Highway System (NHS). For non-NHS pavements, only the overall index is available. In addition to comparing F-mix and B-mix performance, the most frequent distresses identified in the maintenance supervisor survey were compared to the PMS pavement distress data.

The results of the PMS analysis are discussed in Section 2.5.

2.1 F-MIX PAVEMENT DISTRESSES

Questions Q:STRESS1 – Q:STRESS14 (see Appendix A) asked the maintenance supervisors to rank the frequency of occurrence of 14 difference distress types as “have not seen it,” “rare,” “scattered,” or “pervasive.” These responses were assigned values of 1, 2, 3, and 4 respectively for compiling and analyzing results. Thus, the higher the numerical score, the more frequent the distress. Figure 2.1 shows the ranking of the fourteen distresses statewide. All distresses except tire stud rutting showed average frequency of occurrence between “rare” and “scattered.” Tire stud rutting scored between “scattered” and “pervasive,” although closest to “scattered.”

The top seven distresses have statewide scores that are closer to “scattered” than to “rare”. They are, in order from highest frequency, tire stud rutting, icing problems, raveling, gouging, deformation rutting, clogging, and potholes. The remaining seven distresses scores are closer to “rare” than to “scattered.”

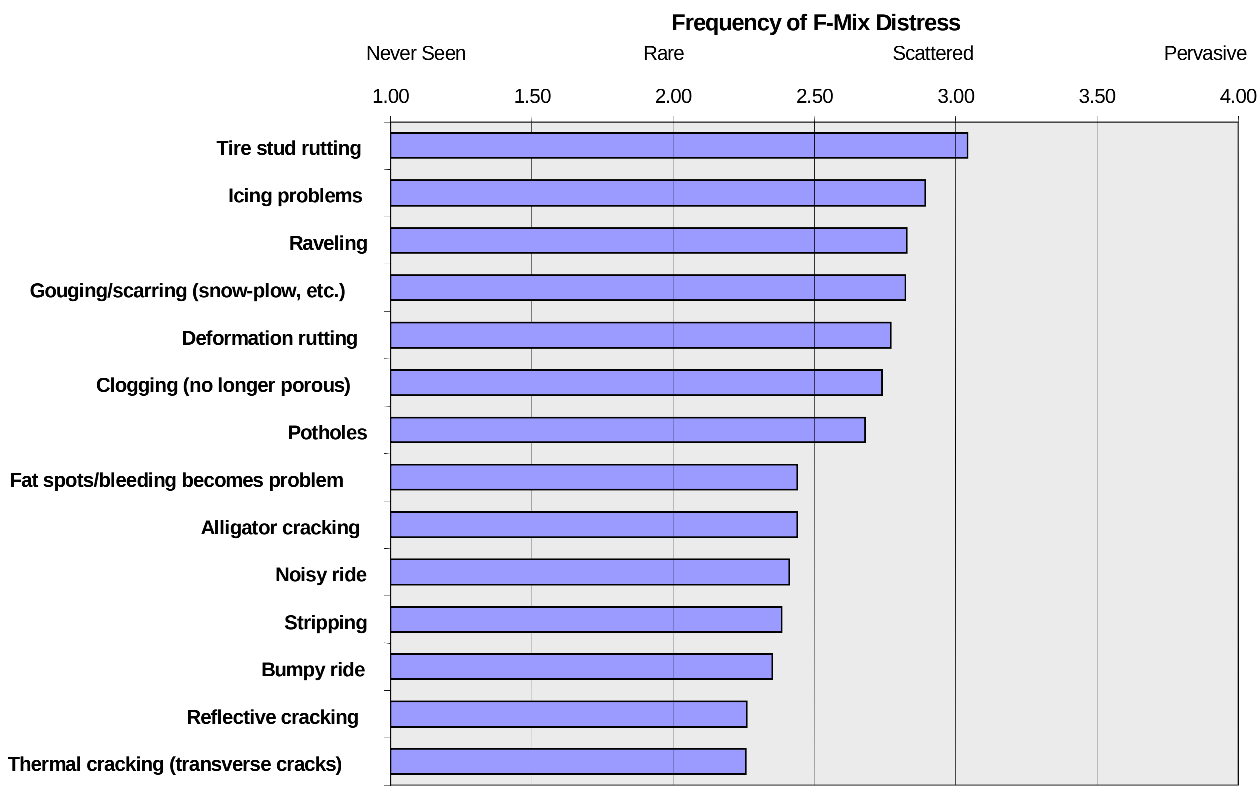

Figure 2.1: Frequency of F-mix Distress

Distress trends over time are shown in Table 2.1. Because rating scales were slightly different over the three surveys, only the ranks of the distresses are shown. The 1999 survey listed the same 14 distresses as the 2001 survey. It is interesting to note that although in different order, the top seven distresses of the 2001 survey were also the top seven distresses of the 1999 survey. The 1997 survey listed the same distresses as the 1999 and 2001 surveys, except that "potholes" was not listed as a possible choice. For consistency, the rankings for '97 assume that potholes would have received the average rank of the 1999 and 2001 surveys (5th).

Table 2.1: F-mix Distress Trends Over Time.

	RANK		
	1997	**1999**	**2001**
Tire stud rutting	7	1	1
Icing problems	2	5	2
Raveling	10	7	3
Gouging/scarring (snow-plow, etc.)	8	4	4
Deformation rutting	6	2	5
Clogging (no longer porous)	1	6	6
Potholes		3	7
Fat spots/bleeding becomes problem	3	10	8.5
Cracking due to inadequate structure (alligator cracking)	4	12	8.5
Noisy ride	9	8	10
Stripping	12	9	11
Bumpy ride	11	11	12
Reflective cracking	14	13	13
Thermal cracking (transverse cracks)	13	14	14

The ranking of raveling rose from 10th in 1997 to 7th in 1999, and to 3rd in 2001. This is consistent with European literature on porous pavements that states that failure of F-mix pavements at the end of their service lives is through extensive raveling *(Rogge and Hunt 1999)*. Therefore, it is consistent that raveling becomes a bigger problem as ODOT's inventory of F-mix pavements ages and more pavements near the end of their economic lives. When extensive replacement of these aging pavements takes place, this distress should decline.

The 2001 survey data were analyzed for differences between ODOT Regions. Figure 2.2 shows a map of ODOT's regions. Region 1 includes the Portland metropolitan area, the most densely populated area of the state. Regions 2 and 3 include the state's coastal zones, coast range mountains, interior valleys, and western slopes of the Cascade Mountains. These are areas where rain is common from October through June. Regions 4 and 5 include the semi-arid regions of Central and Eastern Oregon, and the Blue Mountains.

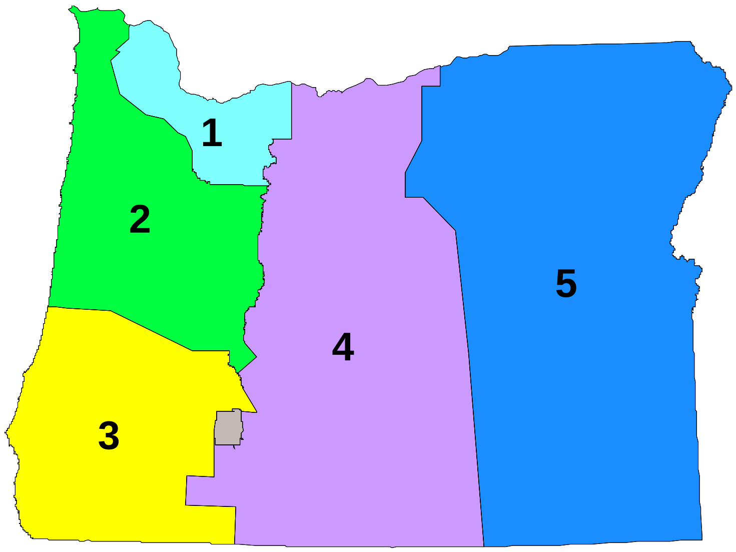

Figure 2.2: ODOT's Regions

Table 2.2 shows the scores by region for each of the 14 distresses as well as rankings of the various distresses within the regions. Regions 2 and 3 account for the majority of ODOT's F-mix pavement mileage and account for 9 of the 11 individual Region scores in excess of 3.0 ("scattered").

Among distress scores above 3 ("scattered") are scores of 3.45 and 3.32 for tire stud rutting in Region 4 and Region 2 respectively. Region 2 gave the highest score for clogging (3.42). High scores were given for raveling (3.31), potholes (3.08), gouging (3.08), and deformation rutting (3.08) in Region 3. Icing problems and raveling received scores of 3.08 and 3.04 respectively in Region 2. Raveling and potholes appear to be lesser problems in Region 1 than the rest of the state, with scores of 2.2 and 2.13, and rankings of 8th and 9th respectively. Tire stud rutting was considered less of a problem in Region 3 (2.5 and 9th place) than in the rest of the state. Regions 4 and 5, with predominantly arid climates, gave clogging scores of only 1.8 and 2.09, with ranks of 12th and 11th respectively.

The biggest anomaly in the rankings was for alligator cracking due to inadequate structure. Although in the lower tier of stresses statewide and ranked no higher than 10th of 14th in any of the other regions, Region 2 ranked alligator cracking as the third most frequent distress in F-mix, with a 3.16 score.

In the opinion of the maintenance supervisors, thermal cracking and reflective cracking are the least frequently experienced distresses in F-mix. Thermal cracking was ranked 13th or 14th in all three surveys (1997, 1999, and 2001), and in all Regions except Region 4 in the 2001 survey, where it was ranked 6th. Reflective cracking was 13th or 14th overall in all three surveys. In the 2001 survey it was only 12th, 12th, 8th, 11th, and 14th most significant in Regions 1, 2, 3, 4,and 5 respectively. Reflective cracking was the only distress not rated in the top half of distresses in any Region in the 2001 survey.

Table 2.2: F-mix Distress Scores and Rankings by Region

	Average Score	Overall Rank	Average score by region					Rank by region						
			1	2	3	4	5	1	2	3	4	5	MIN	MAX
Tire stud rutting	3.04	1	2.93	3.32	2.5	3.45	2.7	2	2	9	1	7	1	9
Icing problems	2.89	2	3.07	3.08	2.54	2.64	2.91	1	4	7	2	2	1	7
Raveling	2.83	3	2.2	3.04	3.31	2.45	3	8	5	1	4	1	1	8
Gouging/scarring (snow-plow, etc.)	2.82	4	2.8	2.88	3.08	2.5	2.73	3	7	3	3	4	3	7
Deformation rutting	2.77	5	2.73	2.88	3.08	2.09	2.91	4	8	4	9	3	3	9
Clogging (no longer porous)	2.74	6	2.6	3.42	2.92	1.8	2.09	5	1	5	12	11	1	12
Potholes	2.68	7	2.13	3	3.08	2.18	2.73	9	6	2	7	5	2	9
Fat spots/bleeding becomes problem	2.44	9	1.73	3.16	2.46	2.09	2.09	14	3	10	10	10	3	14
Cracking due to inadequate structure (alligator cracking)	2.44	8	2.07	2.76	2.69	2.36	2	10	10	6	5	12	5	12
Noisy ride	2.41	10	2.27	2.61	2.31	2.18	2.55	7	13	14	8	8	7	14
Stripping	2.38	11	2.36	2.79	2.38	1.73	2.18	6	9	12	13	9	6	13
Bumpy ride	2.35	12	1.93	2.71	2.46	1.64	2.73	11	11	11	14	6	6	14
Reflective cracking	2.26	13	1.87	2.7	2.54	1.82	2	12	12	8	11	14	8	14
Thermal cracking (transverse cracks)	2.26	14	1.8	2.58	2.38	2.27	2	13	14	13	6	13	6	14

The differences in reporting of cracking types may be due to misclassification. In retrospect, asking maintenance supervisors to distinguish between alligator cracking, thermal cracking, and reflective cracking without definitions, explanations, or sample pictures may have been expecting too much. Requesting classification as longitudinal, transverse, or alligator cracking may have produced better results. It is difficult for maintenance personnel to identify reflective cracking if they are not familiar with pavement condition prior to overlay.

The 2001 survey contained questions soliciting other F-mix distresses. “Have you noticed any other pavement distresses on F-mix asphalt?” “What are those other distresses that you have seen?” Where possible, similar responses were grouped. Table 2.3 shows the distresses and number of times mentioned. Pushing and shoving could have been categorized as deformation rutting on the questionnaire checklist. Snowplow damage could have been recorded as gouging/scarring. Delamination should have resulted in raveling or potholes. Thus the most prevalent issue not addressed on the checklist is grass and vegetation.

Table 2.3: Additional Distresses in F-mix Asphalt

Maintenance Challenge	Number Responding
Grass and vegetation	6
Pushing, shoving, and tearing	4
Delamination	3
Snowplow damage	3
Fuel or oil spills	2
Bump at subdrains	2
Oil migrating in mix	1
Striping difficulties	1
Water daylights and freezes	1
Stays frozen longer	1

The issue of fuel or oil spills into the porous pavement deserves mention. Two maintenance supervisors noted the problem. When these petroleum products disappear into the porous pavement, they are virtually impossible to flush out.

2.2 PREVENTIVE MAINTENANCE

With respect to preventive maintenance, the survey confirmed that ODOT continues to lack convincing evidence about the effectiveness of fog sealing as a preventive maintenance technique for F-mix. Although many maintenance supervisors expressed interest in fog seals, particularly during the first two years while the pavement is in good condition, no one knows where the funding would come from to pay for this treatment. Even those supervisors that see usefulness in fog sealing do not have a source of funding with which to implement a program.

As a result, F-mix pavements are not being widely fog-sealed. Figure 2.3 shows response to the question, “Do you ever use fog seals on F-mix for maintenance in your district/area?” A strong majority of 58% responded that they do not. Only 42% indicated that they do. Those responding “yes” were asked, “What percent of F-mix paved roads are fog sealed in your district/area?”

Figure 2.4 shows the response. Less than 10% was the most frequent choice. Nineteen of 32 respondents indicated less than 30%. (The four respondents indicating greater than 90 % are seeing a much different picture than the majority of respondents.)

