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Performance of Preventive Maintenance Treatments of Flexible Pavements

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Abstract: Actual pavement performances of various rehabilitation strategies for flexible pavements were evaluated using Long-Term Pavement Performance (LTPP) distress data. Forty-eight flexible pavement sections were selected from the southern region of the United States. The Specific Pavement Studies (SPS-3) section of the LTPP database was utilized to study the effectiveness of various preventive maintenance strategies based on performance. In order to assess the rank and effectiveness of preventive maintenance treatments, three primary performance factors; average rate of distress acceleration; average duration of fix; and average distress measure were lumped together to get an overall performance factor of pavement section. The ranking based on overall performance showed that the chip seal had the highest and the crack seal had the lowest performance factors. Although, there was no direct relationship between the pavement condition index and the overall performance factor the ranking of the treatments was consistent using both the indices. The ranking results were confirmed by the pavement condition index, commonly used by the Department of Transportation. This study indicates the significance of the effective use of the LTPP distress data and provides a robust technique to evaluate the performance of various rehabilitation actions. Thus, allowing the state highway agencies to choose rehabilitation alternatives that best suit their needs based on the actual pavement performance.

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Key words: *Chip seal; Flexible pavement; LTPP; Pavement performance; Preventive maintenance.*

Introduction

In recent years, the focus of federal and state agencies has shifted from design and construction of new roads to timely preventive maintenance and rehabilitation of the existing pavements. The pavement maintenances generally used are preventive and corrective. The former is applied at the initial stage and the later at the extensive stage of pavement deterioration. The preventive maintenance is recognized as more cost effective than the corrective.

The preventive maintenance treatments that are usually used include: crack seal, slurry seal, fog seal, chip seal, micro-surfacing and thin overlay. The type of treatment applied largely depends on the distresses and distress level that need to be taken care of for the treatment to be effective. For example, the crack sealing is effective when low to moderate cracks of the fatigue, longitudinal, and/or transverse type is encountered. Micro-surfacing is highly recommended as filler and minor leveling but not very effective for medium to high severity cracking [1]. The cost-effectiveness of the preventive treatment is based on their timely application and is mainly derived from agency's observational experience [2]. Little literature is available on the effectiveness of preventive maintenances based on the performance data. Eltahan et al [3] used the concept of survival analysis and evaluated the survival time for various sections of Long-Term Pavement Performance (LTPP) data base for maintenance treatment. The results showed that for 6 years pavement performance data the chip seal outperformed thin overlays, slurry seals and crack seals, in controlling the reappearance of distresses. It should be noted here that survival time for significant number of sections could not be estimated due to good conditions at the time of last survey. Lin et al [4] evaluated the preventive maintenance effectiveness of flexible pavements (SPS-3) sections of LTPP in Texas and concluded that the thin overlay was the best treatment to resist rutting and should be used on high traffic routes due to its high initial cost. The chip seal had the most sections that performed well and crack seal provided the best alternative for low traffic routes with sound pavement structure due to its low initial cost.

The expected treatment life of a chip seal can vary significantly (3 to 12 years). Based on a survey done by Gransberg and James [5], it seems that the average performance of chip seals in the USA (5.76 years) is poor than that of overseas (10 years); although it is not clear whether the data was qualitative or quantitative in nature. Australia and UK reported the use of chip seals in pavement on about 273,000 and 213,000 lane-miles respectively, which is way above the reported 140,000 lane-miles used by the USA. Only a few states (California, Colorado, and Montana) use chip seals if the ADT is greater than 20,000, whereas it is commonly used in the UK. In the State of Louisiana, the preventive maintenance program involves the use of chip seal and micro-surfacing. A recent study by Shashlkant [1] showed that the median Pavement Condition Indices (PCI) of chip seal and micro-surfacing sections are about 75 and 85 respectively, after about 52 to 60 months of service (PCI: 100-86 = Excellent, 85-71= Very Good, ….. 10-0 = failed). About 70 percent of chip seal sections were in good condition and likewise, most of the micro-surfacing were in good to excellent conditions. Chip seal sections showed bleeding in 70 percent of the sections. This bleeding was due to combination of factors relative to loss of aggregate, additional embankment and/or excess asphalt. However, most skid numbers were in the safe range.

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According to FHWA [6], the performance life of a treatment is influenced by the amount of crack preparation and the type of material used. Crack sealants can provide a life up to nine years depending on the amount of preparation and material used. According to 11 projects in 4 states, application timing ranges from 1 to 38 years, with a service life of up to 4 years [7]. Other studies indicate an extended pavement life or two to six years when a crack seal is applied when the pavement condition ranged from good to fair [8]. Research conducted in Minnesota determined that crack sealing can reduce the roughness of the road and the height of tented cracks [9]. Yut et al. [8], found that crack sealing early in the life of the pavement resulted in a significant increase in the life of the pavement, delayed major rehabilitation and dramatically decreased costs as compared with thin overlay treatment. An analysis of Kentucky roads and the practices of pavement preservation in other states suggest a schedule of preservation treatments can greatly reduce costs as well as systematically improve the quality of roads in Kentucky [10]. Pavement tenting occurs in localized sections of a roadway which undergoes heaving at pavement cracks or joints during winter weather in cold regions. It was determined that crack sealing greatly reduced the severity of pavement tenting [9].

In Arkansas, Kansas and Pennsylvania, rutting returned in 3 to 5 years after micro-surfacing treatment. On the other hand, in the state of Pennsylvania friction loss of 50% occurred in 5 years for micro-surfacing treatment. It must be noted that the treatment life was based upon observation and professional assessment, not quantitative analysis of the condition. California reports a micro-surfacing treatment life of 7 to 10 years [11]. Smooth joints, edges and shoulders can be difficult to achieve due to the quick breaking of the micro-surfacing slurry. This takes skill to perform correctly and possibly by hand-working the slurry [11]. State of Indiana reported an extension of approximately three years [12]. According to Peshkin and Hoerner [13], the Michigan Department of Transportation recommends a life extension of 3 to 5 years for single course micro-surfacing and 4 to 6 years for multiple course micro-surfacing application.

Objective of the Study

The objectives of the study are:

1. Evaluate the LTPP distress data for preventive maintenance of flexible pavements.
2. Quantify the effectiveness of the various preventive maintenance strategies based on actual pavement performance.

Data Source and Pavement Sections

The LTPP data especially preventive maintenance effectiveness of flexible pavements (SPS-3) focuses on the effectiveness and performance of the flexible pavement after application of treatments. The specific pavement studies (SPS) data were developed to investigate the effects of specific design and rehabilitation features on performance, for this reason the data available from these sections were analyzed with consideration of the factors included in the paper. The LTPP data release 11.5 version NT 3.0 was used in this study. Approximately, 271 sections were downloaded from LTPP database, 127 SPS-3 sections were analyzed for the states of Arkansas, Alabama, Texas, Louisiana, Florida, Georgia and Mississippi. Finally, 48 sections were selected that provided good record of pavement performance over the past ten years. It should be noted that the final selected sections consist of the performance data for alligator, longitudinal and transverse cracks. The summary of the selected sections is listed in Table 1.

Data Analysis

To assess the rank and effectiveness of preventive maintenance following five performance factors were evaluated.

1. Average duration of fix (F_f).
2. Average slope of distress (F_s).
3. Average distress measure (F_d).
4. Overall performance factor (F_o).
5. Pavement condition index (*PCI*).

