evaluation of minor improvements

grooved pavement (supplemental report) part 8, Sept '75

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16. Abstract
This report was prepared to check the validity of the findings of an earlier report. This report substantiates the findings of the report on this same subject published in December 1972.

A "before and after" technique was used to evaluate 322 lane-miles of grooved portland cement concrete pavement on State freeways in Los Angeles. In addition, 750 lane-miles of ungrooved PCC pavement were used as a "control". Accidents (fatal and injury only) were evaluated for a two-year before and after period on both the grooved and ungrooved sections of freeway.

Grooving produced an average 69% reduction in wet pavement accident rates on the 23 projects studied. Dry pavement accident rates did not change. Sideswipe and hit object accidents had the largest reductions during wet weather. Grooving did not appear to have an adverse effect on motorcycle safety during either wet or dry conditions.

A different method was developed to predict wet pavement accident rates after grooving on future projects. The method depends on accounting for any trends in the wet and dry pavement accident rates that have occurred in the past. Even after grooving, the wet pavement rates can be expected to be about four times the dry accident rates.

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was prepared by the California Department of Transportation, Office of Traffic

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FOREWORD

An earlier study reported the effectiveness of pavement grooving in reducing accidents and presented a method of predicting wet pavement accidents after grooving (1). The original study has been questioned on the following grounds:

1. Only a limited mileage of grooved pavement was available for study (34 lane-miles).

2. There was limited wet pavement travel exposure (about 11 million vehicle miles in the before period and 12 mvm in the after period).

3. The sections were not grooved to the State's current standards (0.095-inch wide, by 1/8 inch deep, on 3/4-inch centers).

4. Limited accident data was available on the question of motorcycle safety (a total of 15 motorcycle accidents).

This current study was designed to overcome the shortcomings of the original study, and to check the validity of the earlier findings.

ACKNOWLEDGMENTS

The authors would like to thank James I. Karr and Milburn Guillory who designed this study and completed the original data analyses on this project.

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(1) See References, Page 29.

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ABBREVIATIONS

AADT	Average Annual Daily Traffic
Acc	Accident
CHP	California Highway Patrol
F+I	Fatal plus Injury Accident
MV	Million Vehicles
MVM	Million Vehicle Miles
PCC	Portland Cement Concrete
PDO	Property Damage Only
PW	Percent of Wet Time

I. SUMMARY

This report describes a two-year before and after study of grooved Portland Cement Concrete (PCC) pavement. All of the grooved pavement sections, as well as the ungrooved control sections, are located on freeways in the urbanized part of Los Angeles County. This supplemental report includes 322 lane-miles of grooved pavement. The control sections consisted of 750 lane-miles of ungrooved PCC pavement. This study included only projects grooved to the State's current specifications.

Fatal and injury accidents only were included in this study. Property Damage Only accidents were excluded because of a change in accident reporting procedures during the study period.

Average daily traffic varied from 60,000 to 200,000 on these freeway study sections. For the grooved sections, total traffic exposure was over 4,000 million vehicle miles (mvm) on dry pavement and about 70 mvm on wet pavement in each of the before and after periods. Exposure on the control sections was about twice these amounts.

Wet pavement accident rates decreased an average of 70% on the 23 projects, compared to a 2% reduction on the control sections. An average reduction of 69% in wet pavement accident rates is attributed to the grooving. Reductions in wet pavement rates were significant (at the 90% confidence level) on 17 of the 23 projects. Dry pavement accident rates did not change as a result of the grooving. These findings confirm the results of the original study.

Although there have been questions about the adverse effect that grooved pavement may have on motorcycle safety, there is no indication from the data that grooving causes motorcycle accidents. There were five wet pavement motorcycle accidents during the before period and two during the after period on the grooved sections. There were 114 dry pavement motorcycle accidents before grooving and 102 after. The reduction in dry pavement accidents is significant if it is assumed that motorcycle travel increased in proportion to registrations. (Actual motorcycle travel is unknown.)

By accident types, the largest reductions in wet pavement accidents were in sideswipe and hit object accidents. Rear-end and miscellaneous accidents showed the next largest reduction, and head-on accidents decreased the least.

It was concluded that grooving produced an average 69% decrease in wet pavement accident rates for the particular projects studied. A different method was developed to predict wet pavement accident rates to be expected after grooving on future projects. This method depends on accounting for any trends in the wet and dry pavement accident rates that have occurred in the past. After grooving, the predicted wet pavement accident rates will be about four times the dry pavement rates.