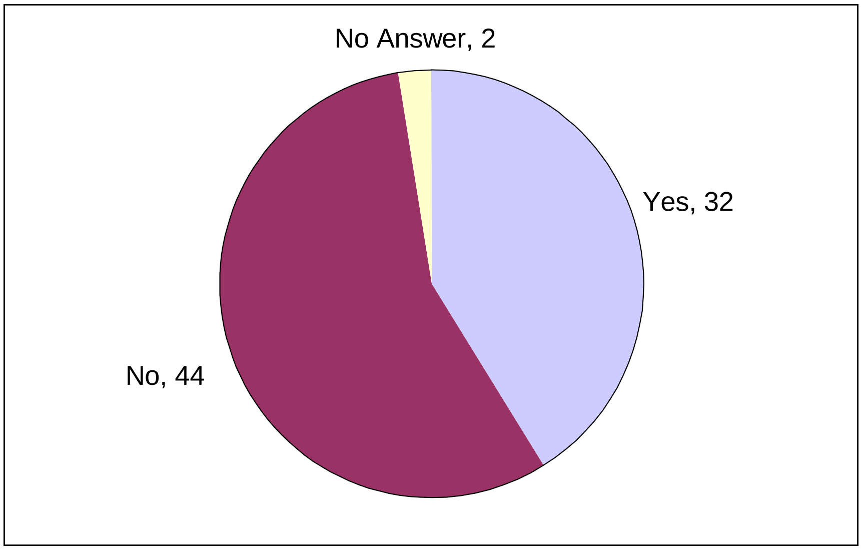

Figure 2.3: Response to Question, “Do you ever use fog seals on F-mix for maintenance in your district/area?”

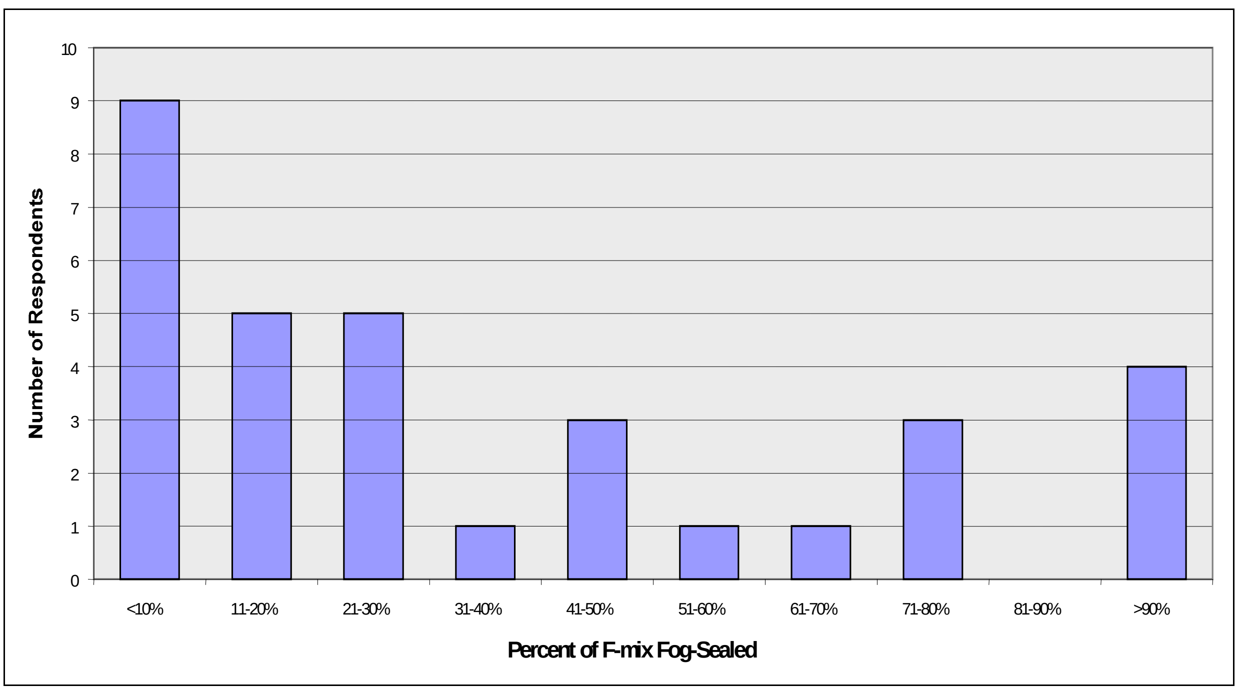

Figure 2.4: Response to Question, “What percent of F-mix paved roads are fog-sealed in your district/area?”

Those who indicated that they use fog seals were also asked, “How often are those pavements fog sealed, on average?” Figure 2.5 shows that once every 5 years was the most frequent response.

Eight of the nine respondents indicating “other” reported experiences with only one F-mix fog seal. None of the author’s anecdotal data has uncovered evidence that any maintenance district within ODOT routinely fog seals F-mix on any given frequency. It is suspected that respondents indicating every 2, 5, 6, 7, 8, 10, and 12 years are reporting a goal rather than reality.

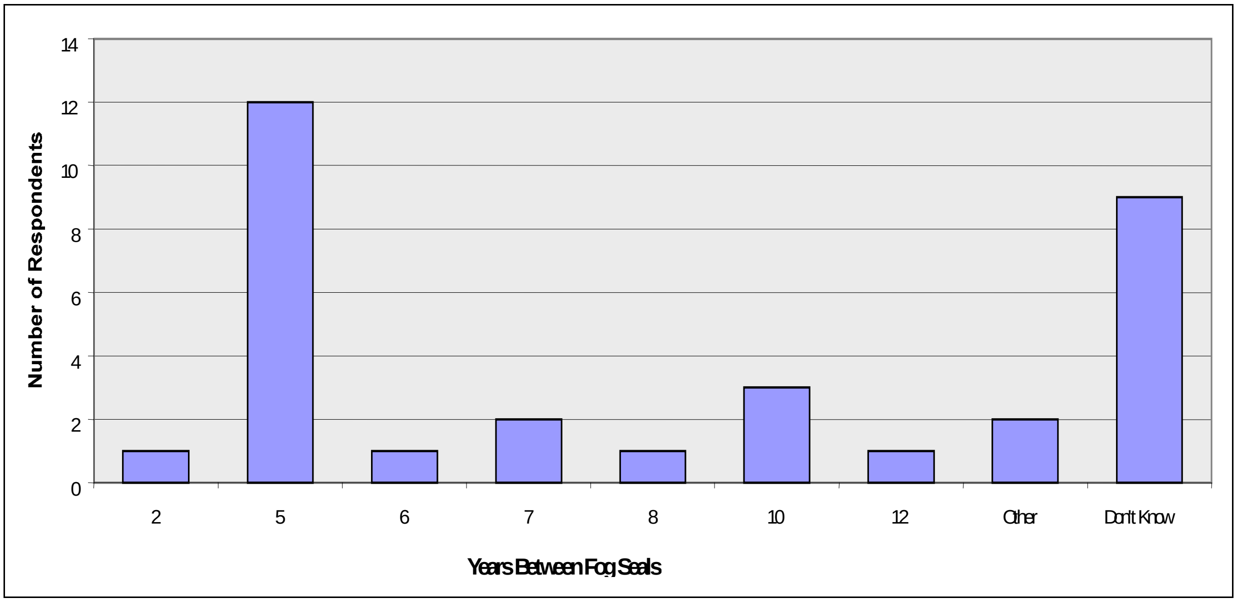

Figure 2.5: Response for, “How often are those pavements fog-sealed, on average?”

In response to the question, “Do you have any convincing evidence that fog sealing prolongs the life of F-mix?” only four of the 32 respondents reporting F-mix usage said “yes.” They cited anecdotal evidence of success. The most convincing statement was, “It stopped the unraveling on I-5 and we are working on our third year in the section.”

The 32 respondents with fog seal experience were also asked, “Do you have any convincing evidence that fog-sealing does not prolong the life of F-mix?” Three answered yes. As with the responses to the previous question, the evidence from the three maintenance supervisors was not very convincing either. The strongest statement was, “It was gone in less than six months. Six months after the fog seal, the rocks continued to come out and you could see bare spots where the fog seal was no longer there on the surface.”

The respondents were asked the question, “Do you have any ideas about how preventative maintenance for F-mix could be improved?” The responses can be grouped into the categories of Table 2.4. After, “Don’t know,” fog seals have the greatest support. Apparently, at least these fourteen respondents would use fog seals if funding were available. Other common recommendations were, “Don’t use F-mix,” “Use it selectively – avoid mountain passes,” “make sure you have adequate base and a high quality mix,” “patch or inlay with dense-graded mix,” “chip seal,” and “good rotation of asphalt overlay over time.”

ODOT's pavement design guidelines have already restricted the areas where F-mix's are to be used. Mountain passes are an important area where F-mix will not be used. ODOT continues to refine and improve F-mix design. Clearly, an overlay or mill and inlay of F-mix at the end of its service life is the optimal solution, but again, requires adequate funding.

Table 2.4: Suggestions for Improvments in F-mix Preventive Maintenance

Response	#
Don't know	19
Fog seal	14
Don't use F-mix	12
Good base – high quality mix at start	7
Use selectively – avoid mountain passes	6
Dense-graded patch/inlay	6
Chip seal	3
Good rotation of asphalt overlay over time	3
Running shoes on snow plow	1
Keep clean	1
Leave it alone	1
Use lime additive	1
Frequent treatment	1
Grind & inlay	1

2.3 EFFECTIVENESS OF F-MIX MAINTENANCE TECHNIQUES EMPLOYED

Questions Q:SUCC1 – Q:SUCC16 (see Appendix A) asked the maintenance supervisors to rank the effectiveness of 16 different maintenance treatments as "not at all successful," "not very successful," "somewhat successful," and "completely successful." In compiling and analyzing responses, these responses were assigned values of 1, 2, 3, and 4 respectively. Thus, the higher the score the greater the success of treatment.

Figure 2.6 shows the ranking of the sixteen treatments statewide. The six top-rated treatments show average scores between "somewhat successful" and "completely successful. The next two treatments, "emulsion chip seal" and "crack sealing" were scored as "somewhat successful." The remaining eight treatments' scores descended below "somewhat successful" toward "not very successful."

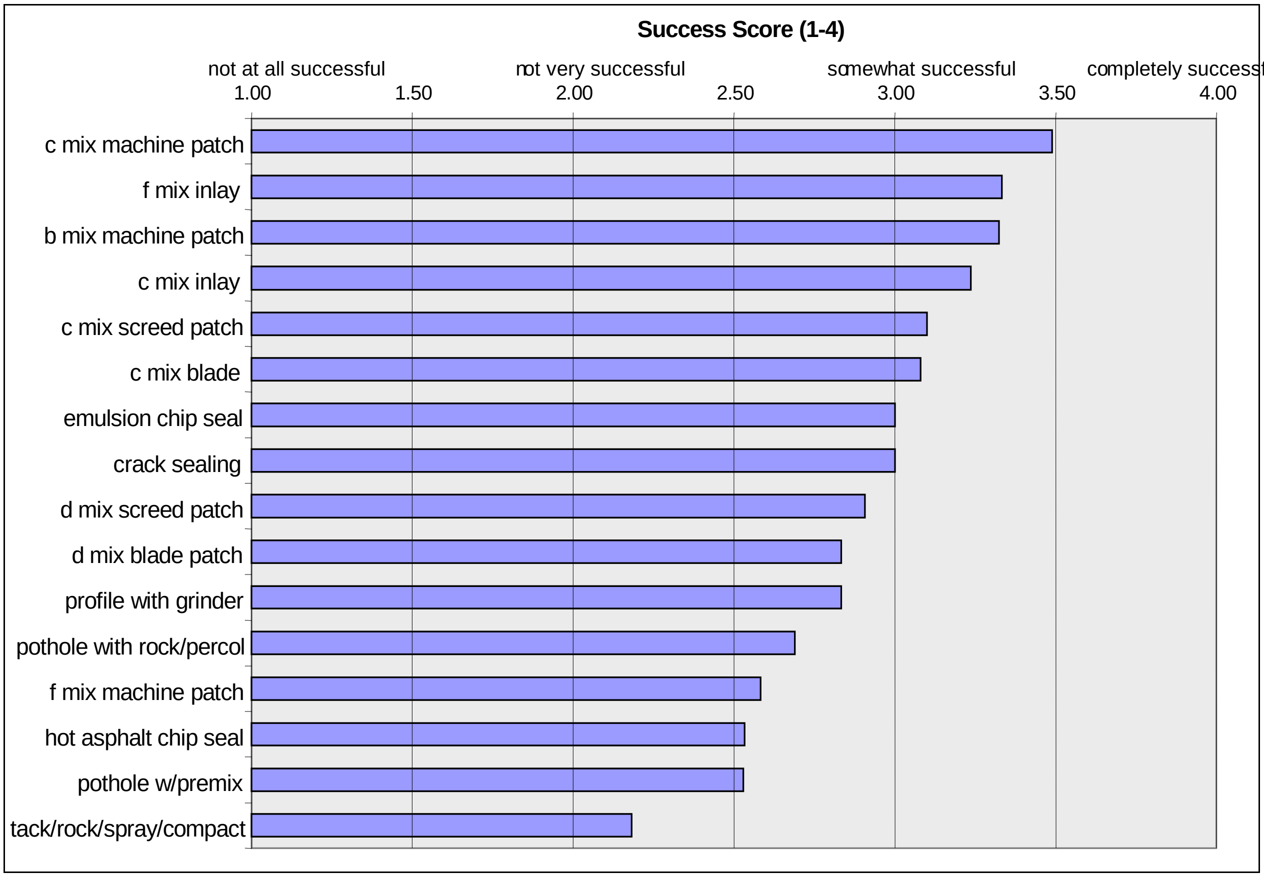

Figure 2.6: Rankings of 16 F-mix Maintenance Treatments

Figure 2.7 shows the number of respondents reporting experience with each maintenance treatment, presented in order from the most successful (top) to least successful (bottom) treatment. Sixty-eight of the 78 respondents, or 87%, have experience with pothole repair with premix, so the low rating reported in Figure 2.6 is convincing. On the other hand, fewer respondents have used the F-mix machine patch (12), hot asphalt chip seal (15), tack/rock/spray/compact (22), and F-mix inlay (24). Thus, the high ranking for F-mix inlay and the low rankings for F-mix machine patch, hot asphalt chip seal and tack/rock/spray/compact are based on information from 31% or less of respondents.