The distress data in terms of high, medium and low severity for transverse, longitudinal and alligator cracks were extracted along with the data collection date using the SPS-3 module. For simple analysis each distress severity was summed up and plotted as a function of time in days [14]. Fig. 1 shows a typical plot of transverse cracks as a function of time for section 48-L320. Best-fit curves using linear, polynomial and exponential function were obtained using the MS Excel regression option. The best-fit curve that established the high R^2 was selected for further analysis. Fig. 1 shows the polynomial function as it represents highest R^2 of all the curves. Similar plots and best- fit functions were obtained for longitudinal and alligator cracks. The average duration of fix (F_f) was obtained by taking the second derivative of the regression equation and setting it to zero and solving for **"x".** Similarly, the average slope of distress (F_s) was obtained by substituting F_f value into the first derivative of the equation and solving for **"y".** Next by substituting the value of F_f in the regression equation would give the average distress measure (F_d). The F_s and F_d represent rate of acceleration and critical range of distress respectively [14].

To calculate the overall performance factor (F_o), the effects of each of the three average performance measures were first determined. In order to account for the total effect of the transverse, longitudinal and alligator cracks, following combined measures were implemented. Simple normalizing and averaging procedures were adopted to accomplish the combined effect as shown in the following equations:

Average Normalized Duration of Fix:

$$\left(F_f\right)_n = \left[\frac{\left(F_f\right)_t}{\left(F_f\right)_{tt}} + \frac{\left(F_f\right)_l}{\left(F_f\right)_{lt}} + \frac{\left(F_f\right)_g}{\left(F_f\right)_{gt}}\right] \div 3 \tag{1}$$

Average Normalized Slope Measure:

$$\left(F_s\right)_n = \left[\frac{\left(F_s\right)_t}{\left(F_s\right)_{tt}} + \frac{\left(F_s\right)_l}{\left(F_s\right)_{lt}} + \frac{\left(F_s\right)_g}{\left(F_s\right)_{gt}}\right] \div 3 \tag{2}$$

Average Normalized Distress Measure:

$$\left(F_d\right)_n = \left[\frac{\left(F_d\right)_t}{\left(F_d\right)_{tt}} + \frac{\left(F_d\right)_l}{\left(F_d\right)_{lt}} + \frac{\left(F_d\right)_g}{\left(F_d\right)_{gt}}\right] \div 3 \tag{3}$$

Table 1. Summary of the Selected Sections for the Study.

State	State Code	SHRP ID	Maintenance Type	Climatic Region
Alabama	1	A320	Slurry Seal	Wet Freeze
	1	B320	Slurry Seal	Wet Not Freeze
	1	C320	Slurry Seal	Wet Not Freeze
	1	A330	Crack Seal	Dry Not Freeze
	1	C330	Crack Seal	Wet Not Freeze
	1	A350	Chip/Agg Seal	Wet Not Freeze
	1	C350	Chip/Agg Seal	Wet Not Freeze
Arkansas	5	A320	Slurry Seal	Wet Not Freeze
Florida	12	A320	Slurry Seal	Wet Freeze
	12	B320	Slurry Seal	Wet Not Freeze
	12	C320	Slurry Seal	Wet Not Freeze
	12	A330	Crack Seal	Wet Not Freeze
	12	B330	Crack Seal	Wet Not Freeze
	12	C330	Crack Seal	Wet Not Freeze
	12	A350	Chip/Agg Seal	Wet Not Freeze
	12	B350	Chip/Agg Seal	Wet Not Freeze
	12	C350	Chip/Agg Seal	Dry Not Freeze
	28	A320	Slurry Seal	Wet Not Freeze
Mississippi	28	A330	Crack Seal	Dry Not Freeze
	28	A350	Chip Seal	Wet Not Freeze
	48	B320	Slurry Seal	Wet Not Freeze
Texas	48	D320	Slurry Seal	Wet Not Freeze
	48	E320	Slurry Seal	Wet Not Freeze
	48	F320	Slurry Seal	Wet Not Freeze
	48	H320	Slurry Seal	Wet Not Freeze
	48	K320	Slurry Seal	Wet Not Freeze
	48	L320	Slurry Seal	Wet Not Freeze
	48	M320	Slurry Seal	Wet Not Freeze
	48	Q320	Slurry Seal	Wet Not Freeze
	48	3749	Patch Seal	Wet Not Freeze
	48	3835	Patch Seal	Wet Not Freeze
	48	1039	Patch Seal	Wet Freeze
	48	1056	Patch Seal	Wet Not Freeze
	48	1065	Patch Seal	Dry Not Freeze
	48	1068	Patch Seal	Wet Not Freeze
	48	1076	Patch Seal	Wet Not Freeze
	48	1077	Patch Seal	Wet Not Freeze
	48	1087	Patch Seal	Wet Not Freeze
	48	D330	Patch Seal	Wet Not Freeze
	48	D330	Crack Seal	Wet Not Freeze
	48	H330	Crack Seal	Wet Not Freeze
	48	L330	Crack Seal	Wet Not Freeze
	48	Q330	Crack Seal	Wet Not Freeze
	48	D350	Chip Seal	Wet Not Freeze
	48	L350	Chip Seal	Wet Not Freeze

After determining the combined performance factors the overall performance factor was calculated using the following equation:

Overall Performance Factor:

$$F_0 = \lfloor (F_f)_n' + (F_s)_n + (F_d)_n \rfloor \div 3 \tag{4}$$

where,

$(F_f)_{t,l,g}$ = average duration of fix for transverse, longitudinal and alligator cracks, respectively.

$(F_s)_{t,l,g}$ = average slope of regression curve for transverse, longitudinal and alligator cracks, respectively.

$(F_d)_{t,l,g}$ = average critical distress measure for transverse, longitudinal and alligator cracks, respectively.

$(F_f)_{tt,lt,gt}$ = total average duration of fix for transverse, longitudinal and alligator cracks for all the sections used in the analysis, respectively $(F_s)_{tt,lt,gt}$ = total average slope of curve for transverse, longitudinal and alligator cracks for all the sections used in the analysis, respectively.

$(F_d)_{tt,lt,gt}$ = total average critical distress measure for transverse, longitudinal and alligator cracks for all the sections used in the analysis, respectively.

$(F_d)_{tt,lt,gt}$ = total average critical distress measure for transverse, longitudinal and alligator cracks for all the sections used in the analysis, respectively.

$(F_f)_n^{/}$ = complementary value of F_f

The lowest value of average slope and average distress measure indicates best performance. However, lowest value of average duration of fix reflects worst performance. Therefore, the $(F_f)_n^{/}$ value was used instead of F_f to ensure that all rankings were from best to worst in ascending numerical order [14].

The pavement condition index (PCI) is basically a ranking tool. Although, there is no consensus in the highway agencies on the standard PCI, it ranks the inspected pavement from bad to excellent (0 to 100). The PCI calculation is based on the deduct points that in turns is a function of distress weight factor, severity and extent level of various distresses with in a pavement section. The following equation was used for the analysis [1]:

$$PCI = 100 - TDP \tag{5}$$

$$TDP = \Sigma[(DWF)(SWF)(EWF)] \tag{6}$$

where,

TDP = total deduct points

DWF = distress weight factor

SWF = severity weight factor

EWF = extent weight factor.

Table 2 shows the summary of distress, severity, and extent weight factors for calculating the total deduct points for a pavement section. For example, if a pavement section has an alligator cracking with severity level of 1/8" and extent between 10-30% than the deduct point for alligator cracking is calculated as (15 x 0.6 x 0.8= 7.2). Similarly, the deduct points for each distress types within the pavement section is calculated and summed up to determine the total deduct point for calculating PCI (Eqs. (5) and (6)).

