STUDY OF BITUMINOUS SURFACE TREATMENTS IN VIRGINIA

Analysis of Factors that Significantly Influence the Quality of Bituminous Surface Treatments

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

It is obvious that many variables may influence the quality of a surface treatment, but the relative importance of the many variables involved is a matter of conjecture. The purpose of this study was to define those variables which do significantly influence the quality of surface treatments in Virginia and to determine the acceptable limits for them.

The range in conditions and materials encountered were limited to those normally found in Virginia. Also, since the data were obtained from surface treatment projects included in the regular work schedule, there was very little opportunity to establish any experimental design. Because of this limitation it was impossible to evaluate all the variables it was hoped could be included in the study.

Of the many variables included air temperature, surface temperature, average vehicles daily, and age at the time of evaluation seem to most significantly affect the performance of a surface treatment. Three of these variables, air temperature, surface temperature, and AVD, are controllable and one, age, is not controllable.

Based on the information obtained in this study it appears that the lower limit for air temperature should be 70°F., and the upper limit for AVD should be approximately 400, assuming procedures for surface treatment work remain the same as encountered in this project. It was found that air and surface temperatures correlate well, and it is only necessary to control one. Air temperature was chosen as the one to control since it is easier to measure.

The percentage distribution of the surface treatment jobs evaluated in this study was 40% good, 32% fair, 16% poor, and 12% very poor. Adoption of the guidelines suggested above for air temperature and AVD would have changed the percentage distribution to 47% good, 39% fair, 10% poor, and 4% very poor; but under these guidelines 49% of the jobs would not have been placed.

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INTRODUCTION

It is obvious that many variables may influence the quality of a bituminous surface treatment, but the relative importance of the many variables involved is a matter of conjecture. Most highway engineers and many sub-professional personnel involved in surface treatment work could define the ideal conditions and materials or the most undesirable conditions and materials. However, there is a large gray area between these two extremes in which the important variables need to be defined and the limits for these variables determined.

This report covers the final phase of a HPR financed study of surface treatments which began in 1964. Previous phases covered evaluations of a design method and efforts toward improving upon bituminous distributors and surface treatment training, methods of control of binder distribution, and effects of moisture on surface treatment materials.[1-5]

PURPOSE

The purpose of this investigation was to define those variables which do significantly influence the quality of surface treatments in Virginia and to determine the acceptable limits for them. Special emphasis was placed on determining the important variables that can be controlled.

SCOPE

The ranges in conditions and materials encountered obviously were limited to those normally found in Virginia. Data were collected in four of the eight highway construction districts during 1967 and in three during 1968. In all, five districts were included: two from the eastern half of the state and three from the western half. It was believed that these five districts would include most of the variations in conditions and materials found in Virginia. Data were recorded for three test sections during a work day; the area covered by the first and last distributor loads and a distributor load during the early afternoon. In all, usable data were recorded for two hundred and twelve test sections. A sample data sheet is appended.

The greatest shortcoming in this project was the limited control that could be exercised. Because all of the treatments included were in the regular work schedule and were placed as advertised and in the method normally employed by the contractor involved, the data were recorded by the inspector who happened to be assigned to the project. In order to distinguish between this project and a well controlled project, the following must be considered. Among the variables that this study hoped to evaluate were: (1) type of asphalt, (2) type of aggregate, (3) contractor procedures, and (4) weather conditions. To do this in a well controlled study, one would select, perhaps, four of each of the variables — i.e., asphalt, aggregates, contractors, and weather conditions — and combine them in every possible combination. This would, in effect, isolate each variable for evaluation and analysis. This study fell far short of this kind of control since a contractor usually worked in only one district with only one or two asphalts, very few aggregate sources, and, for the most part, with reasonably good weather conditions. These shortcomings were anticipated but not to the degree to which they occurred. For these reasons, many of the variables, as shown in Appendix A, that the study intended to deal with were deleted or combined with other variables. Also, the authors stress that while many of the variables which were included in the study were judged not to be significant this does not mean they are not important. This simply means that within the limits encountered for these variables in this study they were not significant.

TEST SECTION EVALUATION

Each of the test sections was rated after the placement of the surface treatment. Originally it was planned that three persons, the two authors and Paul F. Cecchini, Assistant Maintenance Engineer, would rate the test sections; but only two, Cecchini and Mahone, were able to rate them all. Therefore, only the evaluations made by these two persons are included in the report.

Each test section was rated subjectively on a numeric scale from one to five. A rating of one was considered excellent, two was good, three was fair, four was poor, and five was very poor. The evaluators rated each section at the same time, but worked independently and did not exchange information until they had rated all the test sites.

The average ratings for each evaluator are broken down by district and year in Table I. As can be seen, Cecchini consistently rated the test sections better (closer to one) than did Mahone. (The ratings that Runkle did make were very close to those of Mahone.) What is important here is that the difference between the raters is consistent, which indicates that the rating method is reliable.

TABLE I

AVERAGE RATING BY EACH EVALUATOR

District	Year	D. C. Mahone	P. F. Cecchini	Mahone-Cecchini Difference
1	1967	3.43	2.96	0.47
1	1968	3.02	2.50	0.52
2	1967	3.21	3.16	0.05
2	1967	2.23	1.95	0.28
3	1967	3.24	2.98	0.26
4	1967	2.32	2.03	0.27
5	1968	3.00	2.30	0.70

VARIABLES ANALYZED

After a preliminary review of the data, the variables listed in Table II were selected for analysis. Also shown in Table II is the variable type; that is, whether they are qualitative or quantitative.

A few of these variables need some explanation. "Stone delay" refers to the delay in minutes between the time the asphalt was applied and the time the stone was applied. "Traffic delay" refers to the delay in hours between the time the job was completed (rolling finished) and the time traffic was allowed on the new surface. "Age" refers to the age in months of the test section at the time it was evaluated. "Last rain" refers to any rains occurring within 24 hours prior to the job. The "contractor" variable is a combination of all the variables shown in the Appendix which relate to the contractor's procedures and equipment. Some of the variables shown were broken down into several categories, as will be discussed as the analysis is made.