II. BASIC INFORMATION

A. Grooved Projects

This supplemental study includes 23 projects, with a total length of 322 lane-miles of grooving. All of the projects are on freeways in the urbanized area of Los Angeles County, and the pavement surface on all projects is Portland Cement Concrete (PCC). The projects ranged from 0.40 miles to 3.20 miles in length. (In the original study, the project lengths ranged from 0.04 to 1.31 miles long, with only two projects 0.5 miles or longer.)

All projects were grooved to the State's current standards -- 0.095-inch wide , by 1/8-inch deep, on 3/4-inch centers (2). See Appendix B for current specifications. (The original study included nine different grooving patterns.)

Control sections were used in the accident analyses. The control sections consisted of ungrooved, urbanized area, PCC freeways in Los Angeles County with a total length of 108 miles (approximately 750 lane-miles).

B. Accident Data

Two-year before and two-year after periods were used in the accident analyses for both the grooved and control sections.* All ramp accidents were excluded. In addition, Property Damage Only (PDO) accidents were excluded from this study because of a change in

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*"Control sections" refer to the sections that remained ungrooved. The treated sections are referred to as "grooved sections", even though they were ungrooved in the before period.

reporting procedures. The California Highway Patrol (CHP) began taking over jurisdiction of the Los Angeles area freeways from the City of Los Angeles in April 1968 and completed the takeover in October 1969. This change in jurisdiction occurred during the study period. An earlier study showed that, in general, a higher percentage of PDO accidents are reported by the CHP than by city police departments. Reporting levels for fatal and injury accidents were nearly the same for all jurisdictions (3). In fact, a check of the accident data in this study for both the grooved and control sections indicates that 65% of all accidents in the before period were PDO, compared to 75% in the after period. Since no reason for this change was apparent, other than the change in reporting jurisdiction, it was decided to omit the PDO accidents from the analyses. (The original study included PDO accidents.)

Roadway surface condition is determined by the police officer in the field and coded on the accident report forms. The codes for roadway surface condition are: wet, dry, snowy or icy, and slippery from mud, oil, etc. Those accidents coded wet were tabulated as wet pavement accidents; those coded dry were tabulated as dry pavement accidents; and the remaining miscellaneous accidents (very few in number) were excluded from the study. (The original study included the miscellaneous accidents.)

C. Traffic Volumes

Since all the project locations are on Los Angeles urban freeways, traffic volumes are high. Annual average daily traffic (AADT) varied from a low of about 60,000 to nearly 200,000. (Most of the original projects were also on high volume Los Angeles freeways.)

The total traffic exposure (travel during both wet and dry pavement conditions) on the grooved projects was 4,300 million vehicle miles (mvm) in the before period and 4,400 mvm in the after period. (This is ten times the travel included in the original study.) More importantly, the 70 mvm of travel under wet pavement conditions on the grooved pavement was substantially higher in this study. (There was only 11 mvm of wet pavement travel in the original study.) See Section E below for definition of travel under wet pavement conditions.

D. Rainfall

Data on annual rainfall and the number of hours during which 0.01 inch or more rain fell were obtained from 12 continuous recording weather stations operated by the U.S. Department of Commerce (4). Individual rainfall data for each of the 23 grooved projects were obtained from the weather station nearest to that project. The stations were generally within ten miles of the project location. The average rainfall of all 12 weather stations was used for the control sections, since these stations were relatively well dispersed in relation to these control sections.

Figure 1 shows the average annual rainfall from the 12 weather stations, along with the before and after time periods of the individual grooved projects. Variation of rainfall at the different stations was not extremely large. For example, in 1970 the average