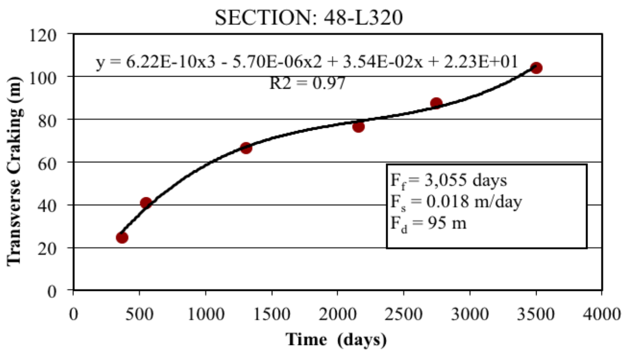

Fig. 1. Typical Plot for the Determination of F_f, F_s and F_d.

Results and Discussion

Four preventive maintenance treatments for flexible pavements: slurry seal, crack seal, chip/aggregate seal and patch seal were evaluated using the above performance factors. The results are shown in Tables 3 through 9. Recall, based on good performance and historical data total of 48 pavement sections from southern region of United States were selected using LTTP database. The distribution of the selected sections for the treatments is shown in Fig. 2. The sections for slurry seal, crack seal, chip seal and patch seal constitute of 35, 23, 21, and 21 percent, respectively, of the total selected sections for the study.

Table 3 shows the summary of the results of average duration of fix (F_f) for four preventive maintenance treatments. The table was sorted based on the treatments and then the normalized average duration of fix $(F_f)_n$ values were ranked in descending order for each individual treatment. It should be noted that the higher $(F_f)_n$ value indicates best performance. It can be seen from the table that the $(F_f)_n$ for patch seal exhibits the lowest value of 0.87 with a standard

Table 2. Summary of Distress Level, Severity Level, and Extent Level Weight Factors for Various Distress Types.

Distress Type	Weight Factor	Severity Level				Extent Level			
		None	Low	Medium	High	None	Low	Medium	High
Longitudinal/ Transverse Cracking	20	None	<1/4"	1/4"	>1/4"	None	<10%	10-30%	>30%
		0.1	0.2	0.6	1.0	0.1	0.4	0.58	1.0
Alligator Cracking	15	None	<1/8"	1/8"	>1/8"	None	<10%	10-30%	>30%
		0.1	0.2	0.6	1.0	0.1	0.4	0.8	1.0
Edge Cracking	10	None	<1'	1-2'	>2'	None	<10%	10-30%	>30%
		0.1	0.2	0.6	1.0	0.1	0.4	0.8	1.0
Patch/ Pothole	10	None	Small	Medium	Large	None	<5/1000'	(5-10)/1000'	>10/1000'
		0.1	0.2	0.6	1.0	0.1	0.4	0.8	1.0
Rutting	10	<1/4"	1/4-1/2"	1/2-1"	>1"				
		0.1	0.3	0.7	1.0				
Aggregate Loss	10	None	Small	Medium	Large	None	<5/1000'	(5-10)/1000'	>10/1000'
		0.1	0.3	0.8	1.0	0.1	0.5	0.8	1.0
Bleeding	10	None	Slight	Moderate	Severe	None	<10%	10-30%	>30%
		0.1	0.6	0.8	1.0	0.1	0.6	0.8	1.0
Roughness	15	Good	Fair	Poor					
		0.2	0.6	1.0					

Table 3. Summary of Average Duration of Fix (F_f) for Various Preventive Maintenance of Flexible Pavements.

State Code	SHRP ID	Maintenance Type	Duration of Fix Alligator	Duration of Fix Longitudinal	Duration of Fix Transverse	Normalized Duration of Fix Alligator	Normalized Duration of Fix Longitudinal	Normalized Duration of Fix Transverse	Average Normalized Duration of Fix	Remarks	
48	L320	Slurry Seal	1731	1482	3055	1.457	1.322	2.426	1.73	Sections	17
1	C320	Slurry Seal	1118	NA	2600	0.941	-	2.064	1.50	Average	1.0
48	B320	Slurry Seal	2200	1744	940	1.851	1.556	0.746	1.38	St. Dev.	0.35
1	A320	Slurry Seal	1800	1352	1709	1.515	1.206	1.357	1.36	CV	35
5	A320	Slurry Seal	1667	1667	1111	1.402	1.487	0.882	1.26	Rank	2
48	K320	Slurry Seal	833	1667	1429	0.701	1.487	1.134	1.11		
1	B320	Slurry Seal	1325	1129	-	1.115	1.007	-	1.06		
48	Q320	Slurry Seal	1111	1333	833	0.935	1.190	0.662	0.93		
12	A320	Slurry Seal	1111	1333	778	0.935	1.190	0.617	0.91		
12	C320	Slurry Seal	1111	1100	1000	0.935	0.981	0.794	0.90		
28	A320	Slurry Seal	222	1111	1875	0.187	0.991	1.489	0.89		
48	F320	Slurry Seal	1003	763	1132	0.844	0.681	0.899	0.81		
12	B320	Slurry Seal	1111	NA	778	0.935	-	0.617	0.78		
48	D320	Slurry Seal	-	-	833	-	-	0.662	0.66		
48	H320	Slurry Seal	950	437	1000	0.799	0.390	0.794	0.66		
48	E320	Slurry Seal	833	500	500	0.701	0.446	0.397	0.51		
48	M320	Slurry Seal	556	-	667	0.467	-	0.529	0.50		
48	L330	Crack Seal	3125	3750	1000	2.629	3.346	0.794	2.26	Sections	11
1	A330	Crack Seal	1700	-	3191	1.430	-	2.534	1.98	Average	1.15
48	Q330	Crack Seal	-	1333	2500	-	1.190	1.985	1.59	St. Dev.	0.57
12	A330	Crack Seal	1429	1333	1333	1.202	1.189	1.059	1.15	CV	49
48	H330	Crack Seal	-	1667	952	-	1.487	0.756	1.12	Rank	1
1	C330	Crack Seal	952	-	1580	0.801	-	1.255	1.03		
48	D330	Crack Seal	-	917	1500	-	0.818	1.191	1.00		
12	B330	Crack Seal	1111	-	833	0.935	-	0.661	0.80		
28	A330	Crack Seal	1333	30	1333	1.122	0.027	1.059	0.74		
12	C330	Crack Seal	333	667	833	0.280	0.595	0.662	0.51		
12	C330	Crack Seal	333	667	833	0.280	0.595	0.661	0.51		
28	A350	Chip Seal	-	1111	3333	-	0.991	2.647	1.82	Sections	10
48	L350	Chip Seal	-	-	1923	-	-	1.527	1.53	Average	0.92
12	C350	Chip/Agg Seal	-	1250	1667	-	1.115	1.323	1.22	St. Dev.	0.51
1	A350	Chip/Agg Seal	1667	-	1111	1.402	-	0.882	1.14	CV	55
12	A350	Chip/Agg Seal	1150	333	1667	0.968	0.297	1.323	0.86	Rank	3
1	C350	Chip/Agg Seal	-	-	952	-	-	0.756	0.76		
1	C350	Chip Seal	-		950	-	-	0.754	0.75		
12	B350	Chip/Agg Seal	700	-	-	0.589	-	-	0.59		
48	D350	Chip Seal	-	556	167	-	0.496	0.132	0.31		
12	A350	Chip Seal	2323	344	188	-	0.307	0.149	0.23		
48	1087	Patch Seal	-	1451	1548	-	1.295	1.229	1.26	Sections	10
48	3749	Patch Seal	1741	-	1005	1.465	-	0.798	1.13	Average	0.87
48	3835	Patch Seal	176	1796	1926	0.148	1.603	1.529	1.09	St. Dev.	0.26
48	1068	Patch Seal	1427	946	1124	1.201	0.844	0.892	0.98	CV	29
48	1039	Patch Seal	1070	962	1003	0.900	0.858	0.796	0.85	Rank	4
48	1065	Patch Seal	-	1161	808	-	1.036	0.642	0.84		
48	1076	Patch Seal	1020	891	951	0.858	0.795	0.755	0.80		
48	D330	Patch Seal	-	811	839	-	0.724	0.666	0.69		