TABLE II

VARIABLES ANALYZED

Variable	Variable Type
Air Temperature	Quantitative
Surface Temperature	Quantitative
Asphalt Temperature	Quantitative
Asphalt gsy	Quantitative
Stone psy	Quantitative
Stone Delay	Quantitative
Traffic Delay	Quantitative
Average Vehicles Daily	Quantitative
Age	Quantitative
Last Rain	Qualitative
Surface Condition	Qualitative
Asphalt Source and Type	Qualitative
Asphalt Distribution	Qualitative
Stone Source	Qualitative
Stone Condition	Qualitative
Contractor	Qualitative

DETERMINATION OF SIGNIFICANT VARIABLES

For the purpose of analysis, the two evaluations (Mahone's and Cecchini's) for each test section were averaged. The test sections were then grouped into four categories, good, fair, poor, and very poor, according to their average evaluations. Average ratings less than two were considered good; those equal to or greater than two but less than three were considered fair. Those equal to or greater than three but less than four were considered poor; and those equal to or greater than four were considered very poor.

The means and ranges of the several quantitative variables were determined for each of the four categories and are shown in Table III. Table IV presents the occurrences and percentage breakdown for each category for the qualitative variables, and Table V shows the percentage deviation for each category of each qualitative variable from the total sample percentage breakdown.

TABLE III

MEANS AND RANGES BY CATEGORIES

Variable	Good (1-2)			Fair (2-3)			Poor (3-4)			Very Poor (4-5)		
	N*	Ave.	Range	N	Ave.	Range	N	Ave.	Range	N	Ave.	Range
Air Temperature	81	77	54-98	67	74	56-92	35	74	60-90	24	71	49-92
Surface Temperature	81	93	52-119	67	89	62-130	35	93	68-120	24	85	56-130
Asphalt Temperature												
AP-00	15	331	285-360	12	300	285-310	4	304	300-310	7	300	300-302
CAE-2	34	161	150-175	24	164	150-175	3	162	150-175	3	165	150-170
Asphalt gsy												
AP-00	25	.27	.19-.35	20	.26	.19-.38	13	.29	.23-.31	9	.27	.20-.32
CAE-2	47	.34	.19-.45	38	.32	.23-.37	19	.32	.30-.33	12	.31	.20-.36
Stone psy	75	23	16-30	62	24	15-38	33	24	19-35	20	23	12-34
Stone Delay (minutes)	76	2.8	0-18	67	2.6	0-25	35	2.4	0-8	20	1.4	0-7
Traffic Delay (minutes)	80	0.6	0-4.5	67	0.9	0-4.5	35	0.9	0-5.1	20	0.8	0-3.3
AVD	79	195	47-840	61	199	46-840	35	247	42-932	25	271	49-589
Age (months)	84	9.6	5-20	67	9.7	6-20	36	10.7	6-18	25	11.4	6-18

N* refers to the number of test sections falling in each category for the variable in question.

TABLE IV

OCCURRENCES AND PERCENTAGES BY CATEGORIES

Variable		Occurrences by Evaluation Ranges					Percentage by Evaluation Ranges			
		Total	Good	Fair	Poor	Very Poor	Good	Fair	Poor	Very Poor
Sample Distribution		212	84	67	36	25	40	32	16	12
Last Rain:		23	4	8	5	6	17	35	22	26
Surface Condition:	Damp-Wet	31	9	11	6	5	29	36	19	16
	Dry	178	74	56	30	18	41	32	17	10
Asphalt Source:	A	29	7	6	11	5	24	21	38	17
	B	19	10	3	1	5	53	16	5	26
	C	90	52	19	12	7	58	21	13	8
	E	15	5	6	2	2	33	40	13.5	13.5
	F	40	7	20	10	3	18	50	25	7
Asphalt Type:	AP-00	75	25	24	16	10	33	32	22	13
	CAE-2	119	56	31	20	12	47	26	17	10
Asphalt Distribution:										
	Good	198	83	60	33	22	42	30	17	11
	Fair	13	0	9	1	3	0	69	8	23
Stone Source:	A	30	6	9	13	2	20	30	43	7
	B	18	8	6	3	1	44	33	17	6
	D	10	2	2	4	2	20	20	40	20
	F	39	24	7	2	6	62	18	5	15
	G	16	4	6	2	4	25	38	12	25
	H	11	2	6	1	2	18	55	9	18
	I	10	0	7	1	2	0	70	10	20
	J	23	9	5	7	2	39	22	30	9
	L	25	17	7	1	0	68	28	4	0
Stone Size:	#8	33	10	10	7	6	30	30	21	19
	#78	166	68	52	27	19	41	31	16	12
Stone Type:	Limestone	40	9	19	4	8	22	48	10	20
	Granite	127	59	34	23	11	46	27	18	9
Stone Condition:	Dry	75	35	22	10	8	47	29	13	11
	Wet	135	48	44	26	17	36	32	19	13
	Clean	189	69	59	36	25	37	31	19	13
	Dirty	21	14	7	0	0	67	33	0	0
Contractor:	1	28	7	6	11	4	25	21	39	15
	2	41	26	7	2	6	63	17	5	15
	3	70	18	30	12	10	26	43	17	14
	4	42	13	14	10	5	31	33	24	12
	5	31	20	10	1	0	65	32	3	0