ANNUAL RAINFALL AND BEFORE AND AFTER PERIODS

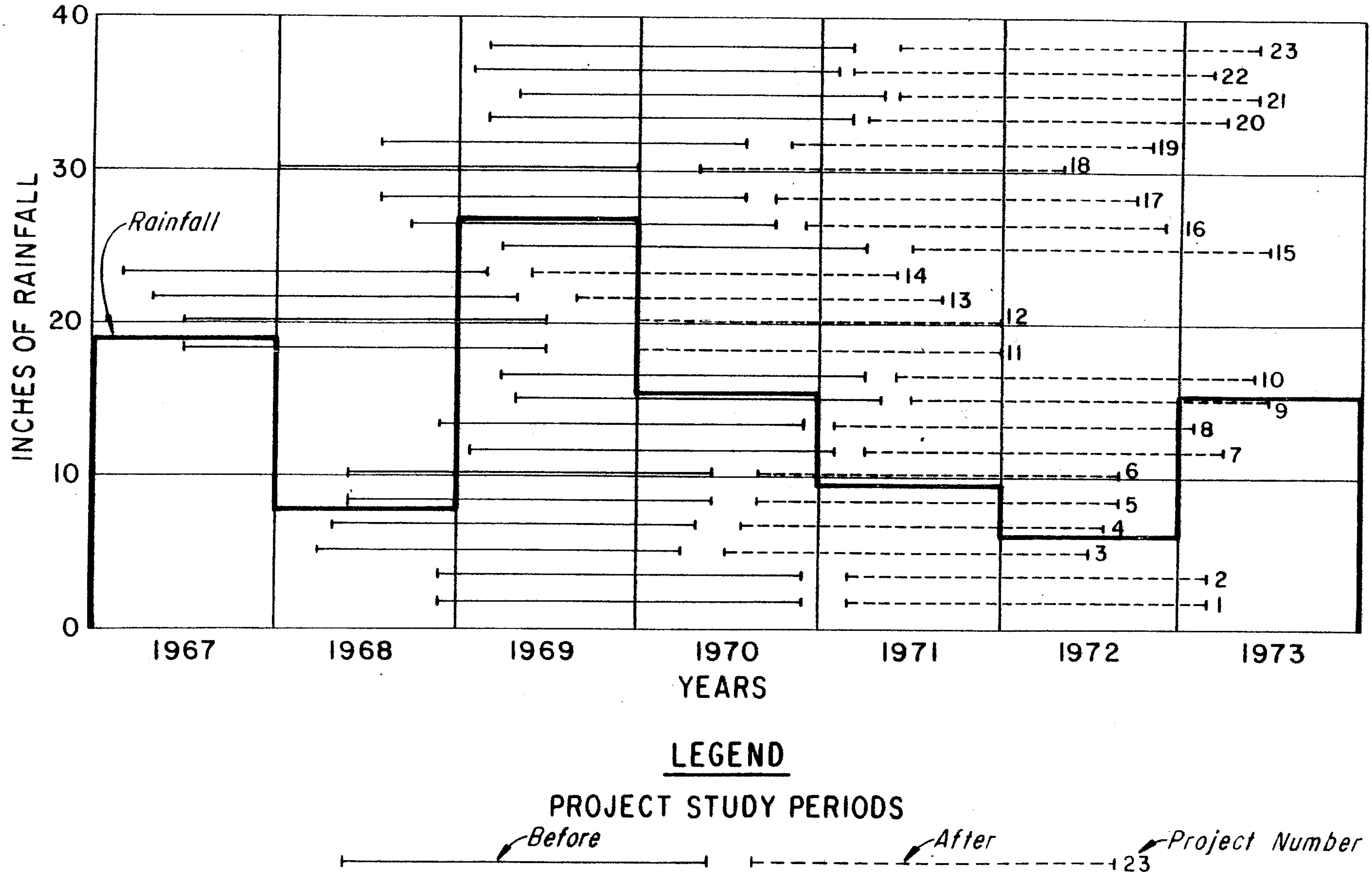


Figure 1

rainfall for all stations was 16.27 inches. The highest station recorded 21.92 inches, and the lowest station recorded 11.32 inches. (These same procedures were used in the original study.)

E. Wet Pavement Exposure (Travel)

An earlier study concluded that a rainfall rate of 0.01 inch per hour or more is necessary to keep the pavement wet throughout the hour (5). Therefore, travel occurring during any hour with 0.01 inch or more of rain was calculated as wet pavement travel.

Since peak travel periods, (usually summer) do not normally coincide with the rainy months (usually winter), an adjustment factor (K) is required. The equation used to compute wet pavement travel is:

$$WE = K \cdot PW_{0.01} \cdot AADT \cdot T \cdot L$$

WE = Wet Pavement Exposure (million vehicle miles)

K = 0.98 (1 - 0.44R)

R = Average summer month ADT less average winter month ADT divided by AADT (Typically, R is near zero in Los Angeles.)

$PW_{0.01}$ = Proportion of wet time (in decimal)

AADT = Average annual daily traffic (million vehicles)

T = Length of time (days)

L = Length of project (miles)

(This equation was also used in the original study.)