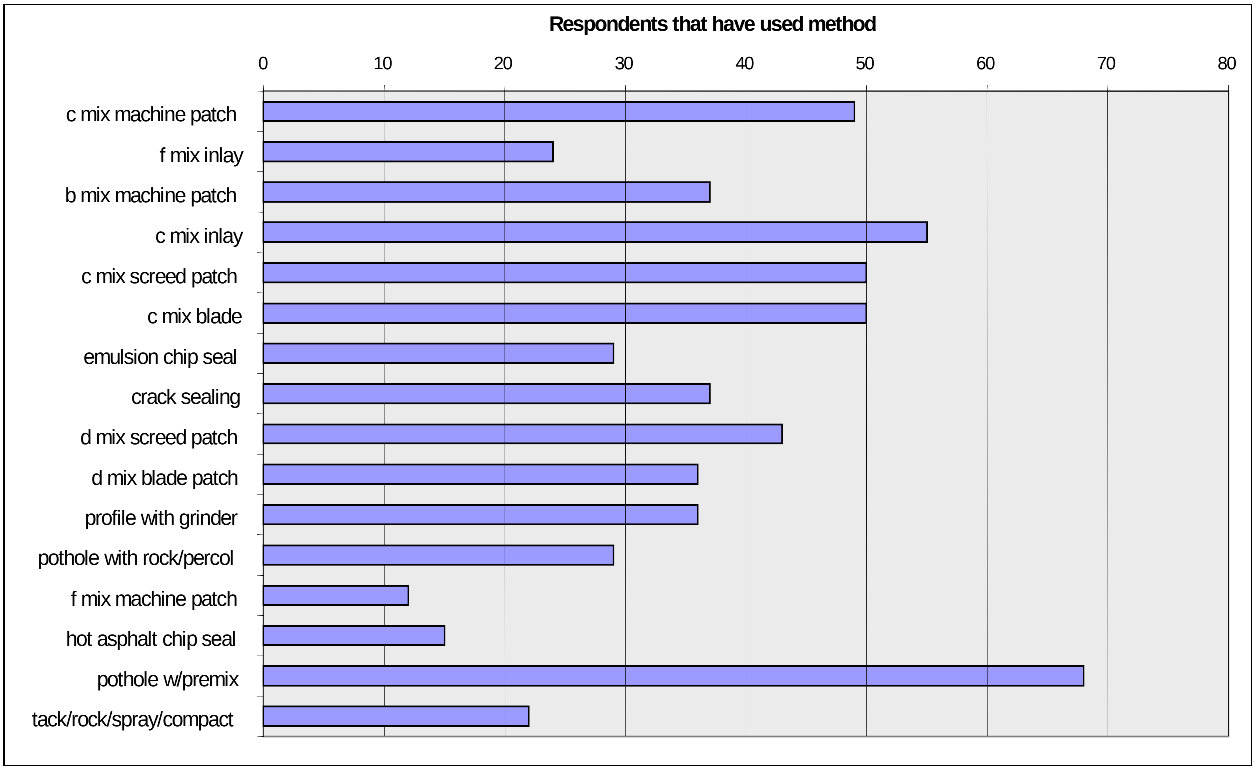

Figure 2.7: Number of Respondents with Experience Using Maintenance Treatment

Table 2.5 shows variations in repair treatment success by ODOT Region. The C-mix machine patch and the C-mix inlay were the only two treatments that did not receive a score lower than 3.0 (somewhat successful) from any of the ODOT Regions.

It is informative to note that in individual Regions, some treatments scored close to "completely successful" (score >3.50). If averages based on scores from only two or less respondents are disregarded, ten region scores fell into this elite group. Six of these scores were achieved by C-mix machine patch (Regions 1, 2, and 4) and F-mix inlay (Regions 1, 3, and 4). The other four scores in this category were B-mix machine patch in Regions 2 and 4, emulsion chip seal in Region 4, and F-mix machine patch in Region 1. Curiously, F-mix inlay received a relatively low score in Region 2, and F-mix machine patch received poor reviews in Regions 2 and 3. The low number of respondents with experience using these methods (31% for F-mix inlay and 14% for F-mix machine patch) no doubt contributes to the disagreement.

The ratings discussed above show great variation. All 16 techniques received the lowest score, "not at all successful," and all 16 treatments received the highest score, "completely successful" by some maintenance supervisors in the survey. For the treatments that they rated, only two respondents rated all of the treatments they had used equal; one gave five completely successful scores, and one gave nine somewhat successful ratings.

Table 2.5: Treatment Success by ODOT Regions

	Rating						# of Respondents						Rank					
	Region					ODOT Avg.	Region					All	Region					ODOT Avg.
2001	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
C-mix machine patch	3.60	3.67	3.00	3.75	3.00	3.49	10	18	7	8	6	49	2.5	1	8	1.5	8.5	1
F-mix inlay	3.60	2.67	3.63	3.75	2.00	3.33	5	6	8	4	1	24	2.5	9	2	1.5	15	2
B-mix machine patch	3.17	3.64	3.22	3.67	2.60	3.32	6	11	9	6	5	37	7	2	6	3	11.5	3
C-mix inlay	3.44	3.00	3.30	3.27	3.43	3.24	9	18	10	11	7	55	4	5.5	4	8	3	4
C-mix screed patch	3.00	3.07	2.75	3.30	3.33	3.10	8	15	8	10	9	50	9	4	11.5	7	4.5	5
C-mix blade	2.25	3.29	2.75	3.25	3.11	3.08	4	21	8	8	9	50	13.5	3	11.5	9	6	6
Emulsion chip seal	1.50	2.60	3.29	3.57	3.33	3.00	2	10	7	7	3	29	15.5	11	5	4	4.5	7.5
Crack sealing	3.20	2.64	3.38	3.14	3.00	3.00	5	14	8	7	3	37	6	10	3	10	8.5	7.5
D-mix screed patch	2.80	2.84	2.63	3.43	3.00	2.91	5	19	8	7	4	43	11	7	13	6	8.5	9
D-mix blade patch	2.25	3.00	3.00	3.00	2.40	2.83	4	13	7	7	5	36	13.5	5.5	8	11.5	13	10.5
Profile with grinder	3.40	2.71	3.00	2.50	2.33	2.83	5	14	10	4	3	36	5	8	8	14.5	14	10.5
Pothole with rock/Percol	3.00	2.33	2.80	2.67	4.00	2.69	4	12	5	6	2	29	9	13	10	13	1.5	12
F-mix machine patch	3.67	2.00	2.33	2.50	Not Used	2.58	3	4	3	2		12	1	14.4	16	14.5		13
Hot asphalt chip seal	1.50	2.00	4.00	3.50	4.00	2.53	2	8	2	2	1	15	15.5	14.5	1	5	1.5	14.5
Pothole w/premix	2.50	2.36	2.54	3.00	2.60	2.53	12	25	13	8	10	68	12	12	14	11.5	11.5	14.5
Tack/rock/spray/compact	3.00	1.78	2.50	1.33	3.00	2.18	4	9	4	3	2	22	9	16	15	16	8.5	16
Average	2.87	2.72	3.01	3.10	3.01	2.92												
Min	1.50	1.78	2.33	1.33	2.00	2.18												
Max	3.67	3.67	4.00	3.75	4.00	3.49												
< 3 respondents																		

Question Q:SUCC17 (Appendix A) requested information regarding other surface maintenance techniques used for F-mix. Nine respondents described experience with maintenance treatments not listed in the survey (in Appendix C). Three indicated that they have used hot mix for winter pothole patching with some success. Use of "instant road repair" for small areas was mentioned. A rubber and rock patch was described, where rubber is used with washed aggregate. Also used is a specially formulated cold patch repair, and an asphalt plug for bridge joints was noted.

One reason that "hot" F-mix is not widely used to repair F-mix pavements is due to the perceived cost and difficulty of obtaining it in small quantities. This is likely a strong contributing factor that results in the two repair techniques using F-mix being two of the four least-used treatments (Figure 2.7). The surveys attempted to gather more information on this issue.

Figure 2.8 shows the response to the question, "Thinking of your local suppliers of F-mix, if they are not already producing F-mix for a construction contract, will they provide you with less than sixty tons?" Less than 10% felt that they could obtain the mix. Of those nine, six believed that they could obtain amounts as small as 30 tons, and of these, three respondents thought that they could obtain amounts as small as 10 tons or less.

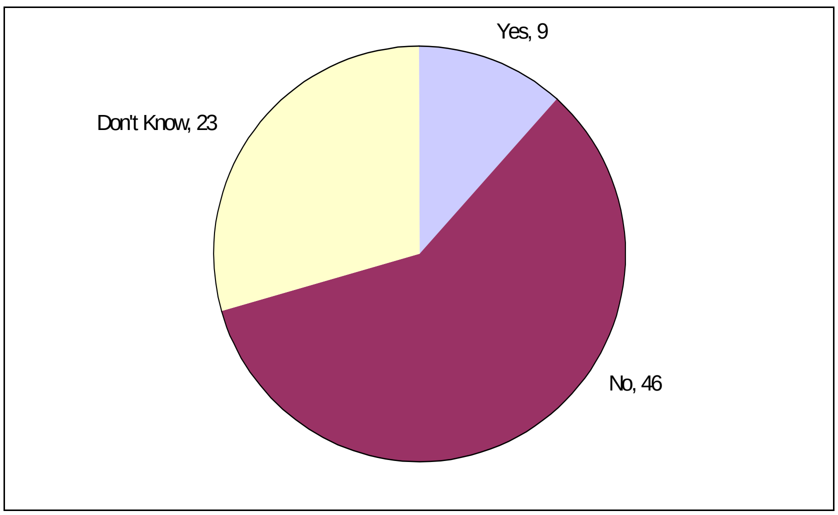

Figure 2.8: Response by ODOT to "Can less than 60-ton of F-mix be obtained?"

Members of the Asphalt Paving Association of Oregon were surveyed to determine their ability to supply F-mix in small quantities. Figure 2.9 shows the response to the question, "If you are not already producing F-mix for a construction contract, will you supply ODOT maintenance forces a quantity of less than sixty tons?" Four of nine respondents indicated that they would supply less than 60 tons. Five respondents indicated that they would not. Suppliers were also asked about the cost premium to supply this amount. Estimated premiums ranged from less than 20% to greater than double. The four respondents indicating that they would supply less than 60 tons, also indicated that they would supply less than 10 tons. All but one agreed that costs would be more than double the normal supply costs. One supplier noted that at least 15 - 20 tons would have to be made to bring the F-mix into specification.

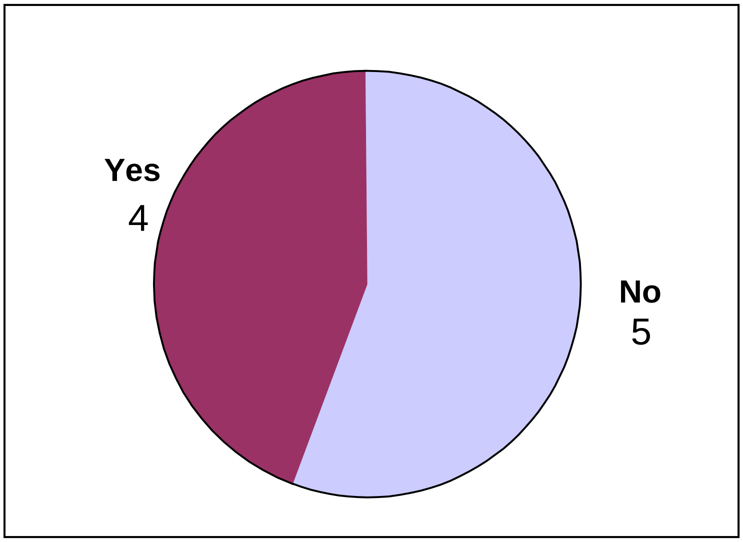

Figure 2.9: Response of Suppliers: Can less than 60-ton of F-mix be supplied?

In reality, even if F-mix can be obtained in small amounts, it is not likely to be widely used. It will be more expensive than dense mix, and cost will be a big factor with ODOT maintenance crews. F-mix cannot be used for blade or screed patches because the large aggregate does not allow a feathered edge. For most surface patches (blade or screed), drainage through the underlying F-mix should not be affected by use of dense-graded mix on the surface; thus, for small inlays where the geometry is such that damming of water will not occur, dense mix is likely to be used.

2.4 WINTER MAINTENANCE

It is known that F-mix behaves differently than dense-graded asphalt pavements in freezing conditions. To determine how ODOT maintenance forces meet this challenge, this question was asked. "What procedures have you found to be effective in maintaining F-mix pavements during the winter?" All responses are listed in Appendix C. Common responses were grouped together when appropriate, and are shown in Table 2.6.

Table 2.6: Most Common Winter Maintenance Techniques for F-mix

Treatment	#
Sanding	20
Liquid de-icer or anti-ice agent	15
Magnesium Chloride	15
CMA	7
Larger quantity of de-icer	7
Run shoes on plows	5
Reduce plow speeds	2
Rubber bits	1
CMA & CF 7	1
Magnesium Chloride and CF7	1

Sanding and de-icing agents, either alone or in combination, were the most commonly reported winter maintenance techniques. Some respondents referred to deicers in generic terms, while others specified magnesium chloride, CMA, or CF7. The need for a greater quantity of deicer (as well as earlier, more frequent, and longer application) for the porous F-mix than for dense surfaces was noted.

Specific selected comments relating to sanding included, "You have to stay on top of it," "It tends to plug it up," "Sanding is a last resort," "Sanding is less successful than deicer," and "Cinders are best – they go down into pores more easily."

Specific comments relating to magnesium chloride included, "It is more effective than CF7 or CMA," "Pretreating with magnesium chloride works best as a deicer," "Need to apply it twice as heavy," and "We've been really effective with it."

Specific comments relating to CMA included, "Use CMA for frosting," "CMA is temperature and moisture sensitive," and "Thirty percent solution of CMA has proven somewhat successful."

Comments relating to deicers in general are as follows, "You have to do it within 60 minutes before a storm. We don't do pre-treating because it's not effective. The material goes down into the asphalt." and "They are all effective, but magnesium chloride is more temperature sensitive than CMA."

Based on the comments obtained from the survey, it is apparent that there is no clear consensus on most effective F-mix winter maintenance. Although the maintenance supervisors did not reach a consensus, the literature on open-graded friction courses and porous asphalt shows agreement on major points. The interim report *(Rogge and Hunt 1999)* discusses this topic at considerable length. Since the interim report, an NCHRP synthesis has been published *(Huber 2000)*, and a report on porous asphalt trials from the UK has been obtained *(Nicholls 1997)*. Both are recommended for their discussions of winter maintenance.