TABLE V

DEVIATION OF VARIABLE PERCENTAGE FROM TOTAL SAMPLE DISTRIBUTION PERCENTAGE, BY CATEGORY

Variable	Good	Fair	Poor	Very Poor
Last Rain				
Surface Condition:				
Damp-Wet	-11	+ 4	+ 3	+ 4
Dry	+ 1	0	+ 1	- 2
Asphalt Source:				
A	-16	-11	+22	+ 5
B	+13	-16	-11	+14
C	+18	-11	- 3	- 4
E	- 7	+ 8	- 2.5	+ 1.5
F	-22	+18	+ 9	- 5
Asphalt Type:				
AP-00	- 7	0	+ 6	+ 1
CAE-2	+ 7	- 6	+ 1	- 2
Asphalt Distribution:				
Good	+ 2	- 2	+ 1	- 1
Fair	-40	+37	- 8	+11
AP-00 — Limestone	- 8	+10	0	- 2
— Granite	- 1	-10	+ 1	+10
CAE-2 — Limestone	-10	+19	- 2	- 7
— Granite	+10	- 5	+ 2	- 7
Stone Source:				
A	-20	- 2	+27	- 5
B	+ 4	+ 1	+ 1	- 6
D	-20	-12	+24	+ 8
F	+22	-14	-11	+ 3
G	-15	+ 6	- 4	+13
H	-22	+23	- 7	+ 6
I	-40	+38	- 6	+ 8
J	- 1	-10	+14	- 3
L	+28	- 4	-12	-12
Stone Size:				
#8	-10	- 2	+ 5	+ 7
#78	+ 1	- 1	0	0
Stone Type:				
Limestone	-18	+16	- 6	+ 8
Granite	+ 6	- 5	+ 2	- 3
Condition: Dry	+ 7	- 3	- 3	- 1
Wet	- 4	0	+ 3	+ 1
Clean	- 3	- 1	+ 3	+ 1
Dirty	+27	+ 1	-16	-12
Contractor: 1	-15	-11	+23	+ 3
2	+23	-15	-11	+ 3
3	-14	+11	+ 1	+ 2
4	- 9	+ 1	+ 8	0
5	+25	0	-13	-12

The quantitative variables judged to be significant were those for which the mean varied a relatively large amount between categories. The qualitative variables judged to be significant were those for which the percentage deviation by category from the total sample percentage breakdown was relatively large (Table V). Also, in judging which of the qualitative variables was significant consistency was regarded as intrinsic. For instance, if a variable had a negative deviation in the good and fair categories (such as stone source A), thus it must have been positive in the poor and very poor categories and would have been considered consistent. If, however, it had a negative deviation in the good category and a positive deviation in the fair category and like results in the poor and very poor categories (such as fair asphalt distribution), then it would have been considered inconsistent and less likely to be significant. Also, a large deviation in the good category with a corresponding opposite deviation in the very poor category (such as last rain) was judged to be the most likely indication of a significant variable.

Of the quantitative variables in Table III, it appears that air temperature, surface temperature, average vehicles daily, age at the time of evaluation, and, to a lesser extent AP-00 temperature were the most significant in influencing the rating of a job.

It is important to note averages by evaluation ranges are used to indicate which variables seem to be significant and, the variability in the data is quite high as indicated by the ranges shown for each category. This high variability indicates interaction effects of the variables. For instance, a low air temperature alone may not cause a poor job, but it may if combined with a high traffic volume. These interaction effects are discussed in more detail later in the report.

With regard to the qualitative variables shown in Tables IV and V, it appears that last rain (rains occurring within 24 hours prior to the job), asphalt source, stone source, stone conditions, and contractor had the most effect on the outcome of a job.

In an attempt to eliminate some of the interaction effects between the variables and thus to determine which variables are the most important, the variables which seemed to be most significant were analyzed in two additional ways as shown in Tables VI and VII. Table VI presents a breakdown of the apparently significant variables by District-Year groups. Table VII presents a list of the jobs rated very poor with the seemingly significant variables included, and also includes a list indicating the apparent reason for failure in each of the jobs.

It seems evident in looking at Table VI that some variables (AP-00 temperature and stone condition in particular) appeared to be significant because they were associated with other variables that were significant, such as air and surface temperature, AVD, age, and to a lesser extent, rain.

Air and surface temperatures clearly were significant variables. With the exception of District 1 — 1967 the average air and surface temperatures generally were higher as the average evaluation improved (decreased). The fact that air and surface temperatures were highest in District 1 — 1967, where the average evaluation was worst (highest), obviously indicates that several variables may, in fact, have been significant.

TABLE VI

ANALYSIS OF SIGNIFICANT VARIABLES BY DISTRICT-YEAR GROUP

District-Year	Ave. Eval.	Temp.		AP-00 Temp.	AVD	Age	Rain	Asphalt Source						Stone Source														Stone Cond.		Con.
		Air	Sur.					A	B	C	D	E	F	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Dirty	Clean	
1-67	3.20	83	105	—	270	14	3	28	-	-	-	-	-	11	2	3	10	-	-	-	-	-	-	-	-	-	-	3	25	1
2-67	3.18	70	77	310	222	18	0	-	12	6	1	-	-	-	-	-	-	-	19	-	-	-	-	-	-	-	-	0	19	2
3-67	3.11	74	83	301	222	8	7	-	-	-	-	15	17	-	-	-	-	-	-	16	11	10	-	-	-	-	-	4	33	3
1-68	2.76	69	84	—	165	6	10	1	-	41	-	-	-	19	16	-	-	-	-	-	-	-	-	-	-	-	5	0	42	4
5-68	2.65	76	96	—	269	10	3	-	-	7	-	-	23	-	-	-	-	-	-	-	-	-	23	5	-	-	-	1	30	3
4-67	2.18	79	93	—	147	8	0	-	-	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	6	-	14	16	5
2-68	2.09	81	98	348	180	9	0	-	7	15	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	0	22	2

TABLE VII

ANALYSIS OF SIGNIFICANT VARIABLES FOR EACH JOB RATED VERY POOR

District-Year	Site	Month Placed	Air Temperature °F	Surface Temperature °F	AVD	Age, Days	Variables Causing Very Poor Rating		
							Temperature °F	AVD	Age, Days
1-67	1	August	92	130	589	14		X	X
	4	August	72	86	416	14	X	X	X
	22	August	92	109	51	14			X
	23	August	85	125	51	14			X
2-67	9	October	49	56	457	18	X	X	X
	13	October	61	69	552	18	X	X	X
	15	October	70	73	174	18	X		X
	16	October	78	82	86	18			X
	18	October	66	71	174	18	X		X
	19	October	60	65	70	18	X		X
3-67	3	August	82	88	129	9			
	4	August	82	89	129	9			
	16	September	-	-	404	8		X	
	17	September	85	87	404	8		X	
	18	September	75	76	404	8	X	X	
	25	September	61	68	312	8	X	X	
	26	September	64	72	312	8	X	X	
	27	September	59	70	294	8	X	X	
1-68	3	April	64	82	210	6	X		
	29	May	62	78	210	6	X		
	30	May	60	80	210	6	X		
	32	May	66	70	210	6	X		
	33	May	70	94	210	6	X		
5-68	4	May	78	106	49	11			X
	18	May	70	96	430	11	X	X	X

1069

Incidently, it was said that AP-00 temperature may be significant because the average temperature was higher for the good rated jobs than for the jobs rated fair through very poor (Table III). However, in looking at Table VI it can be seen that AP-00 temperature was available in only three District-Year groups, and that the high temperatures occurred only in District 2 — 1968, which had the best overall average evaluation because of the favorable conditions of the other variables; viz., high air and surface temperature, low traffic volumes, relatively low age, and no rain. Thus, in the judgment of the authors the AP-00 temperature was not a significant variable.