III. STUDY RESULTS

A. General Results

Table 1 summarizes the results of this two-year before and after study of PCC grooving on Los Angeles freeways. Pertinent points are: 1) the wet pavement fatal plus injury accident rate on the grooved sections decreased 70%, whereas the wet accident rate decreased only 2% on the control sections; 2) the dry pavement accident rates on both the grooved and control sections decreased about 20%. A check of all urban freeways in District 07 (Los Angeles, Orange and Ventura Counties) shows that fatal plus injury accident rates decreased 23% between 1969-1970 (which is roughly the before period - See Figure 1) and 1971-1972 (roughly the after period). Thus, the control sections that were selected are representative. From the above, it can be concluded that grooving reduces wet pavement accidents, but has no effect on dry pavement accident rates.

It is also interesting to note the ratio of wet pavement accident rates to dry pavement accident rates. These are: grooved sections, 10.7:1 before, 4.1:1 after; control sections, 6.3:1 before, 8.2:1 after.

Table 2 shows the changes in accidents by severity classification. Fatal accidents decreased more than injury accidents during both wet and dry pavement conditions, and on both the grooved and control sections. However, the fatal accident rate decreases are not significantly greater than injury accident rate decreases.

Table 1

PCC GROOVING SUMMARY
(Fatal plus Injury Accidents)

Pavement Condition	Accidents			*Rates		
	Before	After	% Change	Before	After	% Change
Grooved Sections						
Wet	528	126	- 76%	6.07	1.83	- 70%
Dry	2,407	1,981	- 18	0.57	0.45	- 21
Wet + Dry	2,935	2,107	- 28	0.68	0.48	- 29
Travel (MVM)						
Wet	87	69	- 21			
Dry	4,225	4,362	+ 3			
Wet + Dry	4,312	4,431	+ 3			
Control Sections (Ungrooved)						
Wet	594	440	- 26%	2.83	2.78	- 2%
Dry	3,977	3,295	- 17	0.45	0.34	- 24
Wet + Dry	4,571	3,735	- 18	0.50	0.38	- 24
Travel (MVM)						
Wet	210	158	- 25			
Dry	8,857	9,660	+ 9			
Wet + Dry	9,067	9,818	+ 8			

Note: * Rates are accidents per million vehicle miles.

Table 2

ACCIDENTS BY SEVERITY
ON PCC PAVEMENTS
(Fatal plus Injury)

Accident Severity	Wet Pavement						Dry Pavement					
	Accidents			*Rates			Accidents			*Rates		
	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change
Grooved Sections												
Fatal	9	1	- 89%	0.103	0.014	- 86%	43	30	- 30%	0.010	0.007	- 32%
Injury	519	125	- 76	5.97	1.81	- 70	2,364	1,951	- 17	0.56	0.45	- 20
Fatal & Injury	528	126	- 76	6.07	1.83	- 70	2,407	1,981	- 18	0.57	0.45	- 20
MVM	87	69	- 21				4,225	4,362	+ 3			
Control Sections (Ungrooved)												
Fatal	16	9	- 44%	0.076	0.057	- 25%	112	83	- 26%	0.013	0.009	- 32%
Injury	578	431	- 25	2.75	2.73	- 1	3,865	3,212	- 17	0.44	0.33	- 24
Fatal & Injury	594	440	- 26	2.83	2.78	- 2	3,977	3,295	- 17	0.45	0.34	- 24
MVM	210	158	- 25				8,857	9,660	+ 9			

Note: * Rates are accidents per million vehicle miles.

The interpretation of these results and the prediction of the improvement to be expected from future grooving projects are included in Section IV. The overall results (i.e., the reduction of 70% in wet pavement accident rates) is nearly the same as in the earlier report - 73%.

Not all grooving projects improved, of course, or improved by the same amount. Table 3 shows the number of projects on which the accident rates (wet, dry, and wet plus dry) improved or became worse after grooving. Also shown in Table 3 are the number of projects for which the changes in accident rates were significant, using the Chi-Square test at the 90% confidence level. (See Appendix A, Section D, for development of the test equations.)

Figure 2 is a plot of the percent change in wet pavement accident rates vs. the cumulative number of projects. For example, 70% of the projects had a reduction in wet pavement accident rates of 60% or more. Figure 3 shows graphically the statistical significance tests of the changes in wet pavement accident rates for the 23 individual projects.