Huber *(2000)* states that, "In freezing climates, open-graded mixtures require a different approach for winter maintenance. Open-graded mixtures tend to be the first section to freeze and the last surface to thaw." He cites studies that show that under clear sky conditions with no wind, ". . . the temperature differential between dense and porous asphalt can be as much as 2 degrees Celsius (3.6 degrees Fahrenheit). He concludes that for open-graded mixtures, "more frequent applications, though not necessarily greater quantities, of salt are needed." Nicholls *(1997)* agrees with this finding stating that for porous asphalt surfacings, "use of more frequent applications, but in lesser quantities, of de-icing salt . . ." is required. He explains that for porous asphalt, "The increase in voids content reduces the thermal conductivity of the material . . ." This means that subsurface heat can not migrate to the pavement surface as rapidly as for dense-graded pavement.

2.5 PAVEMENT MANAGEMENT SYSTEM ANALYSIS

The PMS data were provided to the author in a database. The PMS data contained asphalt concrete pavements listed with ages well in excess of 20 years of age. Pavements were grouped into three categories for analysis:

- 0-5 years;
- 6-10 years; and
- 11-15 years.

Only F-mix and B-mix pavement surface courses were included in the analysis. The pavements were grouped according to their highway classification, either National Highway System (NHS) or non-NHS.

NHS pavements are rated using the "Objective Rating Method." This method results in an overall pavement condition index, which is a composite of five different indices:

- Rutting index;
- Patching index (includes patches and potholes);
- Fatigue crack index;
- Temperature crack index; and
- Raveling index.

Non-NHS pavements are evaluated using the "Good-Fair-Poor" rating system. This system results in an overall pavement condition index being assigned, but individual index values for rutting, raveling, etc. are not determined on non-NHS highway segments.

Table 2.7 contains the mean values of the Pavement Condition Index using the 2001 PMS data. In the PMS, 100 is the highest score possible, so lower numbers indicate more deterioration. The analysis showed that the mean values for overall pavement condition index were better on F-mixes for both NHS pavements and non-NHS pavements for every age category except for non-NHS pavements, 11-15 years.

Table 2.7: Mean Values of Overall Pavement Condition Index

	Age (yrs)	F-mix	B-mix
NHS	0-5	96.0	92.3
	6-10	87.2	73.6
	11-15	70.6	59.7
Non-NHS	0-5	95.5	90.8
	6-10	82.5	70.5
	11-15	54.9	60.0

Table 2.8 shows the mean values for each individual distress index reported for B-mixes and F-mixes on NHS pavement sections. The F-mixes have higher index values in each age category for fatigue cracking, patching and temperature cracking. The raveling index values are about the

same for both F- and B-mixes. For pavements older than five years, the rut index is slightly higher for B-mixes.

Table 2.8: Mean Values for Pavement Condition Indices for B-mix and F-mix

Age (yrs)	Pavement Type	Overall Index	Rut Index	Fatigue Crack Index	Patching Index	Raveling Index	Temp Crack Index
0-5	F-mix	96.0	97.7	99.0	99.0	99.6	99.3
	B-mix	92.3	96.6	97.0	96.4	99.1	98.6
6-10	F-mix	87.2	92.2	98.0	96.6	99.8	99.1
	B-mix	73.6	92.3	86.8	91.9	99.9	97.1
11-15	F-mix	70.6	88.1	88.7	88.1	99.5	98.3
	B-mix	59.7	90.1	75.6	87.1	99.7	92.9

Based on the overall condition ratings for NHS and non-NHS highways and specific condition ratings on NHS highways, the data indicate slightly better condition of F-mix pavements. This may be attributed to a number of factors including mix design, quality of the initial construction, traffic loading, environmental conditions, and possibly the maintenance history. Although the survey data revealed opinions about difficulties in maintaining F-mix, the 2001 distress data shows that the severity of distress is on average, higher in B-mix pavements. However, it is not known if more maintenance dollars are spent on F-mix sections than on dense graded pavements.

In addition to comparing F-mix and B-mix performance, the perceptions of the maintenance supervisors regarding most frequent distresses seen in F-mix were compared with the five individual indices (rutting, raveling, etc.) contained in the PMS for NHS pavements.

The distresses reported on in the maintenance supervisor survey (Table 2.2) did not match directly with the indices contained in the PMS. To compare the PMS with the maintenance supervisor survey data results, survey ratings for tire-stud rutting and deformation rutting were combined and compared to the PMS rutting index. Raveling in the maintenance survey was considered comparable to the raveling index. “Potholes” in the survey was compared with the patching index. The temperature cracking index and thermal cracking on the survey were also considered analogous.

The PMS has separate fatigue crack and temperature crack indices while the survey discusses alligator cracking, reflective cracking, and thermal cracking. The maintenance supervisors probably could not identify reflective cracks because they are not familiar with the cracking in the underlying pavement structure prior to overlay. Therefore, no comparison was attempted for reflective cracking. Alligator cracking is generally considered severe fatigue cracking, so alligator cracking ratings from the survey were compared to fatigue crack index from the PMS.

To compare the two data sets, the distresses were ranked in terms of severity. The survey data rankings were based on the average score received for the distresses in Table 2.2. The rankings for the five distresses which correspond to PMS indices are shown in Table 2.9. Maintenance managers rated rutting as the number one distress mechanism, followed by raveling, potholes, fatigue cracking and temperature cracking.

Table 2.9: Rankings of Distresses Reported in the Maintenance Manager Survey

Distress	Rank
Rutting	1
Raveling	2
Potholes	3
Alligator / Fatigue cracking	4
Thermal / Temperature cracking	5

For the PMS index values, an average value was calculated for each of the five indices for all NHS F-mix pavements 15 years or less in age. The average index values shown in Table 2.10 are presented in rank order. Note again, the lower the index value, the greater the distress severity.

Table 2.10: Pavement Indices for NHS F-mix Pavements 15 Years or Less in Age.

Index	Index Value	Rank
Rutting index	94.2	1
Patching (including potholes) index	96.9	2
Fatigue crack index	97.8	3
Temperature crack index	99.2	4
Raveling index	99.7	5

Table 2.11 presents the 2001 survey distress rankings from Table 2.9 and the corresponding rankings for PMS data (Table 2.10).

Table 2.11: Comparisons of Rankings of Distress from 2001 Maintenance Supervisor Survey and PMS

Distress	Rank of Frequency of Occurrence/Magnitude	
	Survey*	PMS**
Rutting	1	1
Raveling	2	5
Potholes	3	2
Alligator/Fatigue cracking	4	3
Thermal/Temperature cracking	5	4

* From Table 2.9
** From Table 2.10

Aside from raveling distress, the most prevalent F-mix distress expressed by the maintenance supervisors is generally consistent with the ranking from the PMS. Both agree that rutting is the most widespread.. Except for raveling, the other three distresses have similar rankings in the survey and PMS. Raveling ranked as the second highest of the comparable distresses in the survey, while ranking fifth among the five PMS indices. It is speculated that raveled pavements may be patched by maintenance crews before they are measured and recorded in the PMS, thus resulting in greater significance in the maintenance supervisory survey than in the PMS.

3.0 F-MIX PAVEMENT DISTRESSES

Pavement surface maintenance occurs because pavement distress reaches a level where maintenance activity is required to maintain a trafficable road surface, or to prevent more serious damage which would require greater costs for pavement rehabilitation. Distress may be caused by traffic, by environmental factors, or by a combination of the two.

Distresses experienced by F-mix pavements were discussed with the Technical Advisory Committee and with other ODOT maintenance personnel early in the project. Based on these discussions, the 1997 maintenance supervisor survey solicited information regarding the nature of, and extent of distresses most commonly experienced with F-mix pavements. The 1997 data was used to revise the list for the 1999 survey. The 2001 survey used essentially the same checklist of F-mix pavement distresses as the 1999 survey.

This chapter documents the distresses common to F-mix pavements in Oregon. They are presented here in descending order of frequency of occurrence as expressed in the 2001 maintenance supervisor survey. The most "pervasive" distress is discussed first, proceeding to the least common distress of the fourteen listed. The ranking is based on the extensiveness of the distress – not necessarily the severity of the actions or events resulting from the distress.

3.1 TIRE STUD RUTTING

Tire stud rutting is produced when the wheelpaths of the traffic lane are hammered by studded tire wheel passes (Figure 3.1). Over time, very well defined ruts appear, making control of the vehicle difficult, particularly when the ruts become filled with water during rainy periods. Tire stud rutting is a problem on any pavement, including dense-graded asphalt and portland cement concrete, but these pavements types were not addressed in the survey. The maintenance supervisors rated tire-stud rutting the most serious F-mix maintenance problem in 2001.

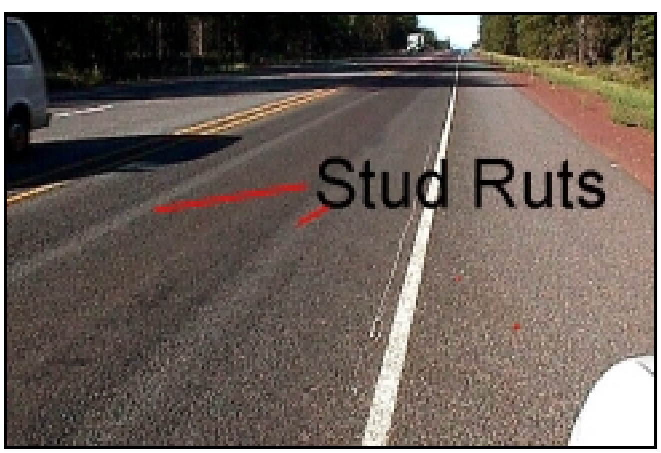

Figure 3.1: Stud Rutting on US 97, MP 150.2 SB near Bend

The PMS data also shows rutting as a primary distress. Table 3.1 shows, by Region, the average rutting index values on F-mix pavements constructed within the last 15 years.

Table 3.1: Rut Index Values on F-mix Pavements Constructed in the Last 15 Years

Region	Number of Pavement Sections	Overall Index	Rut Index
1	44	89.5	91.2
2	90	88.8	95.8
3	71	90.5	96.8
4	73	90.3	92.6
5	25	88.9	91.0

As noted in Chapter 2, the rutting index considers rutting due to both studded tire damage and deformation rutting. Since F-mix is more resistant to deformation rutting, the rut index values presented in Table 3.1 can most likely be attributed to studded tire wear. The highest severity of rutting is occurring in Regions 5, 1, and 4.

3.2 ICING PROBLEMS

In addition to patching and repairing pavements to maintain trafficability, ODOT maintenance crews are charged with maintaining safe driving conditions during winter weather. This includes snow removal and use of sanding and de-icing to improve tire/pavement friction during icing conditions. This section addresses challenges presented in de-icing F-mix. Damage from snow removal is discussed in section 3.3.

ODOT maintenance personnel have observed that F-mix behaves differently than dense-graded pavements in freezing or near-freezing conditions. Extensive studies in Europe, where porous pavements similar to F-mix are widely used, verify and explain the problem. The findings of these studies are summarized in a National Cooperative Highway Research Program (NCHRP) synthesis on open-graded friction courses *(Huber 2000)*. Porous pavements freeze sooner than dense-graded asphalt when ambient temperature drops below freezing. This is because the air voids in the porous pavement serve as an insulator, restricting the flow of heat to the surface from below. Freezing rain on porous asphalt forms ice sooner, and remains on the road longer. In subfreezing weather, dry porous pavements may experience frost formation in the tire tracks. Deicers drain into the pavement pores rather than remaining on the surface, and must be applied earlier and more frequently to porous pavements.

3.3 GOUGING AND SCARRING

Figure 3.2 shows an example of gouging of F-mix. The open texture of F-mix pavements provides more ready access than dense-graded pavements, and less resistance to snowplow blades or other protruding objects with the potential to catch and tear the surface. This damage is most prevalent and most serious in snow zones with repeated snowplowing. Gouging is also caused by metal objects dropping to the pavement or being drug along the pavement surface by vehicle accidents, or by damage from construction equipment. Outside of snow zones the damage is largely aesthetic and is generally not repaired, and trafficability is not usually impaired. When repair is attempted, a surface blade patch or screed patch with dense-graded asphalt is normally employed, which covers a much larger surface area than the gouged area.

Figure 3.2: Gouging on US 97 near Bend

ODOT maintenance personnel report that F-mix is more vulnerable to gouging and disintegration from the action of snowplows and tire chains than are dense-graded pavements. Prior to this research project, the ODOT Pavements Unit was already aware of this vulnerability and had changed policy to no longer use F-mix pavements in mountain snow zones. This decision should greatly reduce the frequency and importance of this distress as the F-mix pavements in snow zones are gradually replaced with SMA or other dense-graded pavements. Consequently, although the existing F-mix pavements in snow zones present an irritant for ODOT maintenance personnel, in the future, the extent of the gouging problem should be reduced as these mountain pass F-mixes are eliminated.

3.4 RAVELING

The literature from Europe, where porous pavements are widely used, agrees that failure for porous pavements at the end of their service lives occurs through extensive raveling *(Rogge and Hunt 1999)*. As the pavement ages, the binder loses its flexibility, and more and more pieces of aggregate separate and are raveled away from the pavement surface. Eventually a point is reached where the pavement surface is no longer trafficable. Based on the survey data presented in Chapter 2, the frequency of raveling distress has increased in the last four years. Maintenance supervisors ranked raveling as the tenth most extensive distress in 1997; in 1999, it was listed as the seventh. In the 2001 survey, the maintenance supervisors ranked raveling fourth among distresses identified in the survey.

Figure 3.3 (from a site near Coquille) shows an F-mix with extensive raveling, nearing the end of its service life. The foreground shows the very open texture of the pavement where aggregate has raveled away. The blade-patch visible in the right lane is from an earlier construction season.

Apparently the distress had been more severe at that location. Figure 3.4 shows a close up in the outside wheeltrack, where the loss of rock and very open surface texture may be seen.

Figure 3.3: Raveled F-mix and Dense-Graded Blade-Patch on ORE 42, MP 18 (approx.) near Coquille

Figure 3.4: Close-up of Wheeltrack Pavement Surface, ORE 42, MP 18 (approx.)

Unlike the survey data, the PMS raveling index values indicate little problems with raveling on F-mix pavements. Table 3.2 lists, by Region, the average raveling index values for F-mix pavements. Raveling indices are close to 100 for all regions, indicating good pavement condition with respect to raveling.

Table 3.2: Raveling Index Values on F-mix Pavements Constructed in the Last 15 Years

Region	Number of Pavement Sections	Overall Index	Raveling Index
1	44	89.5	99.4
2	90	88.8	99.8
3	71	90.5	99.7

4	73	90.3	99.7
5	25	88.9	99.6

3.5 DEFORMATION RUTTING

Deformation rutting is distinguished from tire stud rutting, because the causes of the distress are different. Whereas tire stud rutting is an erosion down into the surface caused by the abrasive action of tire studs, deformation rutting is caused by the deformation and movement of part or all of the pavement structure. Deformation rutting is also known as rutting and shoving, where the surface course may become plastic and flow out of the wheeltracks under wheel loads. This happens with dense-graded asphalts when air voids are reduced below a minimum critical limit. Base courses of asphalt may experience the same phenomenon, or subgrade materials may fail.