Average vehicles daily also was significant. The AVD, with the exception of District 5 — 1968, generally was lower in the District-Year groups which had the best (lowest) average evaluation.

The age of the test section at the time of the evaluation was included in the analysis because the evaluations were made without allowing for the effects of age since it was felt such allowances would not be made in a reliable manner. As shown in Table VI, age was a significant variable in that the two District-Year groups with the worst (highest) average rating also had the highest average age by far. However, in looking at the other five District-Year groups, age does not appear to have been significant and other variables must have been the cause of the difference in the average evaluations.

Rain occurring within 24 hours prior to the job, in the opinion of the authors, was significant only because it often resulted in lower temperatures at the time the work was performed. Of the six times it rained prior to poor jobs, the air temperature was relatively low, 70°F. or less, four times. The remaining two times the air temperature was high, but the rain occurred sixteen hours prior to the job and most likely had little effect.

Asphalt source and stone source were extremely hard to evaluate because, as mentioned earlier, often there was only one source used in a District-Year group and with regard to stone a given source was never used in two separate districts. According to the information shown in Tables IV and V, it appears that Asphalt A performed worse than the other asphalt sources. However, as shown in Table VI, with the exception of one job, asphalt source A was used only in one District-Year group, and no other source was used in that group. Thus, while it may be true that the use of asphalt from source A contributes to poor jobs, this is impossible to prove from the available data.

It appears from the data shown in Tables IV and V that stone sources A, D, and perhaps G seemed to be significant in contributing to poor jobs, and stone source L seemed to be significant in contributing to good jobs. The situation with stone source L is similar to that with asphalt source A in that it was used in only one District-Year group, and in that group it was used in over 80% of the jobs. Therefore, there is no way to make a comparative analysis of stone source L and thus no definite conclusion can be drawn. With regard to stone sources A, D, and G, other stone sources were used in the same District-Year group. A comparative analysis was made within District-Year groups considering all stone sources which were used at least ten times. The results of this analysis are presented in Tables VIII and IX.

TABLE VIII

OCCURRENCES AND PERCENTAGES BY CATEGORY FOR SELECTED STONE SOURCES

	Occurrences by Evaluation Range					Percentage by Evaluation Ranges (Based on Applicable District-Year Group)			
Stone Source	Total	Good	Fair	Poor	Very Poor	Good	Fair	Poor	Very Poor
A & D	21	3	5	10	3	14	24	48	14
A	11	1	3	6	1	9	27	55	9
D	10	2	2	4	2	20	20	40	20
GH & I	37	6	19	4	8	16	51	11	22
G	16	4	6	2	4	25	38	12	25
H	11	2	6	1	2	18	55	9	18
I	10	0	7	1	2	0	70	10	20
A & B	35	12	12	10	1	34	34	29	3
A	19	5	6	7	1	26	32	37	5
B	16	7	6	3	0	44	38	18	0

TABLE IX

DEVIATION OF VARIABLE PERCENTAGE FROM DISTRICT-YEAR SAMPLE DISTRIBUTION PERCENTAGE BY CATEGORY

	Good	Fair	Poor	Very Poor
District 1 - 67				
A	- 5	+ 3	+ 7	- 5
D	+ 6	- 4	- 8	+ 6
District 3 - 67				
G	+ 9	-13	+ 1	+ 3
H	+ 2	+ 4	- 2	- 4
I	-16	+19	- 1	- 2
District 1 - 68				
A	- 8	- 2	+ 8	+ 2
B	+10	+ 4	-11	- 3

Based on the data shown in Tables VIII and IX it seems apparent that the difference in the aggregate sources was not significant. The only comparison which could be judged significant is that one between A and B in District 1 — 1968. However, in that case other variables may have influenced the outcome. Therefore, based on the available information neither stone source nor asphalt source can be termed significant.

It is obvious in looking at Table VI that stone condition appears to be significant, with dirty stone producing better results only because the vast majority of occurrences of dirty stone were in District 4-1967, where the overall results were good because of good conditions with regard to the variables thus far judged as significant (air temperature, AVD, and age).

Contractor is virtually impossible to evaluate as a variable since all the work in a District-Year group was performed by a single contractor. It does seem that, based on the experience of contractors 2 and 3 (Table VI), who had far different results in separate District-Year groups, other variables were far more significant than the contractor.

To summarize, air and surface temperatures, AVD, and the age of the pavement at the time of the evaluation seem to have been the most significant variables influencing the outcome of a surface treatment job.

A reviewing of Table VII indicates which of the three significant variables mentioned above may have helped cause the poor performance. Based on the averages shown for the very poor category in Table III an air temperature of 70°F. or below, a surface temperature of 85°F. or below, an AVD of 250 or more, and an age of ten or more months were considered to cause poor jobs. On the basis of this analysis temperatures were the most significant variables with age and AVD being about equal in importance. There were thirteen sites where age was not considered a factor; air and surface temperatures were considered significant in eight of these, while AVD was considered important in six. In only two cases was the poor result apparently unexplained, and in only four additional cases was age considered the only significant variable.

DETERMINATION OF ACCEPTABLE LIMITS FOR SIGNIFICANT VARIABLES

Age, of course, is not a controllable variable, but some control or at least consideration can be placed on air and surface temperature and AVD before placing surface treatments. The question that then arises is: What are the lowest acceptable air temperatures and surface temperatures and the highest AVD that will not contribute to poor results in surface treatments? Based on the data in Table III it has been noted that an air temperature below 70°F., a surface temperature below 85°F., and an AVD above 250 are not condusive to good results.