In regard to the wet pavement condition, 22 of the 23 projects improved (i.e., the wet pavement accident rate after grooving was less than the rate before). Seventeen of these 22 projects improved significantly at the 90% confidence level. One project became worse, but this change was not significant.

In regard to dry pavement accident rates, 18 projects improved and five became worse. Eleven projects improved significantly,

Table 3

GROOVED PROJECTS
SIGNIFICANCE OF CHANGES
PCC PAVEMENT
(Fatal plus Injury Accidents)

Pavement Condition	All Projects				+Significant Changes			
	*Improved		Worsened		Improved		Worsened	
	No	%	No	%	No	%	No	%
Wet	22	96	1	4	17	74	0	0
Dry	18	78	5	22	11	48	2	9
Wet and Dry	21	91	2	9	17	74	1	4

Note: *The project improved if the after accident rate was less than the before accident rate.

+Significantly improved or worsened at the 90% confidence level using Chi-Square test.

PERCENT CHANGE IN WET ACCIDENTS

RATES OF PCC GROOVING
(FATAL PLUS INJURY ACCIDENTS)

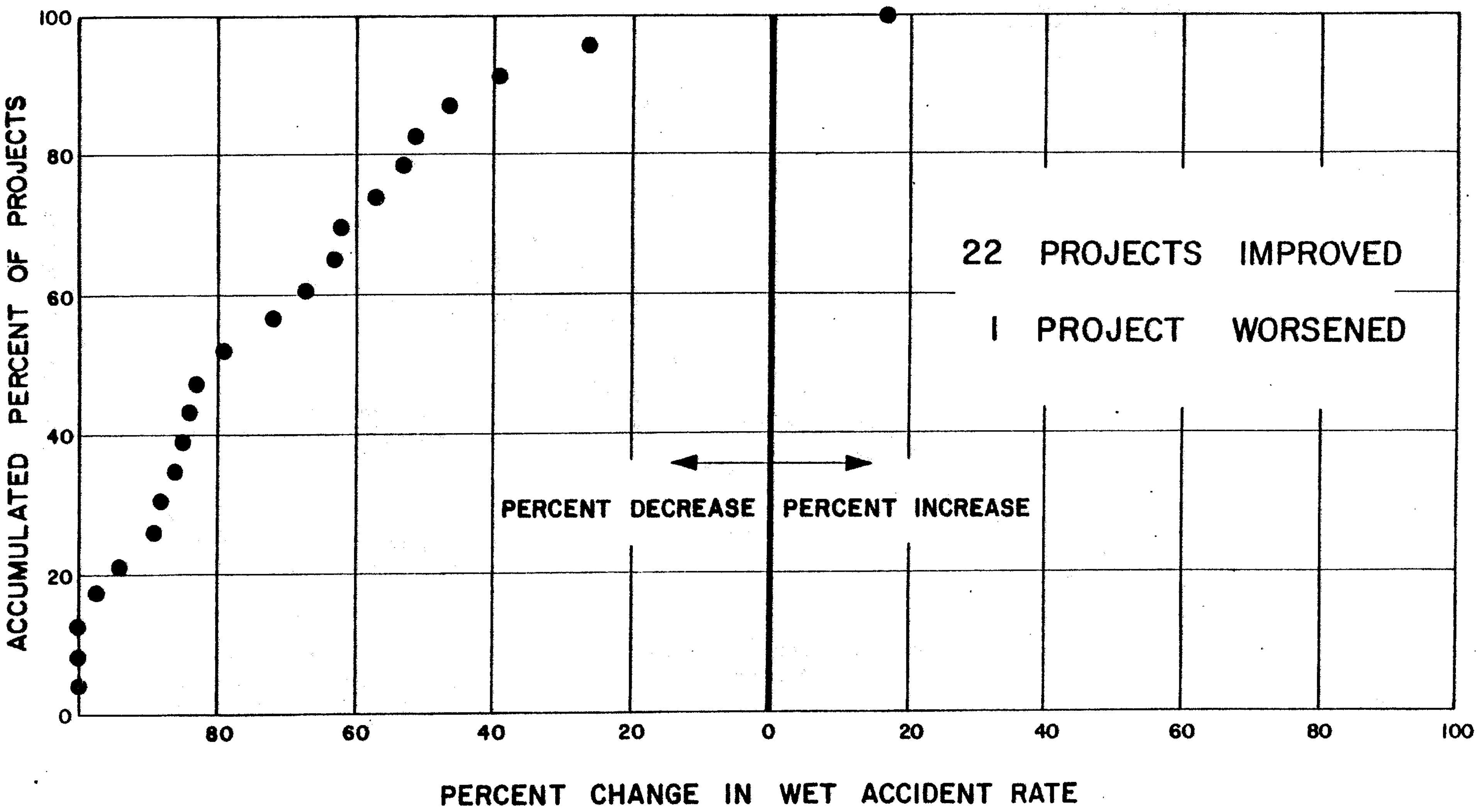
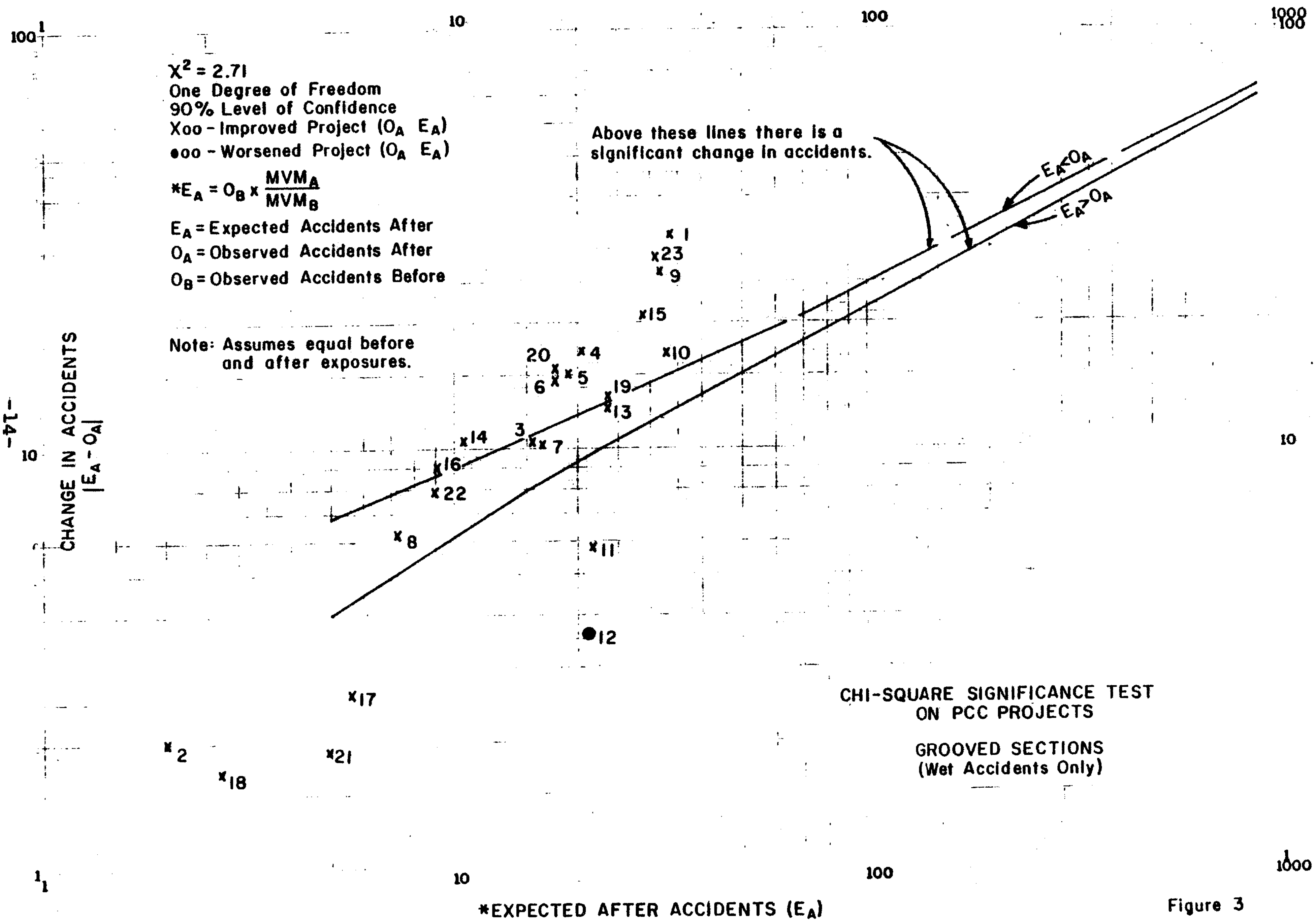