F-mix should be more resistant to deformation rutting than dense-graded asphalt because of the high degree of aggregate interlock resulting from the open-graded mix design. Experience on US 97 in central Oregon substantiates this improved rut resistance.

ODOT's pavement management system generally reports good performance by F-mix pavements with respect to rutting. However, this seems to contradict the perceptions of ODOT maintenance supervisors who have ranked rutting as the fifth most frequently reported distress (Table 2.2). Why? Perhaps some very visible rutting problems have caught the attention of maintenance supervisors. Possible examples are the extensive rutting in the turn lane between ORE 34 westbound, east of Corvallis and the bypass (Figure 3.5 and Figure 3.6), and rutting experienced on I-5 northbound north of Roseburg in District 7. The Corvallis Bypass turn lane presents a very difficult traffic environment, possibly justifying use of portland cement concrete. Some F-mix rutting problems may be due to deformation rutting of the dense-graded asphalt base course or of the subgrade.

The left turn lane from ORE 34 westbound to the Corvallis Bypass was repaired during the summer of 2001. The pavement was milled down through the top 100 mm of F-mix and 150 mm into the underlying dense-graded asphalt pavement. The total depth was replaced with a B-mix inlay.

Figure 3.5: Deformation Rutting in WB Left Turn Lane from ORE 34 to Corvallis Bypass, August 5, 1999

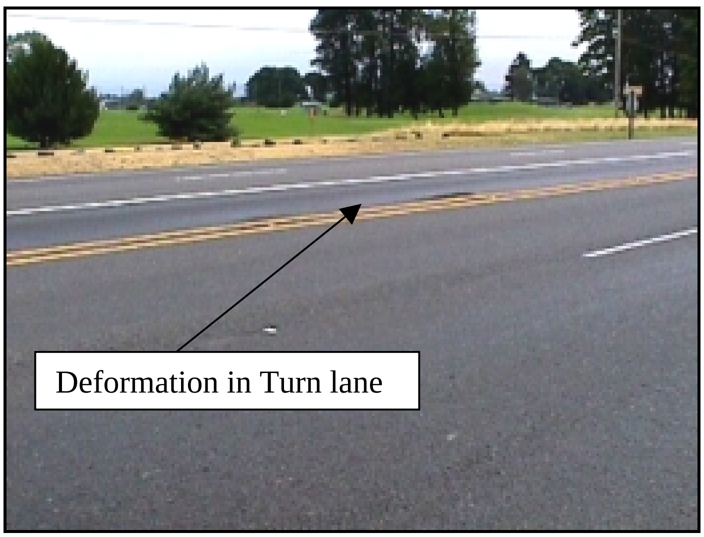

Figure 3.6: Deformation Rutting in WB Left Turn Lane from ORE 34 to Corvallis Bypass, Viewed from the EB Shoulder

3.6 POTHOLES

As with dense-graded pavements, often the first repair required for a section of F-mix pavement in distress is that of a pot hole. A separate research project was conducted by ODOT to evaluate pothole repairs, in both dense-graded asphalt and in F-mix. The preliminary results of that study are presented in "Asphalt Concrete Patching Material Evaluation" *(Berlin and Hunt 2001).* The primary objective was to determine if proprietary patch materials applied in winter conditions would form a more permanent patch than the pre-mix normally used as a temporary repair until permanent repairs can be made in summer. The majority of proprietary mixes performed well in both dense-graded and F-mix pavements.

Table 3.3 shows the PMS patching index values for each region. In determining the patching index, both potholes and patches are rated together (*Mullis and Brophy 2001*). The index values are slightly lower in Regions 2 and 3. In the maintenance supervisor survey data presented in Table 2.2, “potholes” were ranked as the second highest distress feature in Region 2, which correlates to what is seen in the PMS data. In Region 2, maintenance managers ranked “potholes” sixth of 14 on the on the survey, which also is fairly consistent with the PMS data.

Table 3.3: Patching Index Values on F-mix Pavements Constructed in the Last 15 Years

Region	Number of Pavement Sections	Overall Index	Patching Index
1	44	89.5	98.6
2	90	88.8	95.6
3	71	90.5	95.3
4	73	90.3	98.8
5	25	88.9	98.1

3.7 CLOGGING

Clogging is one type of functional failure unique to F-mix and other porous pavements. Virtually as soon as an F-mix surface course is put down, its pores begin to clog with dirt and debris, and its porosity begins to decrease. Over a period of years, its permeability continues to decrease, at some point approaching the permeability of a dense-graded pavement. Clogging is most severe in shoulder sections and outside the wheelpaths. High volumes of high-speed traffic produce a tendency for self-cleaning, due to changes in air pressure induced in the porous network of the pavement by the passing of vehicle tires. The accumulation of dirt and debris is compounded by the application of sand and cinders used to treat icing conditions in the winter.

Figure 3.7 shows water pooled and flowing along the surface of an F-mix pavement. The water came from a field test to check for permeability of the pavement using a field permeameter. If the pavement was not clogged, this small amount of water from the field permeameter would have flowed directly down into the pavement.

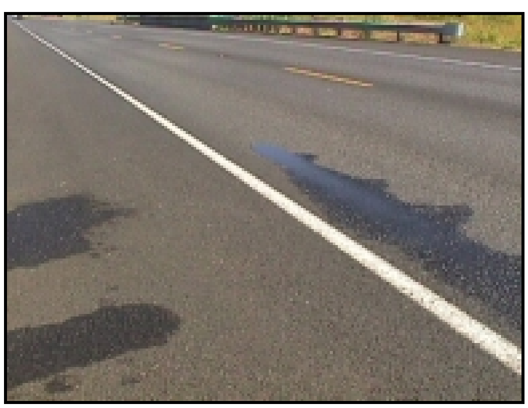

Figure 3.7: Water Pooling on the Surface of a Clogged F-mix

European road maintenance agencies have experimented with high pressure washers to restore permeability *(Rogge and Hunt 1999)*. Although they report some success, the process is slow and does not produce a long-term cleansing. Consequently, the maintenance procedure is seldom performed.

Although clogging is inevitable as dirt and debris accumulate year by year, unclogging is not and has not been a high priority with ODOT. It may be argued that even when fully clogged, the drainage characteristics of F-mix are no worse, and probably still somewhat better, than drainage for a dense-graded pavement. Although clogging is considered commonplace in F-mix pavements, reversing the clogging is given very low priority compared to other much more urgent maintenance needs for ODOT.

A report by Penn State University *(Anderson 1998)* suggests that the anti-hydroplaning advantages of porous pavements may be more related to surface texture than pavement porosity. If this is true, clogging may not reduce hydroplaning advantages. Over time, clogging results in increased splash and spray relative to performance immediately after construction.

3.8 CRACKING DUE TO INADEQUATE STRUCTURE

As the name suggests, cracking due to inadequate structure is a structural problem. The alligator cracking occurs in the surface course as cracks are reflected up from a failing subgrade, base, or base course. To be effective, repairs of this type of distress must improve the structural section. Local failures are most effectively repaired with deep patches, where the structural section is removed and the subgrade is excavated to appropriate depth before building back a thicker pavement section. Extensive sections of roadway with inadequate structure may require structural overlays or total reconstruction. As with dense-graded asphalt pavements, the temporary expedient patch is often a screed patch or a blade patch. Figure 3.8 shows an F-mix pavement with alligator cracking (foreground) and a screed patch repair in the background.

Figure 3.8: Alligator Cracking on ORE 99W North of Corvallis, 1999, prior to Resurfacing

In the survey of maintenance managers, opinions about the severity of fatigue cracking were mixed. As noted in Chapter 2, supervisors in every region except Region 2 ranked fatigue cracking relatively low among the 14 distresses that were ranked in order of severity. In Region 2, fatigue cracking was ranked third (Table 2.2).

The PMS average fatigue crack index values on F-mix pavements for each region are shown in Table 3.4. In Region 2, the fatigue crack index is lower than the other region index values. The lower fatigue crack index is consistent with the opinions expressed in the supervisor survey.

Table 3.4: Fatigue Crack Index Values on F-mix Pavements Constructed in the Last 15 Years

Region	Number of Pavement Sections	Overall Index	Fatigue Crack Index
1	44	89.5	98.8
2	90	88.8	96.7
3	71	90.5	97.7
4	73	90.3	98.1
5	25	88.9	98.9

3.9 FAT SPOTS/BLEEDING BECOMING A PROBLEM

In many cases, F-mix pavements have shown fat spots of excess bitumen without suffering performance problems. Appearance is undesirable, but pavement deterioration does not follow. There are occasions, however, when a problem results. For example, Figure 3.9 shows the F-mix surface course of ORE 99W just north of McCoy Junction after several days of 35°C temperatures during the summer of 1998. During this heat wave, fat spots, which had not presented a maintenance problem before, began to flow, producing surface depressions. Figure 3.10 is a picture of the same section a year later, in 1999. Figure 3.11 shows the same location in September 2001. Figure 3.12 is a view of the worst area of distress from the top of the grade directly north of McCoy Junction. Figure 3.13 shows a close up. Note the almost complete separation of the bitumen from the aggregate. In the Spring of 2002, this location remains primarily an appearance problem. Ride quality is not significantly affected and no maintenance has been performed.

Figure 3.9: SB Lane, ORE 99W, just North of McCoy Junction, 1998

Figure 3.10: Same Location as Figure 3.9, in 1999

Figure 3.11: Same Location as Figure 3.9, in 2001

Figure 3.12: ORE 99W Looking South to McCoy Junction

Figure 3.13: Close-up of Distress of Figure 3.12

3.10 NOISY RIDE

Noisy ride is a manifestation of raveling, where visible raveling may not be apparent to the casual observer. Noise reduction is touted as a significant benefit of porous pavements by European agencies. An ODOT investigation in the 1990's *(Younger 1994)* substantiated this advantage for F-mix to some degree. Therefore, even if raveling has not progressed to a point requiring maintenance, the excessively open texture caused by the onset of raveling will increase noise levels.

3.11 STRIPPING

Stripping is a failure of asphalt pavements where the asphalt binder separates from the aggregates in the presence of moisture. Some aggregates are highly susceptible to stripping. In general, stripping has not presented a problem for F-mix, and traditional testing procedures to protect against stripping have proven overly-conservative when applied to F-mix. Nevertheless, the surveys of ODOT maintenance personnel indicate that stripping can be a problem. Figure 3.14 is a close-up of the distress on a section of I-84 near MP 216 just east of Pendleton, taken in July 1997. Figure 3.15 shows a photograph of the same general area, also taken in July 1997. This distress is attributed to stripping. Four years later in 2001, the distress remained untreated, as shown in Figures 3.16 and 3.17.

The stripping is attributed to several factors. It is believed that the base course placed under the surface course was F-mix in the truck lane, causing a bathtub section. The binder used during construction was off-specification. The aggregate in the mix has been susceptible to stripping and rutting when used in dense-graded mixes. Further, there were questions about the lime treatment of the aggregate. Specification of dense-graded asphalt would not have solved these types of problems.

Figure 3.14: Close-up Image of I-84 Stripping, 1997

Figure 3.15: Stripping at MP ~215.5, I-84 WB Lanes near Pendleton, Looking East, July 1997

Figure 3.16: Stripping on I-84, ~MP 215.5 WB Lanes, Looking East, September 2001

Figure 3.17: Stripping Looking West, September 2001

A distress and repair survey was conducted on September 17 and 18, 2001 on this section of I-84 *(Brooks 2001 – E. Pendleton)*. Areas of local distress are described in Table 3.5. The pavement is scheduled for mill and inlay in 2002.

Table 3.5: Distress Survey Summary, I-84 MP 213 – 216, September 2001.

Lane	Milepost	Feature
Eastbound	213-216	Minor bleeding and raveling
Westbound	216-215	Potholes, raveling 150 meter strip
Westbound	215.5	Center lane shoving
Westbound	213	Left lane bleeding

3.12 BUMPY RIDE

Bumpy ride (listed as rough ride in the 1997 and 1999 surveys) can be caused by many factors ranging from subgrade distress to potholes, surface delaminations, or raveling. In retrospect, such a "catch-all" distress should not have been included in the distress checklist.

3.13 REFLECTIVE AND THERMAL CRACKING

Reflective and thermal cracking were the lowest concerns in the 2001 maintenance supervisor survey. The maintenance supervisors showed more concern for thermal cracking in central Oregon (Region 4) than in western Oregon. This is understandable given the large daily temperature variations frequently experienced in the high desert regions of Oregon. Figure 3.18 shows an image of a sealed thermal crack through F-mix on US 97 near Bend.

Figure 3.18: Thermal Cracking on US 97, ~MP 149, near Bend

Although the maintenance supervisor survey results (Table 2.2) show that thermal cracking was ranked as the sixth most severe distress on F-mixes (out of 14) in Region 4, the PMS distress data does not point to the same result. Table 3.6 shows the average temperature crack index values for F-mix pavements in each Region. The index vales in each region are reasonably close and relatively high, even in Region 4. In this case, the perceptions of the maintenance supervisors in Region 4 are not closely aligned with the PMS distress data.

Table 3.6: Temperature Crack Index Values on F-mix Pavements Constructed in the Last 15 Years

Region	Number of Pavement Sections	Overall Index	Temperature Crack Index
1	44	89.5	98.9
2	90	88.8	99.4
3	71	90.5	99.3
4	73	90.3	99.0
5	25	88.9	98.8

With regard to reflective cracking and F-mix, it has been shown that just adding a new F-mix overlay will not totally retard reflective thermal cracking as these cracks can progress through an overlay. Previous ODOT research (*Sposito and Brooks 1999*) has documented the severity of reflective cracking through an F-mix overlay. In September 1998, test sections on US 97 from MP 213.6 to MP 217.6 were established to study the effectiveness of five different geosynthetics in reducing reflective cracking. The geosynthetic test sections were part of a 50 mm F-mix overlay that was placed over an existing F-mix. Prior to construction, the transverse cracks in the existing F-mix were indexed and mapped. Before placement of the geosynthetics, the cracks in the existing F-mix were cleaned and filled with D-mix. In addition to the five test sections where the geosynthetics were used, two control sections were established. One control section consisted of "no treatment" to the existing cracks prior to the overlay, and on the second control section, the cracks were cleaned and filled with D-mix prior to the overlay. The four-mile series of test and control sections were inspected in May 1999, May 2000 and September 2001. In the most recent inspection, approximately 24% of the original transverse cracking returned for the "no treatment" and "crack-fill-only" control sections. About 9% of the original transverse cracking returned through the geosynthetic products (*Sposito 2001*).