Before the actual control points were established, an analysis was made of the relationship of the air and surface temperatures in the hope that it would only be necessary to consider air temperature since surface temperature was relatively difficult to obtain. The results of this analysis are shown in Figure 1. It can be seen that even though the variability is quite high, there is, as expected, a strong relationship. Furthermore, the tentative 70°F. control point for air temperature corresponds to an 85°F surface temperature. There were only fifteen times that the surface temperature was below 85°F. when the air temperature was above 70°F., and only two of these fifteen jobs were rated as very poor. Thus, the authors feel that only air temperature need be considered.

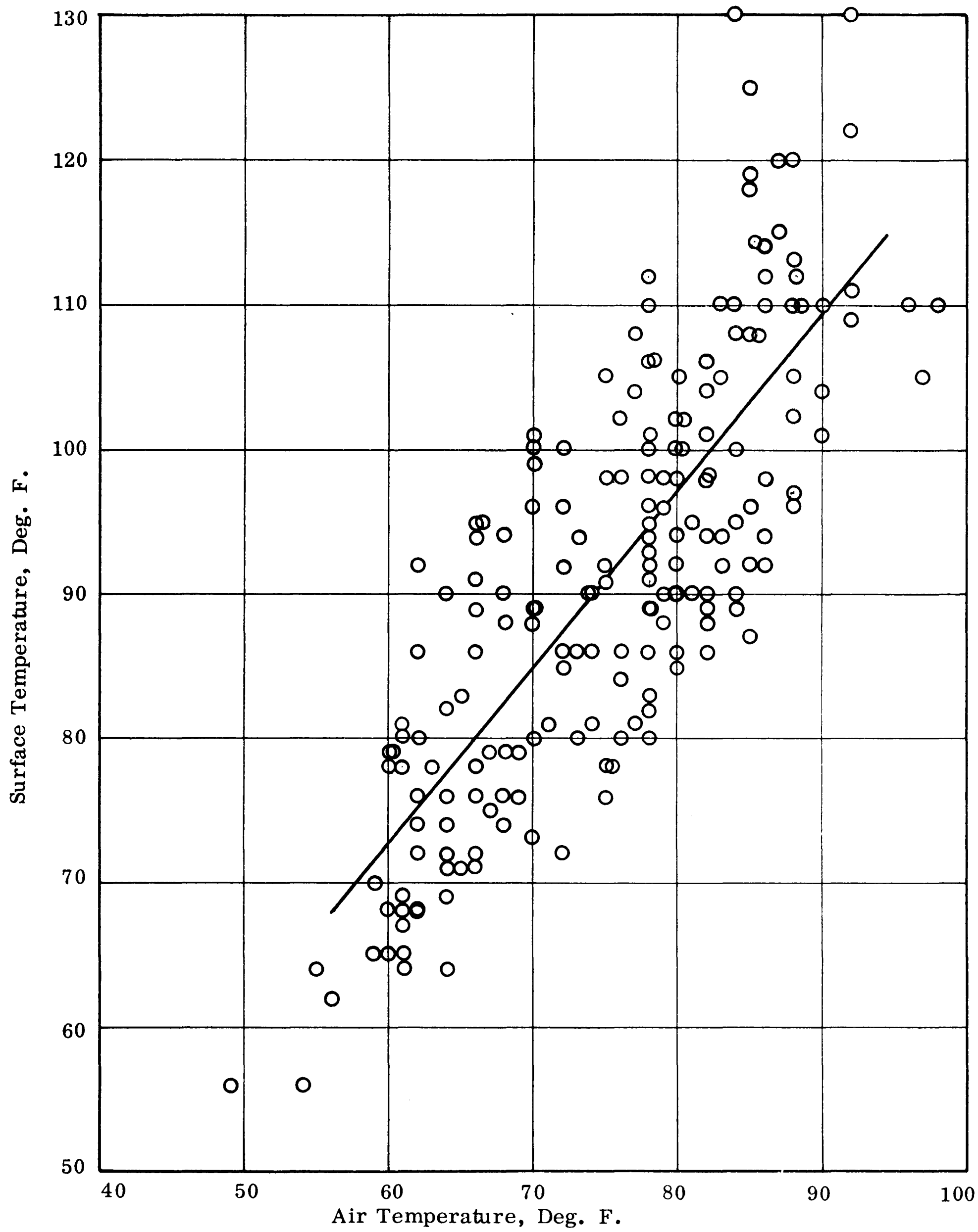

Figure 1. Relationship of air and surface temperature.

Table X presents data on the number of jobs in each category in which the air temperature was below the indicated cutoff temperature. The same information is shown in Figure 2 with the actual numbers being converted to percentage falling below the cutoff temperature.