Table 3. (Continued)

State Code	SHRP ID	Maintenance Type	Duration of Fix Alligator	Duration of Fix Longitudinal	Duration of Fix Transverse	Normalized Duration of Fix Alligator	Normalized Duration of Fix Longitudinal	Normalized Duration of Fix Transverse	Average Normalized Duration of Fix	Remarks
48	1077	Patch Seal	823	966	312	0.692	0.862	0.248	0.60	
48	1056	Patch Seal	500	667	333	0.421	0.595	0.265	0.43	
Total Average			1188	1121	1259	0.972	1.000	1.000	0.99	
Total Standard Deviation=			620	636	736	0.502	0.567	0.584	0.43	

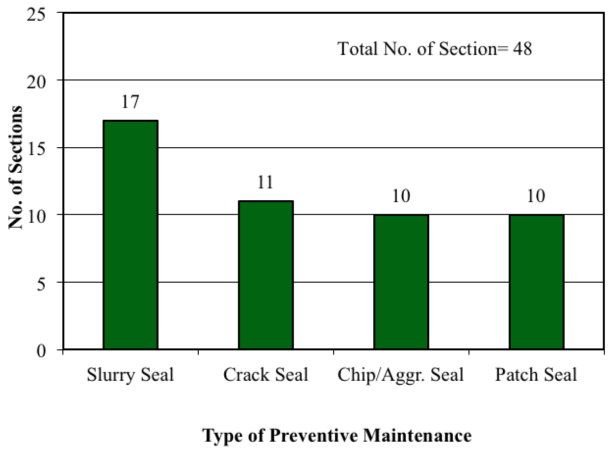

Fig. 2. The Distribution of Selected Sections for Various Preventive Treatments.

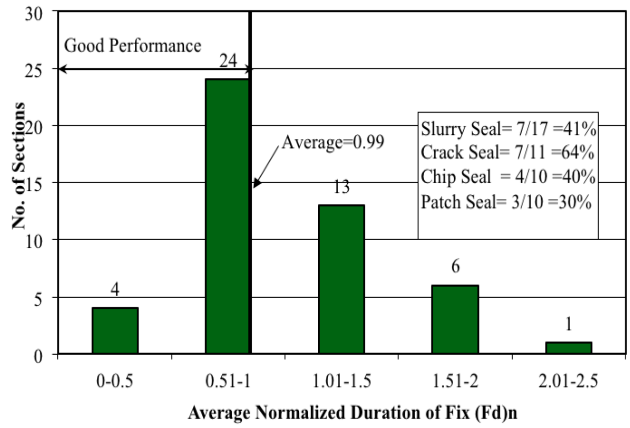

Fig. 3. The Distribution of Sections as a Function of Normalized Average Duration of Fix $(F_d)_n$.

deviation of 0.26. The crack seal shows the highest $(F_f)_n$ value of 1.15 and standard deviation of 0.57. Fig. 3 shows the distribution of the number of sections as a function of $(F_f)_n$. The examination of Fig. 3 and the data in Table 3 reveals that:

- The total average and standard deviation of $(F_d)_n$ factors are 0.99 and 0.43, respectively.
- Approximately, 42 percent (20 sections) sections have $(F_f)_n$ factor higher than the average value.
- Out of 42 percent, the slurry seal, crack seal, chip seal and patch seal sections consist of 33, 33, 19, and 14 percent, respectively.
- Approximately, 64 percent of the crack seal sections are above the average value, followed by slurry seal (41 percent), chip seal (40 percent) and patch seal (30 percent).
- Top 10 percent of the total sections analyzed in the study consist of patch seal and crack seal preventive maintenance treatments.

Based on $(F_f)_n$ the crack seal is ranked first followed by slurry seal and chip seal, and patch seal is ranked last. It should be noted that for simplicity, the factors like materials and subgrade conditions were not considered in the analysis.

The summaries of normalized average slope of distress $(F_s)_n$ and normalized average distress measure $(F_d)_n$ values are listed in Tables 4 and 5, respectively. The $(F_d)_n$ represents the rate of distress acceleration and $(F_d)_n$ indicates the level of distress attained prior to the rapid rate of deterioration of fix. Since the higher values of $(F_s)_n$ and $(F_d)_n$ imply poor performance, the data in Table 4 and 5 were sorted in ascending order relative to the $(F_s)_n$ and $(F_d)_n$ for each type of preventive maintenance. It can be seen from the tables that the slurry seal and chip seal show lower average $(F_s)_n$ and $(F_d)_n$ values. Moreover, approximately 80 percent of slurry seal and chip seal sections have $(F_s)_n$ and $(F_d)_n$ values lower than the average values, thus, indicating better performance. Based on the normalized average

Table 4. Summary of Average Slope of Distress (F_d) for Various Preventive Maintenance of Flexible Pavements.

State Code	SHRP ID	Maintenance Type	Slope Alligator	Slope Longit.	Slope Trans	Normalized Slope Alligator	Normalized Slope Longit.	Normalized Slope Trans.	Average Normalized Slope Measured	Remarks	
1	A320	Slurry Seal	0.049	0.006	0.003	0.565	0.007	0.092	0.22	Sections=	17
1	B320	Slurry Seal	0.151	0.047	-	1.741	0.055	-	0.90	Average=	0.67
1	C320	Slurry Seal	0.209	-	0.197	2.410	-	6.238	4.32	St. Dev.=	1.09
5	A320	Slurry Seal	0.0000	0.070	0.001	0.000	0.082	0.033	0.04	CV=	162
12	A320	Slurry Seal	0.119	0.133	0.000	1.373	0.155	0.000	0.51	Rank=	1

Table 4. (Continued)