4.0 F-MIX SURFACE MAINTENANCE

The research project attempted to follow the progress of fog seals, F-mix distressed pavements, and maintenance procedures over time. However, because of the independent nature of the maintenance offices around the state, tracking the scheduling of specific maintenance treatments became problematic. As a result, all data collected is anecdotal in nature. Specific locations that shed some light on F-mix maintenance issues are presented in this chapter.

4.1 PREVENTIVE MAINTENANCE

Fog seals and chip seals were the only preventive maintenance measures identified in the literature and through conversations with ODOT and other transportation agencies. Chip seals are a surface rehabilitation measure which partially or completely seals the surface, eliminating the benefits provided by the porosity of the F-mix pavement. Chip seals are also more expensive than fog seals. Although the problem of reduced pavement friction immediately after application is avoided, problems of fly rock may result. Emulsion chip seals are more proven within ODOT and were rated as more successful than "hot asphalt" chip seals in the maintenance supervisor survey. Fog seals though, are more economical, and are less clogging than chip seals. Thus, fog seals became the focus of preventive maintenance data gathering.

As stated in the interim report for this project, it is generally agreed that fog seals will reduce the permeability of F-mix, provide a traffic control challenge during their application, and temporarily reduce pavement friction after their application *(Rogge and Hunt 1999).* On the positive side, they are the lowest cost maintenance technique known, and many engineers and maintenance personnel believe that they help keep the asphalt more flexible, thus extending the life, at least marginally. According to the Asphalt Institute, "An asphalt emulsion fog seal can be applied immediately following placement of the open-graded mix to enhance film thickness and to minimize surface raveling. A fog seal can also be applied after approximately five years of service life for the same reason" *(Asphalt Institute 2001).* When contacted, however, the Asphalt Institute could not identify a study from which these conclusions were reached.

No quantitative study of the value of fog seals on porous pavements has been reported in the literature. However, a study conducted at Texas A&M University investigated the use of fog seals on dense-graded asphalt and on chip seals *(Estakhri and Agarwal 1991).* Asphalt rejuvenators were also studied, but open-graded friction courses were not included in the study.

With respect to fog seals applied to dense-graded asphalt, the Texas A & M study concluded that, "based on the limited information obtained in this study, fog seals, applied at residual asphalt rates of 0.05 gallons per square yard, are not effective at sealing the surface to reduce the rate of aging in the mix. They can be used more effectively to correct specific surface problems such as raveling or loss of surface fines. . . . There is insufficient information in this study to conclude when and how much fog seal to apply on asphalt concrete to reduce aging."

Results were more positive for chip seals. The authors of the Texas A&M study concluded that fog seals were beneficial ". . . for reducing the rate of stone shelling in chip seals if placed at the proper application rate and before the first winter season following the chip seal." Otherwise they were not cost-effective for chip seals. If F-mix is viewed as a 50 mm-thick plant-mixed chip seal, this research would support the contention that fog seals can be beneficial if applied prior to visible distress, particularly if the mix shows signs of being under-asphalted.

From the start of this study in 1997 until the writing of the report in September 2001, the author monitored eight fog seal projects on F-mix in Oregon. Table 4.1 lists the projects, and where known, their approximate lengths in lane miles, approximate age at time of fog seal, and the evaluation of fog seal effectiveness in 2001. (The author apologizes for the approximate and vague data, but because there is no summary reporting of this type of information at the state level, all information was obtained through telephone conversations and e-mails.)

Table 4.1: ODOT Fog Seals from 1997 - 2001

Location	Lane Miles	Date	Approx. Age at Fog Seal (years)	Pavement Condition 12/99	Fog Seal Effectiveness Evaluated in 2001
ORE 22, SE of Salem		May 1997	~2	Good	
ORE 34, immediately east of Corvallis	~12	August 1997		Good	Inconclusive
I-84, Meachem-Hilgard	~62	August 1997		Good	Inconclusive Mill & inlay for 2002
I-84, Corbett	~28	August 1997		Fair	Inconclusive Periodic patching; mill & inlay in 2005
US 99, Phoenix-Talent (~MP 12 - ~MP 17)	~10	July 1999		Fair	Inconclusive Chip sealed in 2000
ORE 62 near Tiller Junction (MP 22.7-MP 29.0)	~12	July 1998		Good	OK
US 101 – Cannon Beach-Arch Cape (~MP 31 - ~MP 36)	~10	Sept. 1999		Good	
I-5 near Jump-Off Joe, (MP 60 - MP 66)	~24	Summer 2000	~6	Good	OK Uphill grades show most wear

ODOT Research Group set up control sections without fog seal on two of the projects, ORE 99 south of Medford and the Cannon Beach – Arch Cape section of US 101. The other fog seals did not have control sections.

4.1.1 ORE 99, Phoenix-Talent, Fog Sealed July 1999

Unfortunately, the control sections for the ORE 99 fog seal proved of no value to the research project, as the entire project was chip sealed one year later, without notifying the author. The control section for the northbound lanes was between MP 17.02 (intersection with Valley View Road) and MP 16.84. The other control section was on the north end of the project in the southbound lanes. After the fact, ODOT maintenance crews said that the pavement surface was all equally bad and needed some type of treatment.

Even at the time of the fog seal, the pavement had experienced considerable distress. Appendix D presents a photo-log of surface condition over the entire project prior to fog seal. This information may prove useful in monitoring the success of the chip seal. It documents virtually every type of distress experienced by F-mix pavements.

The 1999 fog seal application rate for Phoenix-Talent was held to 0.54 L/m^2 of CSS-1H (the H indicates a hardener which cures the fog seal quicker). The mixture was 50% water and 50% CSS-1H at a combined temperature of 125°F. Immediately after fog seal application, a very light coating of reject sand (sand rejected for having too much dirt) was applied as a blotter. The Jackson County maintenance foreman in charge of the work said that they found this type of sand made a better blotter than clean sand.

The Phoenix-Talent fog seal provided some information on the effects of fog seals on pavement friction. Table 4.2 compares friction values on the fog sealed and non-fog sealed control sections before and after fog sealing, as well as friction values recorded one month and eleven months after placement.

Table 4.2: Friction Values Before and After Fog Seal – ORE 99, Phoenix-Talent

Time of Testing	**FN**	
	Control area	**Fog-seal area**
Night Before Treatment	53	48
1 hour after traffic	47	18
5 hours after traffic	47	23
1 month after treatment		36
11 months after treatment		49

4.1.2 US 101, South Cannon Beach-Arch Cape, Fog Sealed September 1999

The South Cannon Beach-Arch Cape project had been constructed during the summer of 1998. Some areas failed immediately and were milled and inlaid with dense-graded mix. Remaining areas were determined to be under-asphalted because cores indicated that the blend of aggregates used in construction required higher asphalt content than the materials used for pavement mix design. Application of a fog seal was viewed as a way to improve the under-asphalted condition and provide some insurance. A 3,280 m section at the north end of the job was not fog sealed, to serve as a control section.

The fog seal was applied September 7, 1999, with rates varying from 0.36 to 0.45 L/m^2. Friction measurements were taken on September 9 and 23, 1999 on the fog sealed pavement and the non-fog sealed control section. Table 4.3 shows the results.

Table 4.3: Friction Values at Cannon Beach-Arch Cape Fog Seal

	Mean FN (# of Readings)			
	September 9, 1999		September 23, 1999	
	Mean	Max./Min.	Mean	Max./Min.
SB Fog Sealed Average	33.5 (21)	43.4 max.	34.7 (34)	41.7 max.
SB Control Average	54.2 (1)	54.2 min.	47.0 (2)	46.8 min.
NB Fog Sealed Average	31.3 (17)	38.6 max.	34.3 (32)	38.3 max.
NB Control Average	41.0 (3)	38.1 min.	47.1 (2)	45.2 min.

The friction values for the control sections are based on very few readings. The mean values for fog-sealed readings on both dates are lower than for the non sealed control sections. The fog sealed friction values increased slightly over the approximate two-week period after application, but still had not recovered to the values of the control sections. Overall, mean values in all cases showed reduction in friction from the control sections to the fog-sealed sections. Twenty-three months after the fog seal was in place (August 2001), friction values averaged 50.6.

The friction readings for Phoenix-Talent and Cannon Beach-Arch Cape both demonstrate a reduction in pavement friction experienced immediately after application of a fog seal. However, there are significant increases during the first month after the fog seal has been in place.

4.1.3 I-84, Meacham-Hilgard, Fog Sealed August 1997

Figure 4.1 shows the fog sealing process at the Meacham-Hilgard project. The truck with the distributor bar is headed east in the eastbound passing lane. The fog seal was shot at a rate of 0.45 L/m^2, diluted 50-50. Approximately 32 lane-miles were completed by the contractor each day. One eastbound and one westbound lane were completed in the morning. These lanes were opened to traffic in the afternoon while the remaining two lanes were fog sealed. Figure 4.2 and 4.3 show the same area four years later in 2001. Figure 4.4 shows the EB lanes after the truck lane, fog-sealed in the morning, was opened to traffic. The same section of pavement, four years later, is shown in Figure 4.5.

Figure 4.1: Fog Sealing EB Passing Lane, I-84 near MP 239.9, July 1997

Figure 4.2: EB Lanes (foreground), I-84 near MP 239.9, September 2001

Figure 4.3: Pavement Surface near MP 238 EB, September 2001, Four Years after Fog Seal

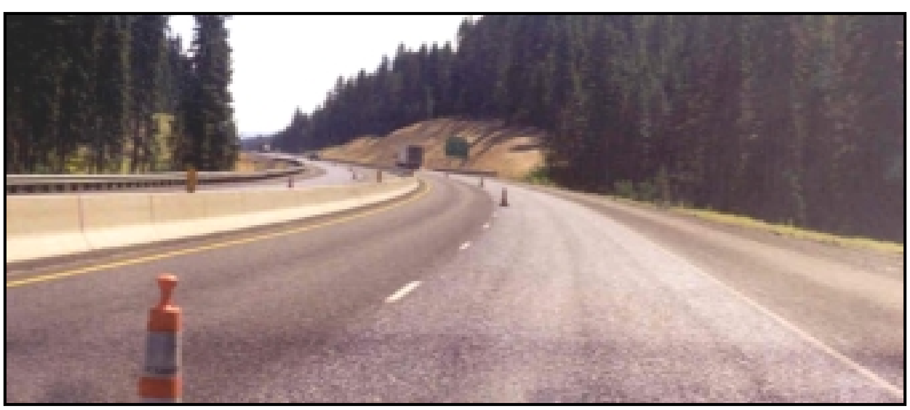

Figure 4.4: Truck Lane near MP 242.8 EB, Immediately after Fog Seal Opened to Traffic, July 1997

Figure 4.5: Same Location as Figure 4.5, Four Years after Fog Seal, September 2001.

Measurements of friction were taken before and after the fog seals (Table 4.4). Friction numbers at this site were comparable to pre-fog seal levels when measured after the project.

Table 4.4: Friction Values for Meacham-Hilgard Section

	Eastbound	Westbound
Before fog seal	52.3	47.1
One year after treatment		52.0
Two years after treatment	49.4	
Three years after treatment		48.9
Four years after treatment	47.3	

A condition survey conducted by ODOT on September 17 and 18, 2001, concluded that, "Generally the surfacing looked good with minor raveling and bleeding. However, some areas of local distress or patching were found . . ." *(Brooks 2001 – Meacham)*. Table 4.5 presents a summary of distresses and patching observed.

Table 4.5: Meacham Hilgard Patching and Distress, September 2001 *(Brooks, 2001-Meacham)*

Lane	Milepost	Feature
Eastbound	238-242	Raveling , minor bleeding, fog seal no patches
Eastbound	242.2	Gouges and stud tire damage, fog seal
Eastbound	243	Reduced raveling, minor bleeding, fog seal
Eastbound	244-252	Raveling, minor bleeding, fog seal
Westbound	253.2	65 m blade patch
Westbound	253-252	Minor bleeding, raveling, chain damage, fog seal
Westbound	250.5	2.2 m patch, patch below grade by 30 mm
Westbound	248.9	86 m patch on Glover Oxing, not fog seal
Westbound	247-247.5	24 small rectangular patches, fog seal
Westbound	245-246	Bleeding, raveling , fog seal
Westbound	243.9	Large spall under uxing
Westbound	238-244	Very minor raveling and bleeding, fog seal

Figure 4.6 shows damage from tire chains, and Figure 4.7 shows a section of this project that has been blade patched. Mill and inlay of this section with SMA is planned for 2002. Current ODOT pavement design guidelines do not allow use of F-mix in snow zones.

Figure 4.6: Tire Chain Damage, WB Lanes Looking East, near MP 252.6, September 2001

Figure 4.7: Blade Patch near MP 253.2 WB, September 2001

4.1.4 I-84, Corbett-Multnomah Falls, Fog Sealed August 1997

The surface condition of the Corbett-Multnomah Falls fog seal project on I-84 has been evaluated over time. Fig 4.8 shows the condition in the WB lanes at MP 28, prior to fog seal in August 1997. Fig 4.9 shows the same location four years later in September 2001. Rock loss in the outside wheelpath of the truck lane is shown in 1997 (Figure 4.10) and two years later in 1999 (Figure 4.11). This rock loss may be contrasted to the retention of rock on the shoulder at the same location in 1997 (Figure 4.12) and in 1999 (Figure 4.13).

Figure 4.8: I-84, MP28 WB, Looking East, August 1997

Figure 4.9: I-84, MP28 WB, Looking East, September 2001

Figure 4.10: I-84, MP28 WB, Aggregate Loss in Outside Wheelpath, August 1997

Figure 4.11: I-84, MP28 WB, Aggregate Loss in Outside Wheelpath, August 1999

Figure 4.12: I-84, MP28 WB, Aggregate Retention on Shoulder, August 1997

Figure 4.13: I-84, MP28 WB, Aggregate Retention on Shoulder, August 1999

Friction values for this section were consistent prior to and following the road work; the friction numbers taken soon after the fog seal were similar to those taken before the treatment. Values over time are shown in Table 4.6.