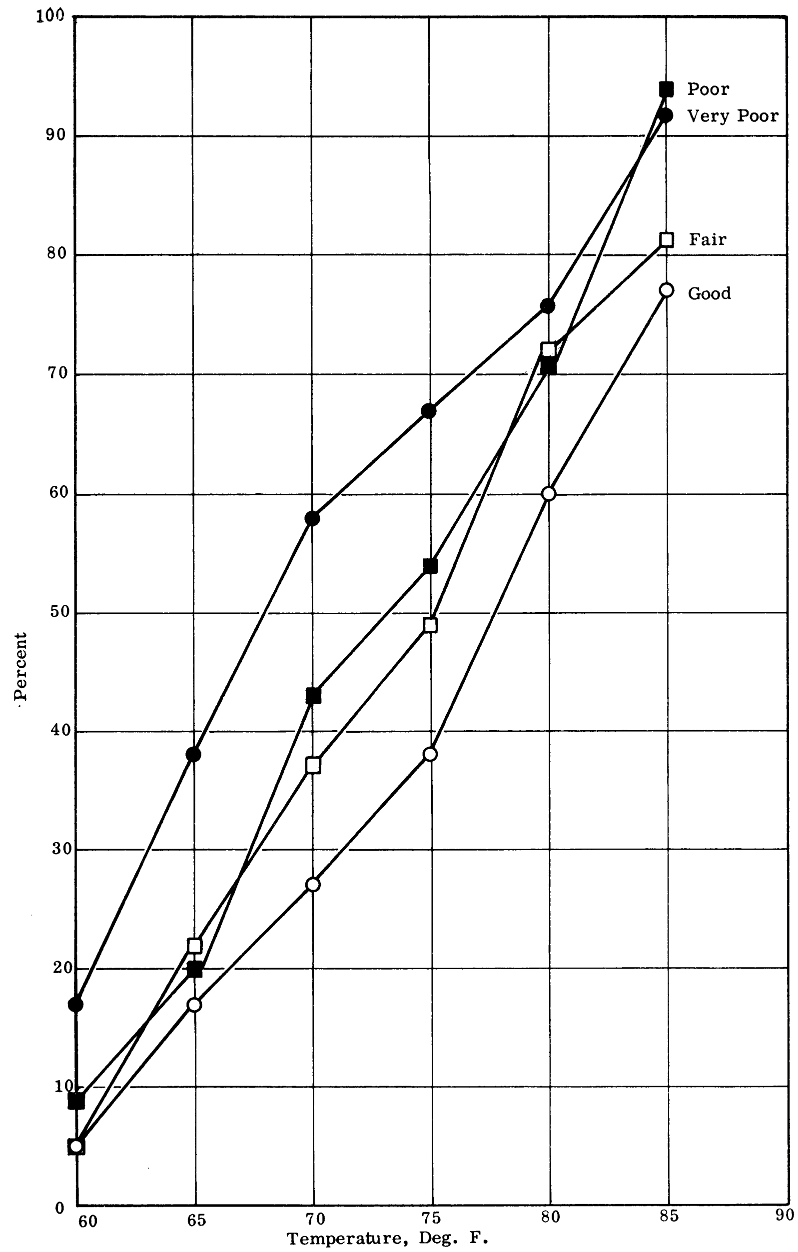

Figure 2. Percentage of jobs falling below stated temperatures.

As can be seen from Figure 2, there is little difference between the poor and fair categories. That is, each time the cutoff temperature is increased, approximately the same additional percentage of fair and poor jobs would be eliminated. However, up to 70°F. the additional percentage of very poor jobs eliminated by raising the cutoff temperature is greater than the additional percentage of good jobs eliminated. For instance, by raising the cutoff temperature from 65°F. to 70°F., an additional 20% of very poor jobs are eliminated while only an additional 10% of good jobs are eliminated. Above 70°F. the reverse is true; i.e., a greater (or equal) percentage of good jobs are eliminated than very poor jobs. Thus, from this analysis it appears that the decision to use 70°F. as the cutoff temperature was correct.

The final question regarding the 70°F. cutoff temperature is if the percentage of good jobs eliminated at this temperature level is acceptable. Looking again at Table X and Figure 2 it can be seen that at 70°F. 58% of the very poor jobs, 43% of the poor jobs, 37% of the fair jobs, and 27% of the good jobs would be eliminated. On a total basis, seventy-five of two hundred and seven, or 36%, of the jobs are eliminated.

It is particularly interesting to note the time of year the very poor jobs occurred and the time of year the jobs for which the air temperature was below 70°F. occurred. This information is shown in Tables XI and XII. It can be seen that of the seventy-five jobs eliminated, only sixteen, or 21%, occurred in the months of June, July, and August; while ninety-two, or 44% of all the jobs occurred in these three months. Also, only six, or 24% of the very poor jobs occurred in June, July, and August. Thus by adopting the 70°F. cutoff for air temperature the vast majority of jobs affected would be those done in the spring and fall months. The average evaluation and average air temperature by month are presented graphically in Figure 3.

Considering the data available the authors feel the 70°F. cutoff for air temperature is acceptable.

TABLE X

NUMBER OF JOBS FALLING BELOW CUTOFF TEMPERATURE

Cutoff Temperature, °F.	Good	Fair	Poor	Very Poor
60	4	3	3	4
65	14	15	7	9
70	22	25	15	14
75	31	33	19	16
80	49	48	25	18
85	62	54	33	22
Total Number of Jobs	81	67	35	24

TABLE XI

AIR TEMPERATURE DATA BY MONTHS

Temperature, $^{o}F.$	April	May	June	July	Aug.	Sept.	Oct.	Total
$\leq$ 60	3	3				5	3	14
61 - 65	8	7	2		5	5	3	30
66 - 70	3	12	7		2	5	2	31
71 - 75	1	7	1		5	7	2	23
76 - 80	2	7	5		9	16	2	41
81 - 85			3	2	22	8	1	36
$\geq$ 85			12	1	16	3		32
Total	17	36	30	3	59	49	13	207
Approximate $\overline{X}$	65^{o}	69^{o}	78^{o}	83^{o}	79^{o}	74^{o}	68^{o}	

TABLE XII

JOB BREAKDOWN BY MONTH

Rating	April	May	June	July	Aug.	Sept.	Oct.	Total
Good	3	14	19	3	25	19	1	84
Fair	6	9	13		15	20	4	67
Poor	7	9	1		13	4	2	36
Very Poor	1	6			6	6	6	25
Total	17	38	33	3	59	49	13	212
Approximate $\overline{X}$	2.8	2.7	2.0	1.5	2.5	2.5	3.5	