State Code	SHRP ID	Maintenance Type	Slope Alligator	Slope Longit	Slope Trans	Normalized Slope Alligator	Normalized Slope Longit.	Normalized Slope Trans.	Average Normalized Slope Measured	Remarks	
12	B320	Slurry Seal	0.119	-	0.004	1.373	-	0.114	0.74		
12	C320	Slurry Seal	0.139	0.000	0.047	1.599	0.000	1.469	1.02		
28	A320	Slurry Seal	0.0000	0.053	0.0000	0.000	0.062	0.000	0.02		
48	Q320	Slurry Seal	0.0002	0.0002	0.000	0.002	0.000	0.006	0.003		
48	H320	Slurry Seal	0.001	0.053	0.002	0.014	0.062	0.066	0.05		
48	E320	Slurry Seal	0.007	0.015	0.004	0.081	0.018	0.130	0.08		
48	F320	Slurry Seal	0.013	0.018	0.005	0.150	0.021	0.161	0.11		
48	D320	Slurry Seal	-	-	0.007	-	-	0.234	0.23		
48	K320	Slurry Seal	0.003	0.034	0.028	0.039	0.040	0.885	0.32		
48	L320	Slurry Seal	0.003	0.003	0.018	0.029	0.004	0.569	0.20		
48	B320	Slurry Seal	0.019	0.010	0.036	0.216	0.012	1.141	0.46		
48	M320	Slurry Seal	0.111	-	0.100	1.282	-	3.160	2.22		
48	H330	Crack Seal	-	0.002	0.000	-	0.002	0.000	0.001	Sections=	11
48	Q330	Crack Seal	-	0.007	0.000	-	0.008	0.000	0.004	Average=	1.82
1	A330	Crack Seal	0.020	-	0.014	0.231	-	0.452	0.34	St. Dev.=	3.05
12	C330	Crack Seal	0.106	0.000	0.000	1.225	0.000	0.000	0.41	CV=	168
48	D330	Crack Seal	-	0.810	0.000	-	0.948	0.000	0.47	Rank=	4
48	L330	Crack Seal	0.008	0.041	0.046	0.086	0.048	1.438	0.52		
12	B330	Crack Seal	0.022	0.000	0.085	0.257	0.000	2.683	0.98		
28	A330	Crack Seal	0.210	0.008	0.024	2.421	0.010	0.769	1.07		
1	C330	Crack Seal	0.338	-	0.039	3.895	-	1.226	2.56		
12	A330	Crack Seal	0.821	0.000	0.000	9.464	0.000	0.000	3.15		
12	A330	Crack Seal	0.050	26.358	0.000	0.576	30.846	0.000	10.47		
1	A350	Chip/Agg Seal	0.002	-	0.000	0.023	-	0.013	0.02	Sections=	10
12	A350	Chip/Agg Seal	0.008	0.000	0.001	0.092	0.000	0.018	0.04	Average=	0.72
12	A350	Chip Seal	0.023	0.000	0.000	0.264	0.000	0.003	0.09	St. Dev.=	1.35
1	C350	Chip/Agg Seal	-	-	0.004	-	-	0.126	0.13	CV=	186
28	A350	Chip Seal	-	0.000	0.016	-	0.000	0.495	0.25	Rank=	2
12	B350	Chip/Agg Seal	0.040	-	-	0.461	-	-	0.46		
48	L350	Chip Seal	-	-	0.017	-	-	0.537	0.54		
48	D350	Chip Seal	-	0.056	0.035	-	0.066	1.106	0.59		
1	C350	Chip Seal	-		0.020	-	-	0.632	0.63		
12	C350	Chip/Agg Seal	-	-	0.143	-	-	4.508	4.51		
48	1056	Patch Seal	0.005	0.001	0.000	0.052	0.002	0.009	0.02	Sections=	10
48	1077	Patch Seal	0.003	0.039	0.004	0.036	0.046	0.126	0.07	Average=	0.95
48	1065	Patch Seal	-	0.005	0.009	-	0.005	0.275	0.14	St. Dev.=	1.29
48	3835	Patch Seal	0.000	0.086	0.033	0.001	0.100	1.043	0.38	CV=	136
48	1076	Patch Seal	0.011	0.064	0.043	0.127	0.075	1.343	0.51	Rank=	3
48	1087	Patch Seal	-	0.303	0.044	-	0.355	1.381	0.87		
48	1068	Patch Seal	0.208	0.032	0.009	2.398	0.037	0.284	0.91		
48	D330	Patch Seal	-	0.880	0.033	-	1.030	1.033	1.03		
48	3749	Patch Seal	0.183	-	0.006	2.109	-	0.192	1.15		
48	1039	Patch Seal	0.036	0.773	0.380	0.410	0.905	12.009	4.44		
Total Average=			0.087	0.854	0.032	1.000	1.000	1.000	1.00		
Total Standard Deviation=			0.153	4.444	0.065	1.761	5.200	2.065	1.81		

Table 5. Summary of Average Distress Measure (F_d) for Various Preventive Maintenance of Flexible Pavements.

State Code	SHRP ID	Maintenance Type	Level of Distress Alligator (m2)	Level of Distress Longit. (m)	Level of Distress Transverse (m)	Normalized Distress Alligator	Normalized Distress Longit.	Normalized Distress Transverse	Average Normalized Distress Measured	Remarks	
1	A320	Slurry Seal	12.4	0.8	0.5	0.369	0.019	0.020	0.14	Sections=	17
1	B320	Slurry Seal	4.9	4.3	-	0.146	0.103	-	0.12	Average=	0.60
1	C320	Slurry Seal	17.7	-	11.1	0.527	-	0.440	0.48	St. Dev.=	0.57
5	A320	Slurry Seal	0.0	36.6	0.0	0.000	0.881	0.000	0.29	CV=	95
12	A320	Slurry Seal	72.9	16.6	6.0	2.171	0.398	0.238	0.94	Rank=	1
12	B320	Slurry Seal	110.0	-	0.0	3.274	-	0.000	1.64		
12	C320	Slurry Seal	7.4	5.0	27.2	0.221	0.121	1.082	0.47		
28	A320	Slurry Seal	3.7	3.3	59.1	0.111	0.079	2.353	0.85		
48	B320	Slurry Seal	4.5	128.0	7.5	0.134	3.079	0.298	1.17		
48	D320	Slurry Seal	-	-	4.0	-	-	0.158	0.16		
48	E320	Slurry Seal	1.4	35.0	55.0	0.042	0.842	2.189	1.02		
48	F320	Slurry Seal	6.0	12.0	13.5	0.179	0.289	0.537	0.33		
48	H320	Slurry Seal	1.0	25.0	6.5	0.030	0.601	0.259	0.30		
48	K320	Slurry Seal	1.8	13.0	0.7	0.052	0.313	0.026	0.13		
48	L320	Slurry Seal	0.5	85.0	95.0	0.015	2.045	3.780	1.95		
48	M320	Slurry Seal	5.0	-	2.5	0.149	-	0.099	0.12		
48	Q320	Slurry Seal	0.0	2.5	3.5	0.000	0.060	0.139	0.07		
1	C330	Crack Seal	2.6	-	1.2	0.079	-	0.048	0.06	Sections=	11
48	H330	Crack Seal	-	2.4	6.5	-	0.058	0.259	0.16	Average=	1.23
48	L330	Crack Seal	10.1	0.0	8.7	0.301	0.000	0.346	0.22	St. Dev.=	1.13
48	Q330	Crack Seal	-	7.0	9.0	-	0.168	0.358	0.26	CV=	92
1	A330	Crack Seal	12.0	-	5.7	0.357	-	0.228	0.29	Rank=	3
28	A330	Crack Seal	-	1.0	40.0	-	0.024	1.592	0.81		
12	C330	Crack Seal	107.2	12.8	56.6	3.191	0.309	2.254	1.92		
12	B330	Crack Seal	202.0	0.0	3.6	6.013	0.000	0.141	2.05		
12	C 330	Crack Seal	131.9	11.2	49.9	3.925	0.270	1.985	2.06		
12	A330	Crack Seal	57.8	-	85.9	1.720	-	3.418	2.57		
48	D330	Crack Seal	-	200.0	35.0	-	4.812	1.393	3.10		
1	A350	Chip/Agg Seal	-	-	0.1	-	-	0.005	0.005	Sections=	10
12	A350	Chip/Agg Seal	-	-	0.1	-	-	0.005	0.005	Average=	0.82
1	C350	Chip/Agg Seal	-	-	0.4	-	-	0.015	0.01	St. Dev.=	1.28
12	A350	Chip Seal	17.0	0.0	0.0	0.506	0.000	0.000	0.17	CV=	155
1	C350	Chip Seal	-	-	5.3	-	-	0.210	0.21	Rank=	2
48	D350	Chip Seal	-	27.0	0.5	-	0.650	0.020	0.33		
12	C350	Chip/Agg Seal	-	4.1	26.7	-	0.098	1.063	0.58		
28	A350	Chip Seal	-	0.0	32.0	-	0.000	1.273	0.64		
48	L350	Chip Seal	-	-	63.1	-	-	2.511	2.51		
12	B350	Chip/Agg Seal	127.0	-	-	3.780	-	-	3.78		
48	1077	Patch Seal	0.3	36.6	12.8	0.009	0.881	0.509	0.47	Sections=	10
48	1076	Patch Seal	9.3	23.4	42.2	0.277	0.563	1.680	0.84	Average=	1.69
48	3835	Patch Seal	0.1	54.3	38.0	0.002	1.306	1.512	0.94	St. Dev.=	0.99
48	1056	Patch Seal	7.2	0.8	80.3	0.214	0.019	3.195	1.14	CV=	59
48	1068	Patch Seal	30.0	125.0	3.6	0.893	3.007	0.141	1.35	Rank=	4
48	3749	Patch Seal	107.0	-	1.5	3.185	-	0.060	1.62		
48	1087	Patch Seal	-	100.2	22.8	-	2.411	0.907	1.66		
48	1039	Patch Seal	4.4	57.6	130.0	0.131	1.385	5.173	2.23		
48	D330	Patch Seal	-	210.0	37.0	-	5.052	1.472	3.26		
48	1065	Patch Seal	-	172.8	65.5	-	4.157	2.606	3.38		
Total Average=			33.6	41.6	25.1	1.000	1.000	1.000	1.02		
Total Standard Deviation=			52.1	59.7	30.7	1.551	1.436	1.223	1.03		