Table 4.6: Friction Values for Corbett-Multnomah Falls

	Eastbound	Westbound
Before fog seal	46.6	48.5
Immediately after fog seal	47.3	46.3
One year after treatment		46.9
Two years after treatment	44.0	
Three years after treatment		47.8
Four years after treatment	45.7	

A condition survey conducted by ODOT on September 17 and 18, 2001, concluded that, "Generally the surfacing looked good with minor raveling and bleeding. However, some areas of local distress or patching were found . . ." *(Brooks 2001 -- Corbett).* Table 4.7 presents a summary of distresses and patching observed. Figure 4.15 shows distress and patch in September 2001. Mill, inlay, and overlay are scheduled for 2005.

Table 4.7: Summary of Distresses and Patching, September 2001, I-84, MP 28-36.5

Lane	Milepost	Feature
Eastbound	28-36.5	Raveling , minor bleeding, fog seal no patches
Westbound	36.5	New pavement, F-mix
Westbound	31.7	Gouges
Westbound	31.05	60 m patch, rightt lane
Westbound	31.02	4 m patch, alligator
Westbound	30.05	Patch and rutting

Figure 4.14: Distressed and Patched F-mix at MP 28.6 WB, Looking West, September 2001

4.1.5 ORE 34 East of Corvallis

In 2001, the 5 km of ORE 34 immediately east of Corvallis that was fog-sealed in 1997 appears to have a more open surface texture than in 1997. Those confident of the value of fog seals would likely say that it is in need of another fog seal, but as of October 2001, none was planned.

Friction numbers for this section show the "recovery of friction" after a fog seal. The friction measurements after treatment indicate that comparable values can be seen within six weeks:

Table 4.8: Friction Values for Corvallis-Lebanon

	Eastbound
Before fog seal	43.0
Immediately after fog seal	25.1
Four days after treatment	29.0
Thirteen days after treatment	39.1
Three weeks after treatment	34.9
Six weeks after treatment	42.1
Ten months after treatment	46.5
Three years after treatment	45.1

4.1.6 Friction Values for Other Fog Seal Projects

Friction values for fog seal projects on other highway segments of US 20, I-5, and ORE 22 were obtained from ODOT Pavements Unit and are presented in Tables 4.9 to 4.11. The results show similar friction recovery numbers as noted previously.

Table 4.9: Friction Values for US 20 (MP 56.2 to 56.8)

	Eastbound
Before fog seal	47.7
Immediately after fog seal	18.0
Four days after treatment	22.4
Thirteen days after treatment	35.3
Three weeks after treatment	36.9
Six weeks after treatment	40.2
Eleven months after treatment	46.7
Three years after treatment	47.6

Table 4.10: Friction Values for I-5 (N. Grants Pass-Jumpoff Joe)

	Southbound	**Northbound**
Before fog seal	42.4	39.9
One month after fog seal	36.5	33.5
One year after treatment		42.8
Two years after treatment	43.1	

Table 4.11 Friction Values for ORE 22 (MP 3.0 to 5.0)

	Eastbound
Immediately after fog seal	24.7
Five days after treatment	30.4
Two weeks after treatment	35.9
Three weeks after treatment	39.9
Four weeks after treatment	42.8
Five weeks after treatment	49.7
Six weeks after treatment	46.9
Seven weeks after treatment	49.4

4.1.7 Fog Seals and Pavement Permeability

One of the reasons that ODOT does not do more fog-sealing is due to concern about reduced permeability. The author attempted to obtain useful permeability data, with little success. Although the idea was to measure permeability before and after a fog seal, the author became aware of fog seal projects only after the fact. Consequently, no opportunity presented itself to compare before and after permeability on the same pavement.

The best permeability data that could be obtained was at Tiller Junction on ORE 62. Travel lanes were fog-sealed in July 1998, but shoulders and turn pockets were not. In November, 1998, the author measured permeability on the shoulder and in the travel lane near MP 28.7 and just north of the entrance to the county park near MP 26.

The falling head permeameter described by Younger, Hicks, and Gower *(1994)* was used. This testing device is heavily influenced by pavement surface texture. A strip sealant was applied around the base of the device at its interface with the pavement in an attempt to overcome this limitation. In this study's interim report, the authors stated that, "the application of the weather-stripping has produced a field permeameter that produces valid and useful readings." *(Rogge and Hunt 1999).* However, additional experience subsequent to that report has changed the author's appraisal of the validity of the results. Although the use of the strip sealant is beneficial, it does not solve the problem for pavement surfaces with a high degree of aggregate loss. The author does not believe that an accurate *k* value (permeability coefficient) can be calculated; therefore, only the time required for the water level to fall between two fixed points in the permeameter is reported. The greater the length of time reported, the less permeable is the pavement.

On ORE 62, the median value for 16 permeability readings in the fog sealed travel lane was 38.5 seconds. The median value for 12 permeability readings on the non fog sealed shoulder was 36.8 seconds. Lower values indicate greater permeability, so the fog sealed travel lane was about 5% less permeable than the non fog sealed shoulder. It should be noted that shoulders generally are less permeable than travel lanes because they are not cleansed by changes in air pressure induced by tire passage. Though far from conclusive, this data seem to support the belief by maintenance personnel that fog seals contribute to reduction in porosity of porous pavements.

Table 4.12 is presented to put the ORE 62 permeability readings in perspective. All readings were taken with the same permeameter, but readings taken from 1998 used strip sealant around the base to control loss of water due to irregularities in the pavement, while the 1993 and 1994 readings did not. For comparison, permeability readings on dense-graded asphalt and concrete pavement using the same device with strip sealant produced essentially infinite time values.

Table 4.12: Permeability Readings of Oregon F-mix Using the Permeameter of Younger, et. al., 1994

Location and Time of Permeability Readings	Median (sec.)	# of Readings	Min. (sec.)	Max. (sec.)
Younger et. Al. 1993 shoulders	1.4	5	0.8	2.1
Younger et. Al. 1994 shoulders	1.4	3	0.9	1.7
Younger et. Al. 1993 travel lane	1.0	15	0.7	1.4
Younger et. Al. 1994 travel lane	1.0	9	0.8	1.7
New construction Joseph Street - Stayton NCL, 1998	2.4	3	1.6	2.8
New construction, Midland Jctn. - Cal. St. Line, 1998	0.3	13	0.2	0.3
Four months after new construction, Grants Pass - Applegate River, 1998	5.3	45	3.1	16.9
ORE 22, No Fog Seal, MP 18 shoulder, 1999	1.4	30	0.6	2.1
ORE 22, No Fog Seal, MP 18 travel lane, 1999	1.0	60	0.4	1.6
ORE 22, 2 years after fog seal, MP 3 shoulder, 1999	1.8	36	0.7	3.1
ORE 22, 2 years after fog seal, MP 3 travel lane, 1999	1.2	72	0.6	2.1
ORE 62, 8 years old, MP 23-29, travel lane 4 months after fog seal, 11/98	38.5	16	16.5	110.0
ORE 62, 8 years old, MP 23-29, shoulder and turn pockets, no fog seal, 11/98	36.8	12	17.8	275.0

The readings by Younger were taken on pavements ranging in age from less than a year to five years of age. Because of the small numbers of readings on diverse projects, the values are useful only for order-of-magnitude evaluation. The projects presented in the three rows below the Younger readings were tested as part of a separate F-mix compaction research project.

The next four rows present data for ORE 22 based on permeability measurements taken in 1999. At that time, the section around MP 18 west of Salem had not been fog sealed. The section near MP 3 had been fog sealed in May 1997. The pavements were constructed separately under different contracts, so differences due to fog seals can not be isolated. Slightly higher times are reported near MP 3 (fog sealed two years earlier) than near MP 18 (not fog sealed). Again, though not conclusive, the difference could support the hypothesis that fog seals reduce porosity.

The last two rows of the table present the previously described ORE 62 data from November 1998. The times reported for this location are much greater than any of the other readings. Possible explanations are operator error or perhaps, clogging by cinders in an area frequently subject to icing conditions. It should also be noted that rain was falling and the pavement was wet at the time these readings were taken. And while much greater than the other times recorded for F-mix, they do not begin to approach the nearly infinite value for dense-graded asphalt or concrete pavement. Even if the ORE 62 values have limitations, the comparison of non-fog sealed shoulder and turn pocket values to fog sealed travel lane values is likely to be valid.

4.2 CORRECTIVE APPLICATIONS

Surface maintenance and surface maintenance repairs were observed, and sometimes monitored over the life of the research project. Information obtained at selected locations is presented in this section to provide better documentation of F-mix distresses and repairs.

4.2.1 ORE 99W Between Lewisburg and Adair Village, North of Corvallis

This section of ORE 99W north of Corvallis received an F-mix overlay in the early 1990's. The overlay was a "maintenance" overlay and did not receive a pavement design. By 1997, numerous areas were experiencing distress including alligator cracking. During the summer of 1997, ODOT maintenance crews laid screed patches in the wheel-tracks at selected locations. Observations were made and photographs were obtained within weeks of the patching.

Figure 4.15 was photographed in July 1997. It shows unpatched alligator cracking distress (foreground) and newly patched screed patches in the background. Figure 4.16 shows a close up of the distress, and Figure 4.17 is a picture of the screed patches. Figure 4.18 is a 1999 image of the same area as taken in 1997 (Figure 4.17). More detail of the reflective cracks through the screed patch can be seen in Figure 4.19, as can the contrast between the screed patched northbound lane and the non patched southbound lane.

Figure 4.15: 1997 Distress and Screed Patch on ORE 99W near MP 77 NB

Figure 4.16: Close-up of Distress from Figure 4.15

Figure 4.17: Close-up of Newly Placed Screed Patches, 1997

Figure 4.18: Two-year Old Screed Patches at Same Location as Figure 4.17, 1999

Figure 4.19: Close-up of Two-year Old Screed Patches Compared to Non-patched SB Lane

In 1999, the section of highway between Lewisburg and Monmouth was milled and inlaid during the summer of 1999 (MP 63.89 to MP 79.80). This entire project was surfaced with F-mix, except for a three centerline mile section north of Coffin Butte, where B-mix was used. The section of B-mix presents the opportunity for a control section for monitoring of relative performance of B-mix and F-mix over time.

4.2.2 Screed Patch Procedure

Figure 4.20 illustrates the screed patching procedure. The dump truck deposits hot mix in front of a screed box which is mounted, in this case, on a front-end loader. The screed box deposits a uniform layer of paving material. The steel-wheeled roller compacts the mix, leaving the finished patch. Figure 4.21 shows the front view of the screed box, and Figure 4.22 shows a close-up of the screed box and the windrow left by the dump truck. This patch is being made on a dense-graded pavement, but the procedure is representative of screed patching procedures, which are essentially the same whether performed on dense-graded mix or F-mix.

Figure 4.20: Screed Patch Procedure Viewed from Behind the Equipment

Figure 4.21: Front View of Screed Box and Windrow

Figure 4.22: Close-up View of Screed Box and Windrow

4.2.3 ORE 99, MP 111 - 116, South of Junction City

The section of ORE 99 between Junction City and the Eugene Airport turn-off was also observed periodically. This pavement was originally constructed as a “modified B-mix” in 1979. This “modified B-mix” was a porous pavement that was a prototype for what became known as F-mix. Attempts to determine if and when the pavement had been fog-sealed over its life did not produce reliable information. It is known that the pavement has served well, and in 1997 was without patches.

A condition survey was undertaken in 1999. Table 4.13 documents all patches and major distresses between MP 111.0 and MP 116.7 on July 20, 1999, and references Figures 4.23 through 4.27. All of the patches were dense-graded patches. During the summer of 2000, the entire section was milled and inlaid resulting in an F-mix surface course.

Table 4.13: US 99 Distress and Patches, July 2000 (21-year Old F-mix)

Milepoint	Directions	Figure #	Distress or Repair
111.5	SB	4.28	Transverse crack
111.8	SB	4.29	Transverse & Longitudinal cracks and patch
111.9	SB		Small patch & rapidly deteriorating pavement
112.8	SB	4.30	Transverse & Longitudinal cracks and patch
114.1	SB	4.31	Extensive raveling
114.7	SB		Small patch
112.4	NB		Two small patches
112.2	NB	4.32	Cracking and patch
111.7	NB	4.33	Small patches in wheelpaths
111.1	NB	4.34	Multiple small patches

Figure 4.23: Transverse Crack on ORE 99 at MP 111.5 SB

Figure 4.24: Cracks and Patching on ORE 99 at MP 111.8 SB

Figure 4.25: Cracks and Patching on ORE 99 at MP 112.8 SB

Figure 4.26: Raveling on ORE 99 at MP 114.1 SB

Figure 4.27: Crack and Patch on ORE 99 at MP 112.2 NB

4.2.4 Plug Patches

Another common maintenance technique used by ODOT maintenance forces is referred to as a "plug patch," a small scale mill and inlay. Plug patches were observed on I-5 through Roseburg during the summer of 2001. Figure 4.28 shows a plug patch at least one year old. Figure 4.29 shows a nearby section that was to be plug patched shortly after the time of observation. Figure 4.30 shows distress at the edge of the plug patch of Figure 4.28. The ODOT maintenance representative indicated that problems of this nature are usually experienced at the interface between the dense-graded plug patch and the existing F-mix. Even though the patch extends well beyond the distressed area, this type of problem occurs. It is theorized that the plug patch creates a dam which holds water migrating through the pavement, which over time, leads to the distress shown. Figure 4.31 shows successful plug patches on ORE 42 near MP 58 eastbound.

Figure 4.28: Plug Patch on I-5 SB in Roseburg

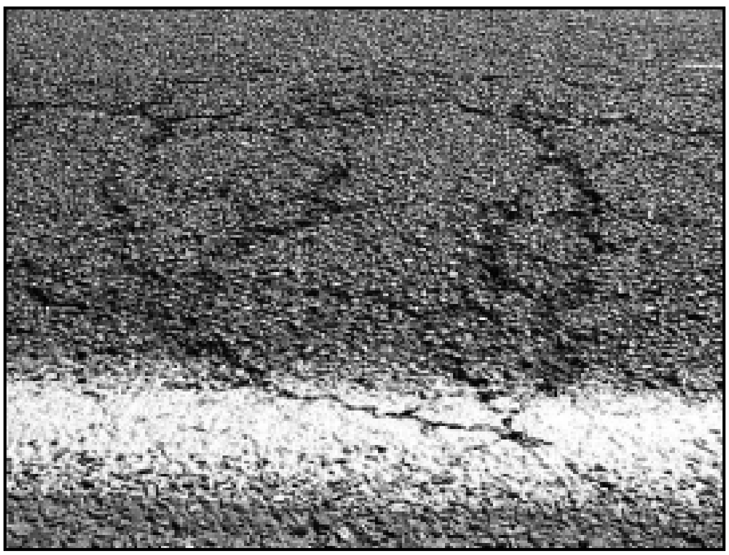

Figure 4.29: Distressed Pavement near Figure 4.28, Planned for Plug Patch Summer of 2001

Figure 4.30: Distress at North Edge of Figure 4.28 Plug Patch, which Occurred after Patch was Installed

Figure 4.31: Successful Plug Patch on ORE 42 near MP 58 EB, 2001

In the European literature on porous asphalts, Nicholls *(1997)* has some recommendations for plug patching. When plug patching with dense-graded material is used, it is recommended that the patch be formed in a diamond pattern (rotated 45 degrees from the direction of traffic). This should allow water flowing across the pavement to more easily flow around the patch and reduce the directness of wheel impact on the joint between the existing pavement and the patch.