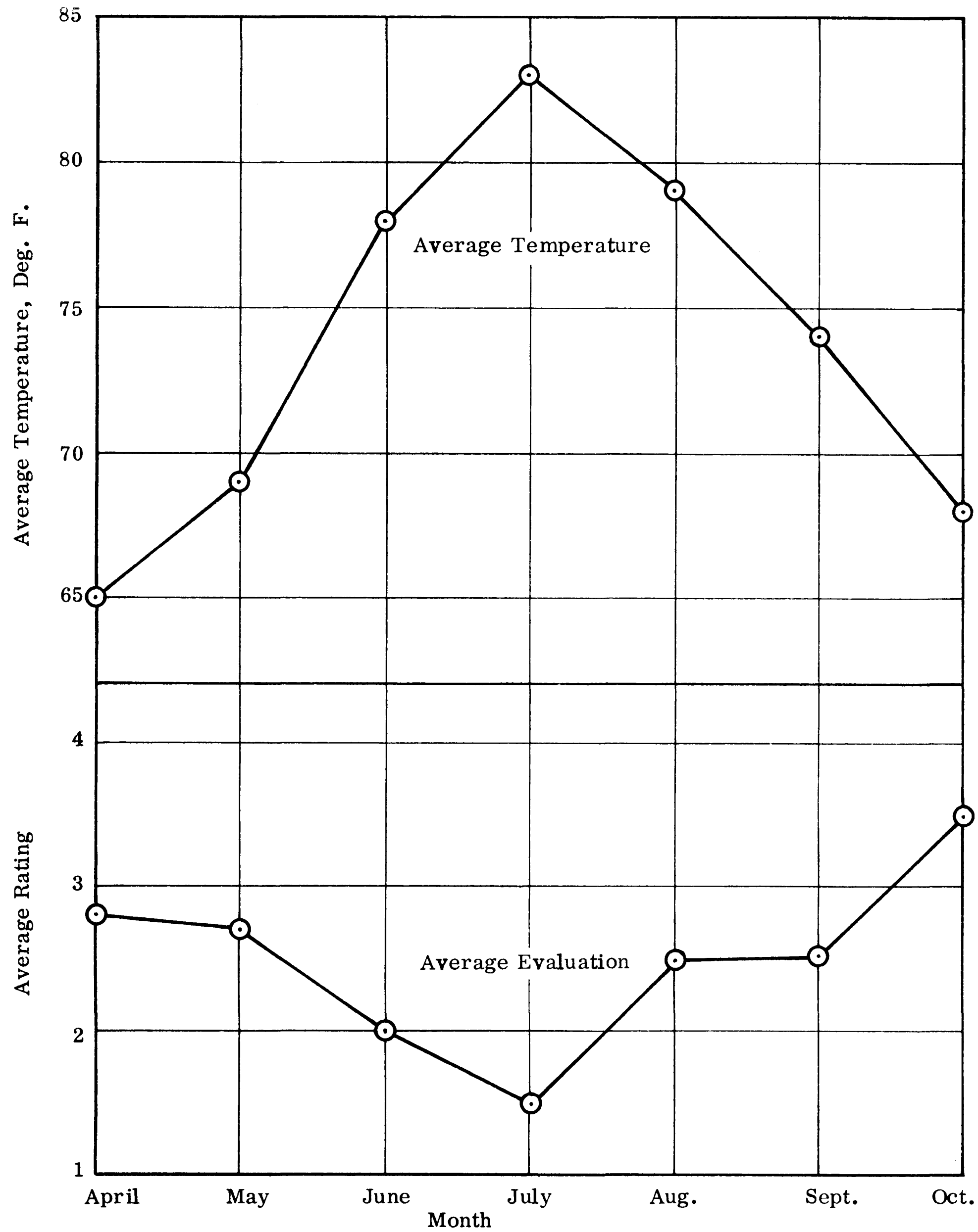

Figure 3. Average air temperature and average evaluation by month.

The same type of analysis that was made for air temperature was made for AVD and the results are shown in Table XIII and Figure 4. As can be seen in Figure 4 the curves are roughly parallel except at about 400 AVD and above. Thus, it appears that if a control point was used for AVD it should be approximately 400 AVD rather than the 250 AVD figure mentioned earlier. For the data in this study, this would eliminate thirty-five jobs (17%) in total with eight (32%) being very poor rated jobs and seven (9%) being good jobs. The enforcement of both the air temperature and AVD limits together would have eliminated 49% of the jobs in this study.

TABLE XIII

NUMBER OF JOBS FALLING BELOW INDICATED AVERAGE VEHICLES DAILY

Volumn	Good	Fair	Poor	Very Poor
< 50 AVD	9	9	2	0
< 100 AVD	27	28	8	2
< 150 AVD	48	33	15	7
< 200 AVD	56	38	18	9
< 250 AVD	64	48	20	14
< 300 AVD	65	49	25	15
< 350 AVD	71	53	26	17
< 400 AVD	73	55	26	17
< 450 AVD	74	58	32	22
Total	80	66	35	25