Table 6. Relative Ranking of the Preventive Maintenance Treatments.

Maintenance Type	No. of Sections	Normalized Average Duration of Fix $(F_f)_n$	Normalized Average Slope of Distress $(F_s)_n$	Normalized Average Distress Measure $(F_d)_n$	Overall Performance Factor (F_o)	Average Pavement Condition Index (*PCI*)
Chip/Aggr Seal	10	3	2	2	1	80 [Very Good]
Slurry Seal	17	2	1	1	2	73 [Very Good]
Patch Seal	11	4	3	4	3	70 [Good]
Crack Seal	10	1	4	3	4	71 [Very Good]

slope of distress and normalized average distress measure, the slurry seal is ranked first followed by chip seal, crack seal and patch seal.

The summary of all ranking based on the above-mentioned three performance factors is shown in Table 6. Since the results of ranking based on the $(F_f)_n$, $(F_s)_n$ and $(F_d)_n$ produced mixed ranking, the effect of each performance factor was combined to generate overall performance factor (F_o). The F_o takes into account the average rate of distress acceleration, the average duration of fix and the average distress attained before deterioration. Simple average of the three normalized performance factors was calculated and the new ranking was established. It should be noted that the complementary of $(F_f)_n$ was used to ensure that all rankings were from best to worst in ascending numerical order. The results of the F_o are shown in Table 7. Interestingly, the average F_o value of chip seal is lower than the slurry seal. The chip seal is ranked first followed by slurry seal and patch seal, and crack seal is ranked last. The distribution of the sections for the four preventive maintenances is shown in Fig. 4. Approximately, 45 percent of the total sections consist of chip seal and slurry seal exhibit F_o values lower than the overall average, indicating good performance. It should also be noticed that 7 out of top 10 sections are chip seal sections. Therefore, the chip seal sections perform the best followed by slurry seal and patch seal, and the crack seal sections perform the worst. Similar findings were also reported by Geoffrey [2], Eltahan et al [3], and Lin et al [4]. This is mainly because the chip seal does not reflect the distresses that preceded the treatment applications.

The pavement condition index (*PCI*) was also determined based on the deduct point policy of Louisiana Department of Transportation and Development. The results are shown in Table 7. It should be noted here that the *PCI* calculations were based on the condition of the sections at the last survey date. Recall that the *PCI* ranks the pavements from poor to excellent (0-100) and there is no consensus in the highway agencies on the standard *PCI*. It is just another pavement condition ranking tool. It is clear from the Table 7 that there is no direct relationship between the *PCI* and the four performance factors discussed earlier. Nevertheless, the ranking based on the average values of *PCI* for the preventive maintenance matches very well to the $(F_o)_n$. The average *PCI* for chip seal is 80 percent with a standing of very good followed by slurry seal. However, there is no significant difference between the average *PCI* values of patch seal and crack seal. The average *PCI* values indicate that the condition of the sections at the last distress survey date is very good for chip seal followed by slurry seal, patch seal and crack seal.

Table 8 summarizes the maintenance ranking based on four performance factors and climatic zones. The pavements sections were classified based on LTTP climatic zone; dry-not-freeze,

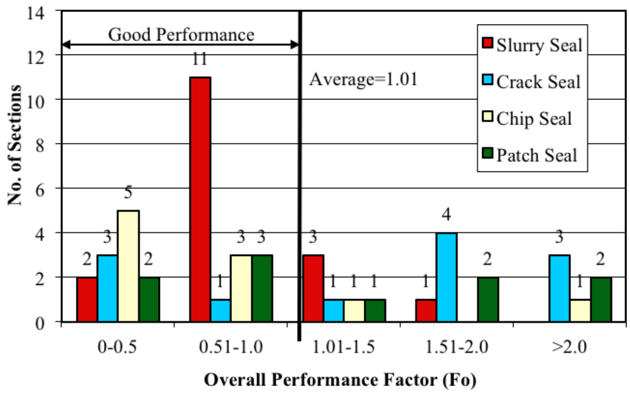

Fig. 4. The Distribution of Four Preventive Maintenance Treatments Relative to Overall Performance Factor (F_o).

wet-freeze and wet-not-freeze. It was found that most of the sections studied belonged to wet-not-freeze zone. The data in Table 8 revealed that even though crack seal exhibited higher average values of distress and rate of distress propagation, the average duration of fix was also higher. On the other hand, the slurry seal chip seal showed low distress measure and rate of distress propagation. Based on the $(F_o)_n$ (overall performance) indicator the slurry seal ranked first followed by chip seal in wet-not-freeze zone. It should be noted that the number of sections in other climatic zones were not sufficient to make comparisons of treatment performance for various climatic zones. However, with few sections available, a preliminary note can be made, that the slurry seal and crack seal performed better in wet-freeze and dry-freeze zones, respectively, relative to the wet-not freeze zone.

The effect of truck traffic on the performance was also investigated. The summary of the results is shown in Table 9. Total truck volume was calculated for the distress survey period. The sections were divided in two main categories based on the truck volume: high and low. If the total truck volume was greater than one million, the section was rated as high truck traffic and vice versa. For low truck volume chip seal showed low average distress measure and average duration of fix even though the average rate of deterioration was high. Conversely, for high truck volume the slurry seal took the lead and exhibited low average distress measure, average rate of distress propagation and high average duration of fix. So, at high truck volume slurry seal outperformed all other treatments followed by chip seal. It was expected that the sections with higher truck traffic would yield higher $(F_o)_n$ values, implying bad performance with increasing traffic volume. However, no strong relationship was observed between the $(F_o)_n$ and truck traffic. Nevertheless, the

Table 7. Summary of Overall Performance Factor (F_o) and Pavement Condition Index (*PCI*) for Various Flexible Pavement Sections.