4.2.5 Full-Width Inlays

Full-width inlays of F-mix for lengths adequate to justify F-mix production at the local asphalt plant apparently do not present problems. The outside lane shown in Figure 4.32 was milled and inlaid with F-mix about 5 years prior to the photograph being taken during the summer of 2001. These are the northbound lanes of I-5 just north of Roseburg.

Figure 4.32: Full-width, 1.6 Km (approx.) Inlay of Outside Lane with F-mix, I-5 NB in Roseburg

4.2.6 Repair of Stud Rutting and Other Distress in ODOT District 10

Studded tire rutting was listed in the 2001 survey as the number one distress experienced by F-mix pavements. ODOT's District 10, located in the high desert area of central Oregon, has developed a procedure for repairing stud-rutted sections of F-mix that they consider successful. Figure 4.33 shows an example of stud rutting in this area at MP 150.2 SB in July 1999, just prior to repair. Figure 4.34 shows a nearby area near MP 150 SB in 2001, two years after repair.

Figure 4.33: Stud Rutting on US 97 near Bend at MP 150.2 SB, July 1999, Prior to Repair

Figure 4.34: Repair of Nearby Stud Rutted Area after Two Years of Traffic

The repair is a full lane-width repair performed with a modified grader that the maintenance personnel call a Barber Orange *(Hunt 1999)*. The equipment observed in 1999 was built in 1998. It includes a blade with adjustable wings that allows the material placement width to vary from 1.8 to 4.25 m. Figure 4.35 shows the modified blade engaging a windrow of ODOT C mix.

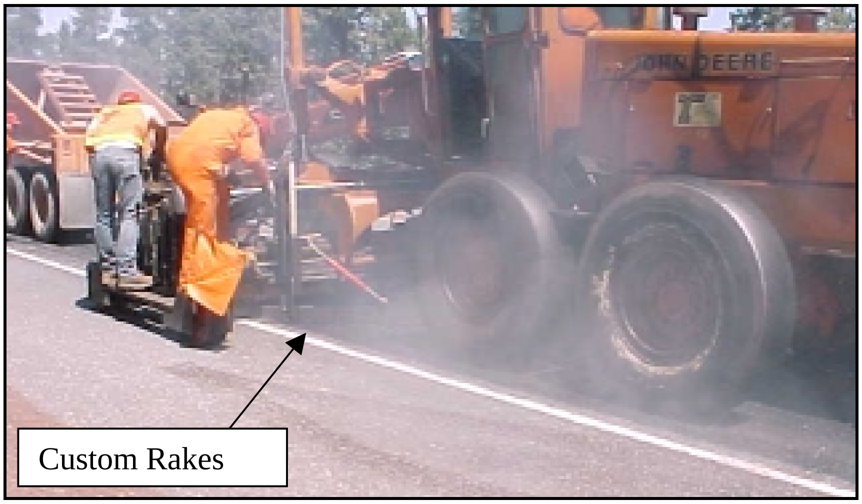

Figure 4.35: ODOT's "Barber Orange"

Because workers would not be able to keep up, rakes are attached behind the blade to move the looser material onto the panel (Figure 4.36). Prior to placing the hot mix, a tack coat was applied using an emulsion, HFE-90-1S, as the tack. Asphalt was deposited in front of the modified grader with a belly dump or end dump truck . The hot mix was leveled and spread over the lane width to an average depth of 12.5 mm by the modified grader.

Figure 4.36: Custom Rakes behind the Blade

A steel wheeled roller followed the grader to compact the material (Figure 4.37). Figure 4.38 shows the full outside lane width repair being rolled, adjacent to the unrepaired passing lane near MP 149.5 southbound. The repair was completed with application of a 6.25 mm-2.08 mm chip seal.

Figure 4.37: Compaction with Steel-Wheeled Roller

Figure 4.38: Outside Lane Repair and Unrepaired Passing Lane, US 97 approx. MP 149.5 SB, July 1999

Although this repair was developed to address the stud rutting problem, it is used for various distresses, on both dense-graded asphalt pavement and F-mix. Figure 4.39 shows deteriorated pavement near MP 148.4 southbound prior to repair in July 1999. Figure 4.40 shows approximately the same location in September 2001, two years after repair. The reflective cracking is not surprising considering the severity of the distress prior to the repair. At the time of the repair, ODOT maintenance estimated a 3-year life for the repair.

Figure 4.39: F-mix Distress at MP 148.4 SB prior to July 1999 Repair

Figure 4.40: MP 148.4 SB Condition after Two Years

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations for preventive maintenance, corrective surface maintenance, and winter maintenance are presented in sections 5.1 through 5.3. Conclusions and recommendations for collection of data regarding cost and life of maintenance treatments on different pavement surfaces are presented in section 5.4. Section 5.5 addresses miscellaneous topics.

5.1 PREVENTIVE MAINTENANCE

5.1.1 Conclusions for Preventive Maintenance

Fog seals and chip seals were identified as preventive maintenance alternatives for F-mix. Fog seals as a preventive maintenance technique appeal to many because of their relative speed and low cost. Unfortunately, no definitive studies have been conducted to establish the value of fog seals for porous pavements. In fact, the only comprehensive study of fog seals that could be found was done at Texas A&M University *(Estakhri and Agarwal 1991)*, and was limited to dense-graded asphalt pavement and chip seals. The study proved inconclusive for dense-graded asphalt, but the authors of the study concluded that fog seals were beneficial for chip seals if applied at the correct rate, and if applied before the first winter season after installation. Neither open-graded friction courses nor porous pavements were included in the study.

Conclusions regarding preventive maintenance are as follows:

1. Expected benefits of fog seals to prolong the life of porous asphalt pavements have not been substantiated with quantitative studies.
2. It is likely that fog seals prolong the life of porous asphalt pavements, at least marginally, by providing a small measure of non-aged asphalt to the surface of the mix.
3. Fog seals are likely to reduce the permeability of F-mix, although permeability measurements made during the research project indicate that the pavements still retain porosity. The rough surface texture is retained, maintaining reduced potential for hydroplaning.
4. Although fog seals are fast and economical, lane closure for a minimum of one-half day is required, creating traffic control challenges for two-lane roads, or high-volume four-lane roads.
5. The application of a fog seal does not affect the aggregate interlock of the F-mix. Thus, the pavement still retains its load related rut resistance qualities.
6. Fog seals reduce pavement friction immediately after application. Friction increases significantly in the first month as the fog seal is worn by traffic.
7. Most of the fog seals of F-mix during the four-year study were really corrective in nature rather than preventive. Installed F-mix had been underasphalted, or was experiencing raveling and/or other distress. The fog seal was viewed as a way to make up for the

asphalt shortfall or as a last ditch effort to hold the pavement together. Expectations for fog sealing may have been unrealistically high.

8. Chip seals are more expensive than fog seals. They more completely seal the surface, essentially eliminating the porous feature of porous pavements. Although the problem of reduced pavement friction immediately after application is avoided, problems of fly rock may result. Emulsion chip seals are more widely used within ODOT than are "hot asphalt" chip seals, and were rated more successful in the maintenance supervisor survey.

5.1.2 Recommendations for Preventive Maintenance:

1. Quantitative data regarding the effectiveness of fog seals should be obtained. There are several options:
   a) A sealer/rejuvenator pilot study is being funded jointly by the National Center for Asphalt Technology, the Foundation for Pavement Preservation, the Arizona Department of Transportation, and the Federal Highway Administration *(Foundation for Pavement Preservation 2001).* It will ultimately consist of test sections in approximately eight states. The study, starting in the spring of 2002, is intended to evaluate the effectiveness of sealers and rejuvenators in preserving a pavement's service life. The study will include dense-graded asphalt, chip seals, and at least one test section of traditional open-graded friction course. Tests of porous pavements such as Oregon F-mix are not part of the study. ODOT should investigate participating in the study. This is recommended as the first choice for determining the cost-effectiveness of fog seals.

   b) A study of fog seal effectiveness could be conducted by ODOT with specifically constructed test and adjacent control sections on F-mix pavements that are still in relatively good shape.

2. When it is acceptable to abandon the free-draining nature of the F-mix, and pavement structure is good, a chip seal may be applied as a cost-effective treatment for rehabilitating the pavement surface and extending the life of the pavement.

5.2 CORRECTIVE SURFACE MAINTENANCE

5.2.1 Conclusions

According to ODOT maintenance supervisors, the six approaches for surface maintenance of F-mix judged to be somewhat successful to completely successful, listed in descending order from most successful are:

a) Machine patch with C-mix
b) Mill and inlay with F-mix
c) Machine patch with B-mix
d) Mill and inlay with C-mix
e) Screed patch with C-mix
f) Blade patch with C-mix

5.2.2 Recommendations

Recommendations for corrective surface maintenance are as follows:

1. The goal should be to mill, recycle, and inlay at the end of a pavement's service life, before substantial funds are expended on extensive patching. This is the philosophy for open-graded friction courses as espoused by Departments of Transportation in Florida and Georgia *(Rogge and Hunt 1999)*. This is also the preferred approach for the Netherlands *(Van Der Zwan 1990).*
2. When repair is necessary, ideal repair, where adequate base exists, is to mill and inlay F-mix. Where required quantities are small, such repair may not be economical, or even possible, due to difficulty in obtaining small quantities of F-mix. When this is the case, repair with dense-mix is the logical choice. If roadway geometry is such that the inlay with dense mix will trap water in the pavement or subgrade, surface maintenance by machine patch, blade patch, or screed patch is preferred. Any of these techniques should allow water to continue to flow through the F-mix pavement underneath, unless the F-mix has completely raveled away.
3. When plug patches with dense-graded mix are required, ODOT should experiment with rotating the patch up to 45 degrees to a diamond appearance to facilitate subsurface flow past the patch and to reduce the directness of wheel impact on the joint between the existing pavement and the patch. This approach has been reported to be successful in the UK *(Nichols 1997).*

5.3 WINTER MAINTENANCE

5.3.1 Conclusions

Conclusions regarding winter maintenance are as follows:

1. F-mix and other porous pavements freeze sooner as air temperatures fall below freezing, and stay frozen longer because of the reduced thermal conductivity of porous pavements *(Huber 2000).*
2. F-mix and other porous pavements generally require larger amounts of de-icing chemicals than dense-graded asphalt pavements. The porous nature of the pavement means that the deicers flow down into the pavement rather than staying at the surface.

5.3.2 Recommendations

Recommendations for winter maintenance are as follows:

1. ODOT should provide information to responsible maintenance personnel on the different behavior of F-mix when temperatures are near or below freezing.
2. An organic deicer that is more viscous than current deicers is commercially available in most of the United States. No one at ODOT reports using it. Since the product is more viscous, it is possible that it might be retained on the surface of the F-mix for a longer period of time. A trial is recommended.
3. ODOT should investigate electrostatic charge technology (as employed with emulsified asphalts) as a way of bonding de-icer to the surface of F-mix.

5.4 RECOMMENDATIONS FOR USE OF COMBINED DATA FROM ODOT'S PAVEMENT MANAGEMENT SYSTEM AND MAINTENANCE MANAGEMENT SYSTEM.

ODOT's pavement management system provides information on pavement condition, and pavement cost. It is possible to compute equivalent annual costs per lane mile based on construction and overlay costs, and pavement life. For pavement surface maintenance activities, ODOT's maintenance management system collects data on costs of maintenance activities by milepoint. The potential exists to combine information from both systems to make more informed decisions based on the total cost of construction and maintenance for ODOT pavements.

Early in the research, opinions were expressed by some ODOT maintenance personnel that, compared to repairs of dense-graded asphalt mix, blade patches and other surface maintenance techniques are more difficult for F-mix, and did not last as long as when performed on F-mix. Because the maintenance management system does not produce reports of quantities and costs of materials, labor, and equipment by area of pavement surface, or by length of highway between beginning and ending milepoint, there was no practical way to verify or refute these opinions.

It appears that a little modification of the maintenance management system, including a more definitive entry of location of maintenance activities, could result in a large, comprehensive database of quantities, costs, and areas repaired for all surface maintenance activities by all ODOT maintenance crews statewide. This database would provide the opportunity for statistical determination of unit costs. A database of this type would provide the information needed to answer questions, such as:

- How does the cost per square meter of blade patch on dense-graded asphalt pavement compare to the unit cost for blade patching F-mix? and
- What is the average life of a blade patch on both surfaces?

Currently, such information is available only through survey of maintenance managers' opinions. Over time, the improved system would allow ODOT engineers and managers to determine the service lives of maintenance activities, on average and for specific highway locations. It is possible that the equivalent annual cost for surface maintenance being expended for a specific section of a highway could exceed the equivalent annual cost for a reconstruction. In making decisions about pavement design, ODOT engineers and managers would know the total cost of construction and maintenance, allowing the most informed decisions possible.

5.5 OTHER RECOMMENDATIONS

1. ODOT should follow the development of porous pavement practices in Europe through the literature and the internet. Porous pavement has been used longer and more extensively in Europe than in the U.S.
2. If one day funding would allow, or if FHWA sponsors an international scanning tour of pavement maintenance practices, ODOT should consider sending representatives to visit Europe to see first-hand how European agencies design, construct, and maintain porous pavements. The Road and Hydraulic Engineering Division of the Directorate-General for Public Works and Water Management in the Netherlands has offered to host a visit. The Netherlands use porous pavement as the preferred pavement surface for their highway network, and climatic conditions are similar to western Oregon. The strategy of the Dutch is to prolong the life through improved design and construction, and mill and inlay using recycled material at the end of the pavement life.
3. If further maintenance research is undertaken, a "champion" for the research should be identified from ODOT to command the attention of, and coordinate, the input of ODOT's diverse maintenance forces.

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