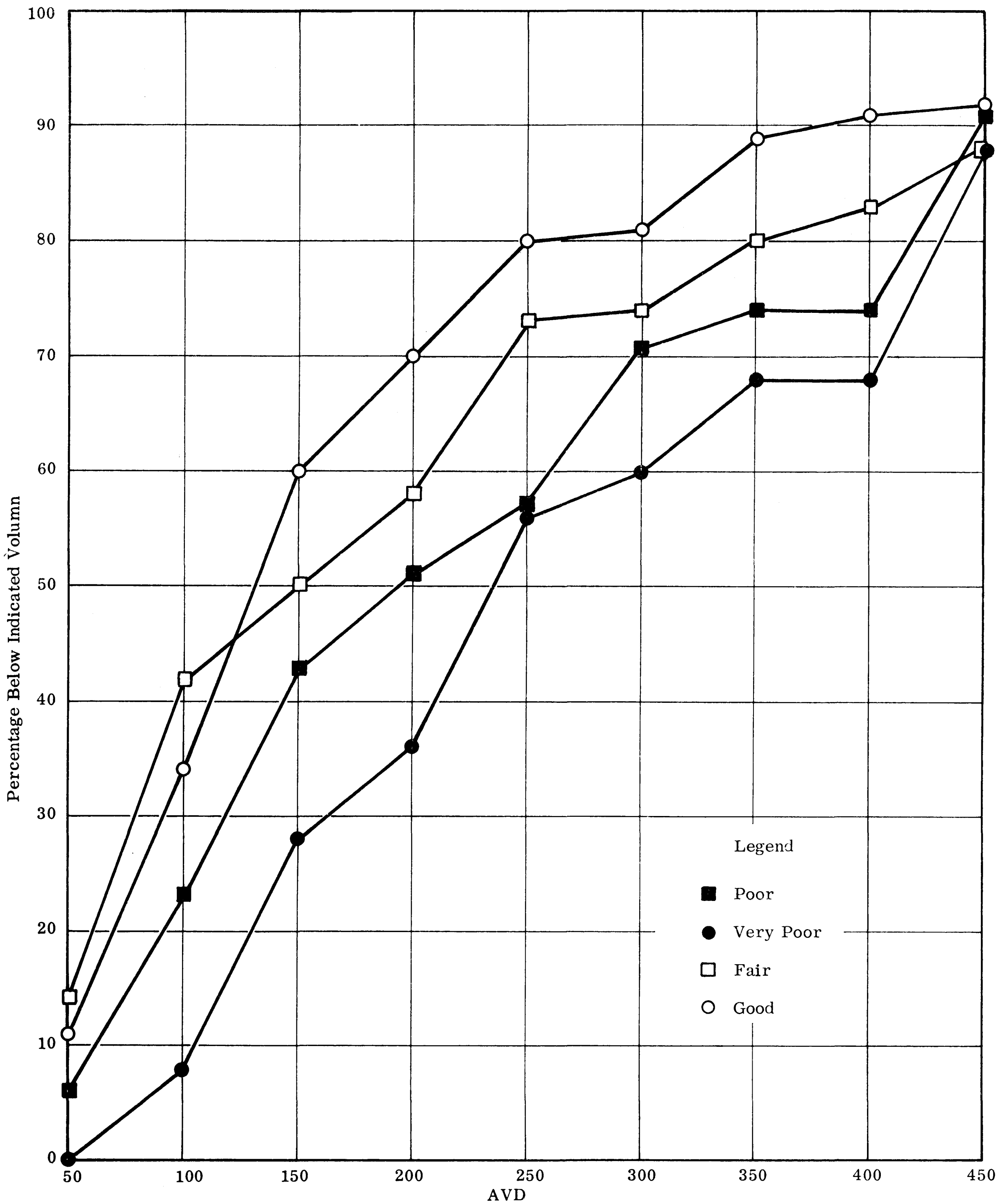

Figure 4. Percentage of jobs falling below indicated average vehicles daily.

SUMMARY AND CONCLUSIONS

Of the many variables included in this study air temperature, surface temperature, average vehicles daily, and age at the time of evaluation, seem to most significantly affect the performance of a surface treatment. Three of these variables air temperature, surface temperature and AVD, are controllable and one, age, is not controllable.

Based on the information obtained in this study it appears that the lower limit for air temperature should be 70^{o}F. and the upper limit for AVD should be approximately 400 AVD, assuming procedures for surface treatment work remain the same as encountered in this project. It was found that air and surface temperature correlate well and it is only necessary to control one. Air temperature was chosen as the one to control since it is easier to measure.

The total sample percentage distribution in this study as shown in Table IV was 40% good, 32% fair, 16% poor, and 12% very poor. Based on the data obtained in this study, adoption of the guidelines suggested above for air temperature and AVD would have changed the percentage distribution to 47% good, 39% fair, 10% poor, and 4% very poor.

RECOMMENDATIONS

If the Highway Department desires an 86% chance of obtaining a fair or good job as opposed to the 72% chance found in this study then the limits of 70^{o}F. air temperature or above and 400 AVD or below should be adopted. It should be recognized, however, that these limits would have eliminated 49% of the jobs evaluated in this study, with most of the jobs eliminated having been placed in the spring or fall months.

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1. Mahone, David C., "Bituminous Surface Treatment Study — Installation and Evaluation of Surface Treatment Test Sections Placed by a Design Method", Virginia Highway Research Council, June 1967.

2. Mahone, David C., and Howard E. Cobb, "Bituminous Surface Treatment — Evaluation of Efforts Directed Toward Improving Upon Bituminous Distributors and Surface Treatment Training", Virginia Highway Research Council, June 1967.

3. Mahone, David C., and Stephen N. Runkle, "Control of Binder Distribution in Bituminous Surface Treatments", Virginia Highway Research Council, a paper presented to the Annual Meeting of the Highway Research Board, Washington, D.C., January 1968.

4. Mahone, David C., "Study of Bituminous Surface Treatments in Virginia — Phase II — Summer 1964: Distribution Characteristics of Materials — Effectiveness of One Size Aggregate — Setting Time", Virginia Highway Research Council, VHRC 70-R22, Summer 1965, Issued November 1970.

5. Arnold, E. D., Jr., "Effect of Moisture on Typical Virginia Surface Treatment Materials", Virginia Highway Research Council, VHRC 70-R21, March 1968, Issued November 1970.

APPENDIX

SURFACE TREATMENT DATA SHEET

GENERAL INFORMATION Date ______________

Inspector ______________

District ______________ County ______________ Route ______________

Work Begins ______________

Work Ends ______________

Contractor ______________ Foreman ______________

Distributor Make ______________ Capacity ______________

Age ______________ Driver ______________ Boot ______________

Chip Spreader Type ______________ Operator ______________

Weather Forecast ______________

% Chance of Rain ______________ Wind ______________

Previous Night Low Temperature ______________ Day's High Temperature ______________

Site Information:

Site I Time ______________

Precise Location ______________

____

____

____

Surface Condition: ___Open___ ___Smooth___ ___Wet___ ___Damp___

___Dry___ ___Shade___

Surface Temperature ______________ Air Temperature ______________

Humidity ________ Wind ________ Last Rain Time Lapse ______________ Inches ______________

Rains After Placement for 72 Hours Time Lapse and Inches: (1) ________ (2) ______________

(3) ______________ (4) ______________

Asphalt Source ______________ Asphalt Type ______________

Distributor Load in Gal. Prior to Shot ______________ After Shot ______________

Sq. Yds. Covered ______________ Asphalt Temperature ______________

Distributor Characteristics: Good ______ Fair ______ Poor ______ Streaked ______

Time Started ______________ Time Finished ______________

1084

Stone Source Including Address: ______________________________

______________________ Type Stone ____________ Size Stone ____________

Stone: Dry ______ Dusty ______ Damp ______ Wet ______ Dirty ____________

Time Started ______________________ Time Finished ______________________

Tons Stone Used ____________________ Sq. Yds. Covered ____________________

Rollers

Steel Wheel ______ No. Wheels ______ Wt. ______ Coverage ______________

Pneumatic _______ No. Wheels __________ Wt. _________ Coverage ____________

Time Started ____________________ Time Finished ____________________

Time Opened to Traffic ______________________________

AVD ______________________________________

Additional information (Particularly that which needs explaining concerning the above)