State Code	SHRP ID	Maintenance Type	$(F_f)'_n$	$(F_s)_n$	$(F_d)_n$	$(F_o)_n$	Remarks		*PCI*
1	A320	Slurry Seal	0.74	0.22	0.14	0.36	Sections=	17	65.7
5	A320	Slurry Seal	0.80	0.04	0.29	0.38	Average=	0.79	79.6
48	K320	Slurry Seal	1.24	0.11	0.34	0.56	St. Dev.=	0.35	66.4
48	M320	Slurry Seal	1.51	0.05	0.13	0.56	CV=	44	76.5
48	L320	Slurry Seal	1.51	0.05	0.30	0.62	Rank=	2	82.5
48	D320	Slurry Seal	1.51	0.23	0.16	0.63			82.0
48	F320	Slurry Seal	1.51	0.23	0.16	0.63			83.7
1	B320	Slurry Seal	0.94	0.90	0.12	0.65			71.1
28	A320	Slurry Seal	1.12	0.02	0.85	0.67			58.2
48	B320	Slurry Seal	0.72	0.45	1.17	0.78			78.6
48	E320	Slurry Seal	0.72	0.45	1.17	0.78			62.8
12	A320	Slurry Seal	1.09	0.51	0.94	0.85			69.0
12	C320	Slurry Seal	1.11	1.02	0.48	0.87			78.0
48	H320	Slurry Seal	1.94	0.08	1.03	1.02			85.3
48	Q320	Slurry Seal	0.90	0.32	1.89	1.04			71.4
12	B320	Slurry Seal	1.29	0.74	1.64	1.22			70.0
1	C320	Slurry Seal	0.67	4.29	0.48	1.81			62.8
1	A330	Crack Seal	0.58	0.39	0.12	0.36	Sections=	11	72.6
12	A330	Crack Seal	1.08	0.003	0.29	0.46	Average=	1.60	76.0
12	B330	Crack Seal	0.97	0.34	0.06	0.46	St. Dev.=	1.20	65.6
48	H330	Crack Seal	1.36	0.41	0.81	0.86	CV=	75	87.7
1	C330	Crack Seal	2.01	2.20	0.07	1.43	Rank=	4	68.2
48	D330	Crack Seal	1.95	0.97	1.92	1.61			60.0
48	L330	Crack Seal	1.00	1.06	3.11	1.72			87.3
48	Q330	Crack Seal	1.00	1.06	3.11	1.72			87.7
12	C330	Crack Seal	0.87	2.55	2.58	2.00			48.5
28	A330	Crack Seal	1.95	3.15	2.06	2.39			78.4
12	C330	Crack Seal	1.25	10.47	2.05	4.59			48.5
12	A350	Chip Seal	0.44	0.00	0.22	0.22	Sections=	10	84.4
12	C350	Chip/Agg Seal	0.88	0.02	0.02	0.30	Average=	0.73	78.8
1	C350	Chip/Agg Seal	0.55	0.24	0.33	0.38	St. Dev.=	0.64	81.7
12	B350	Chip/Agg Seal	0.65	0.53	0.005	0.40	CV=	87	73.3
28	A350	Chip Seal	0.63	0.52	0.26	0.47	Rank=	1	80.0
1	C350	Chip Seal	0.89	0.47	0.16	0.51			81.7
48	D350	Chip Seal	1.33	0.00	0.21	0.51			62.8
48	L350	Chip Seal	1.33	0.62	0.17	0.71			83.4
1	A350	Chip/Agg Seal	4.38	0.09	0.64	1.70			88.9
12	A350	Chip/Agg Seal	3.18	0.58	2.52	2.10			85.3
48	3749	Patch Seal	0.88	0.02	0.02	0.30	Sections=	10	89.2
48	3835	Patch Seal	1.32	0.12	0.00	0.48	Average=	1.29	43.2
48	D330	Patch Seal	1.19	0.14	1.35	0.89	St. Dev.=	0.70	75.7
48	1056	Patch Seal	1.70	0.46	0.58	0.91	CV=	55	78.1
48	1068	Patch Seal	0.88	1.15	0.94	0.99	Rank=	3	71.2
48	1076	Patch Seal	0.91	0.38	2.24	1.18			87.7
48	1039	Patch Seal	1.16	0.04	3.78	1.66			55.1
48	1087	Patch Seal	2.34	0.02	3.39	1.92			64.6
48	1077	Patch Seal	1.17	4.39	1.15	2.24			80.1
48	1065	Patch Seal	0.82	4.45	1.62	2.30			51.9
Total Average=		1.01	1.00	1.02	1.01			73	
Total Standard Deviation=	2.33	1.80	1.03	0.81			12		

Table 8. Summary of Maintenance Ranking Based on Performance Factors and Climatic Zones.

State Code	SHRP ID	Maintenance Type	$(F_f)_n$	$(F_s)_n$	$(F_d)_n$	$(F_o)_n$	Average $(F_f)_n$	Average $(F_s)_n$	Average $(F_d)_n$	Average $(F_o)_n$	Climatic Zone
12	C350	Chip/Agg Seal	1.22	4.51	0.58	0.30	-	-	-	-	
28	A330	Crack Seal	0.74	1.07	0.81	2.39	1.36	0.70	0.55	1.38	Dry Not Freeze
1	A330	Crack Seal	1.98	0.34	0.29	0.36					
48	1065	Patch Seal	0.84	0.14	3.38	2.30	-	-	-	-	
48	1039	Patch Seal	0.85	4.44	2.23	1.66	-	-	-	-	
1	A320	Slurry Seal	1.36	0.22	0.14	0.36	1.14	0.37	0.54	0.61	Wet Freeze
12	A320	Slurry Seal	0.91	0.51	0.94	0.85					
1	C350	Chip Seal	0.75	0.63	0.21	0.51	0.89	0.30	0.74	0.87	
28	A350	Chip Seal	1.82	0.25	0.64	0.47	(3)	(1)	(2)	(2)	
48	D350	Chip Seal	0.31	0.59	0.33	0.51					
1	C350	Chip/Agg Seal	0.76	0.13	0.01	0.38					
1	A350	Chip/Agg Seal	1.14	0.02	0.005	1.70					Wet Not Freeze
12	A350	Chip/Agg Seal	0.86	0.04	0.17	2.10					
12	B350	Chip/Agg Seal	0.59	0.46	3.78	0.40					
1	C330	Crack Seal	1.03	2.56	0.06	1.43	1.03	1.08	1.45	1.59	
12	C330	Crack Seal	0.51	0.41	1.92	4.59	(1)	(4)	(4)	(4)	
48	H330	Crack Seal	1.12	0.001	0.16	0.86					
48	Q330	Crack Seal	1.59	0.00	0.26	1.72					
12	A330	Crack Seal	1.15	3.15	2.57	0.46					
48	D330	Crack Seal	1.00	0.47	3.10	1.61					
12	B330	Crack Seal	0.80	0.98	2.05	0.46					
48	1087	Patch Seal	1.26	0.87	1.66	1.92	0.90	0.56	1.15	1.15	
48	3749	Patch Seal	1.13	1.15	1.62	0.30	(3)	(2)	(3)	(3)	
48	1056	Patch Seal	0.43	0.02	1.14	0.91					
48	1076	Patch Seal	0.80	0.51	0.84	1.18					
48	1068	Patch Seal	0.98	0.91	1.35	0.99					
48	1077	Patch Seal	0.60	0.07	0.47	2.24					
48	3835	Patch Seal	1.09	0.38	0.94	0.48					
1	C320	Slurry Seal	1.50	4.32	0.48	1.81	0.97	0.74	0.64	0.83	
12	C320	Slurry Seal	0.90	1.02	0.47	0.87	(2)	(3)	(1)	(1)	
48	M320	Slurry Seal	0.50	2.22	0.12	0.56					
1	B320	Slurry Seal	1.06	0.90	0.12	0.65					
28	A320	Slurry Seal	0.89	0.02	0.85	0.67					
48	H320	Slurry Seal	0.66	0.05	0.30	1.02					
48	Q320	Slurry Seal	0.93	0.00	0.07	1.04					
48	E320	Slurry Seal	0.51	0.08	1.02	0.78					
48	L320	Slurry Seal	1.73	0.20	1.95	0.62					
48	F320	Slurry Seal	0.81	0.11	0.33	0.63					
48	B320	Slurry Seal	1.38	0.46	1.17	0.78					
48	D320	Slurry Seal	0.66	0.23	0.16	0.63					
12	B320	Slurry Seal	0.78	0.74	1.64	1.22					
5	A320	Slurry Seal	1.26	0.04	0.29	0.38					

Value in "( )" represents the rank of maintenance treatment.

average value of the $(F_o)_n$ (or each maintenance type) yielded good performance for both the chip and slurry seal maintenance regardless of the traffic volume as shown in the Table 9.

Summary and Conclusions

The federal and state agencies have shifted their activities from design and construction of new roads to timely preventive maintenance and rehabilitation of the existing pavements. This has posed various questions about the type of preventive treatments that will perform best for particular type of distress. It is generally accepted that preventive maintenance is more cost effective than the corrective. The LTPP has developed a large database; in particular, the SPS-3 focuses on the effectiveness and performance of the flexible pavement after several of treatment applied. The objectives of the study were to evaluate the LTPP distress data for preventive maintenance of flexible pavements and to quantify the effectiveness of the various preventive maintenance strategies based on actual

Table 9. Summary of Maintenance Ranking Based on Overall Performance Factor (F_o) and Truck Volume.

State Code	SHRP ID	Maintenance Type	$(F_f)_n$	$(F_s)_n$	$(F_d)_n$	$(F_o)_n$	Cumulative Truck Volume (10^6)	Average $(F_f)_n$	Average $(F_s)_n$	Average $(F_d)_n$	Average $(F_o)_n$	Remarks
1	C350	Chip Seal	0.75	0.63	0.21	0.51	0.3	1.14	1.11	0.29	0.67	Low Truck Volume (<1.0 million)
28	A350	Chip Seal	1.82	0.25	0.64	0.47	0.5	-2	-4	-1	-1	
1	C350	Chip/Agg Seal	0.76	0.13	0.01	0.38	2					
12	C350	Chip/Agg Seal	1.22	4.51	0.58	0.3	0.37					
1	A350	Chip/Agg Seal	1.14	0.02	0.005	1.7	0.5					
1	C330	Crack Seal	1.03	2.56	0.06	1.43	0.3	1.16	0.73	0.58	1.89	
12	C330	Crack Seal	0.51	0.41	1.92	4.59	0.37	-1	-2	-3	-4	
48	H330	Crack Seal	1.12	0.001	0.16	0.86	0.5					
28	A330	Crack Seal	0.74	1.07	0.81	2.39	0.5					
1	A330	Crack Seal	1.98	0.34	0.29	0.36	0.5					
48	Q330	Crack Seal	1.59	0	0.26	1.72	0.54					
48	1087	Patch Seal	1.26	0.87	1.66	1.92	0.2	0.89	0.54	1.73	1.32	
48	1065	Patch Seal	0.84	0.14	3.38	2.3	0.25	-4	-1	-4	-3	
48	3749	Patch Seal	1.13	1.15	1.62	0.3	0.27					
48	1056	Patch Seal	0.43	0.02	1.14	0.91	0.28					
48	1076	Patch Seal	0.8	0.51	0.84	1.18	0.67					
1	C320	Slurry Seal	1.5	4.32	0.48	1.81	0.3	0.99	0.83	0.53	0.82	
12	C320	Slurry Seal	0.9	1.02	0.47	0.87	0.37	-3	-3	-2	-2	
48	M320	Slurry Seal	0.5	2.22	0.12	0.56	0.4					
1	B320	Slurry Seal	1.06	0.9	0.12	0.65	0.4					
1	A320	Slurry Seal	1.36	0.22	0.14	0.36	0.5					
28	A320	Slurry Seal	0.89	0.02	0.85	0.67	0.5					
48	H320	Slurry Seal	0.66	0.05	0.3	1.02	0.5					
48	Q320	Slurry Seal	0.93	0	0.07	1.04	0.54					
48	E320	Slurry Seal	0.51	0.08	1.02	0.78	0.6					
48	L320	Slurry Seal	1.73	0.2	1.95	0.62	0.65					
48	F320	Slurry Seal	0.81	0.11	0.33	0.63	0.7					
48	D350	Chip Seal	0.31	0.59	0.33	0.51	2	0.59	0.36	1.43	1	High Truck Volume (>=1.0 million)
12	A350	Chip/Agg Seal	0.86	0.04	0.17	2.1	1	-4	-1	-3	-3	
12	B350	Chip/Agg Seal	0.59	0.46	3.78	0.4	2.4					
12	A330	Crack Seal	1.15	3.15	2.57	0.46	1	0.98	1.54	2.57	0.84	
48	D330	Crack Seal	1	0.47	3.1	1.61	2	-2	-4	-4	-2	
12	B330	Crack Seal	0.8	0.98	2.05	0.46	2.4					
48	1068	Patch Seal	0.98	0.91	1.35	0.99	1.05	0.88	1.45	1.25	1.34	
48	1077	Patch Seal	0.6	0.07	0.47	2.24	1.2	-3	-3	-2	-4	
48	3835	Patch Seal	1.09	0.38	0.94	0.48	1.3					
48	1039	Patch Seal	0.85	4.44	2.23	1.66	1.5					
12	A320	Slurry Seal	0.91	0.51	0.94	0.85	1	1	0.4	0.84	0.77	
48	B320	Slurry Seal	1.38	0.46	1.17	0.78	1.5	-1	-2	-1	-1	
48	D320	Slurry Seal	0.66	0.23	0.16	0.63	2					
12	B320	Slurry Seal	0.78	0.74	1.64	1.22	2.4					
5	A320	Slurry Seal	1.26	0.04	0.29	0.38	2.8					

pavement performance using the LTPP database. Approximately, 127 SPS-3 sections were analyzed from the Southern States and 48 sections were selected with good pavement performance record for further analysis. Five performance factors, average duration of fix, average distress measure, average distress measure, overall performance and pavement condition index were used to assess the rank and effectiveness of preventive maintenance.

The results showed mixed ranking using the five factors, however, the ranking for chip seal and slurry seal were quite consistent. Overall, the chip seal and slurry seal exhibited the best performance. Based on the average F_o and *PCI* values, the chip seal ranked the first followed by slurry seal, and crack seal was ranked the last. Approximately, 80% of the chip seal and slurry seal sections analyzed in the study showed better performance. Moreover, most of the top 10 sections were chip seal sections. The results indicated that at high truck volume and wet-no-freeze zone the slurry seal performed better followed by chip seal. However at low truck volume chip seal had better performance indicators. It was interesting to note that, although there was no direct relationship between the $(F_o)_n$ and *PCI* factors, their average values produced similar rankings for each maintenance there was no direct relationship between the $(F_o)_n$ and *PCI* factors, their average values produced similar rankings for each maintenance type. The $(F_o)_n$ takes into account average rate of distress acceleration, average duration of fix and average distress measure prior to the rapid deterioration of pavement, and seems to be an effective tool in evaluating the performance of the preventive maintenances.

In this study, a robust technique for calculating the performance factors was used. In order to simplify the analysis other factors like subgrade properties and drainage condition were not considered. Moreover, the study was limited to the cracking performance of the fixes. Nevertheless, the findings of the study were similar as reported by other researchers.

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