Figure 2



χ² = 2.71
One Degree of Freedom
90% Level of Confidence
Xoo - Improved Project (O_A E_A)
●oo - Worsened Project (O_A E_A)
*E_A = O_B x MVM_A / MVM_B
E_A = Expected Accidents After
O_A = Observed Accidents After
O_B = Observed Accidents Before
Note: Assumes equal before and after exposures.
Above these lines there is a significant change in accidents.
E_A<O_A
E_A>O_A
CHANGE IN ACCIDENTS |E_A - O_A|
*EXPECTED AFTER ACCIDENTS (E_A)
CHI-SQUARE SIGNIFICANCE TEST ON PCC PROJECTS
GROOVED SECTIONS (Wet Accidents Only)
1
10
100
1000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Figure 3

two projects became significantly worse, and ten did not change significantly.

Tables C-1 through C-4 of Appendix C contain information about the individual grooving projects, including location, hours of wet time, accidents, accident rates and travel before and after grooving. Table C-5 shows statistical test data.

B. Motorcycle Results

The motorcycle population has increased considerably in recent years and questions have been raised as to the effect of grooves on motorcycle safety. Letters have been received from motorcyclists complaining about unstable conditions ("wobbles") and supposed crashes caused by grooves. The California Department of Transportation conducted an extensive study to determine if motorcycle safety was impaired by pavement grooving. Seven motorcycles, ranging from one of the smallest legally allowed on California freeways to one of the largest, were repeatedly driven over sections of grooved pavements by two experienced motorcyclists. The grooving did not present a hazardous riding condition. In general, the lighter machines were more sensitive to the grooving patterns; however, none had a sensitivity level sufficient to cause a control problem in the judgment of these riders (6).

Motorcycle accidents for the two-year before and after periods on the grooved and control sections are shown in Table 4. Since it is possible that grooves could affect both wet and dry pavement accidents, data for both conditions are shown. The average number

Table 4

MOTORCYCLE ACCIDENTS
(Fatal plus Injury Accidents)

Pavement Condition	Grooved Sections			Control Sections (Ungrooved)		
	Accidents			Accidents		
	Before	After	% Change	Before	After	% Change
Wet	5	2	- 60% ns	2	11	+ 450% s
Dry	114	102	- 11 s	171	194	+ 13 ns
Wet & Dry	119	104	- 13 s	173	205	+ 18 ns

Notes:
X^2 at 90% confidence level
s = significant change
ns = not significant
Under assumption that motorcycle travel increased in proportion to motorcycle registration.

MOTORCYCLE REGISTRATIONS
(Los Angeles County)

Before	After	% Change
165,000	189,000	+ 14.5

of motorcycle registrations in Los Angeles County during the before and after periods are also shown in the table.

The number of motorcycle accidents decreased from 119 to 104 on the grooved sections and increased from 173 to 205 on the control sections. There were two fatal accidents involving motorcycles in the before period and four in the after period on the grooved sections. All six of these accidents were on dry pavement. On the control sections, there were six fatal accidents involving motorcycles in the before period and 12 in the after period. One of these accidents was on wet pavement.

Actual travel by motorcycles is unknown. Three assumptions can be made: 1) motorcycle travel increased on both the grooved and control sections in proportion to registrations; 2) motorcycle travel did not change between the before and after periods; 3) motorcycle travel decreased on the grooved sections because riders avoided the discomfort of the grooves.

If it is assumed that travel increased in proportion to motorcycle registrations, then there were significant changes (at the 90% confidence level) as indicated in the table. That is, dry pavement accidents decreased significantly on the grooved sections, and wet pavement accidents increased significantly on the control sections. If it is assumed that motorcycle travel did not change between the before and after periods, the decreases in accidents on the grooved pavement are not significant; on the control sections, the increase in wet pavement accidents is still significant.

Estimates under the third assumption cannot be made since the amount of decrease in motorcycle travel, if any, is unknown.

There have been no reports that motorcycle travel decreased on grooved pavement. It is known that motorcycle _accidents_ did decrease on the grooved sections and increased on the control sections. On a _rate_ basis firm conclusions are more difficult; however, it is the opinion of the authors, based on all available data, that the grooves did not increase motorcycle accident _rates_.

The accident reports for all motorcycle accidents on the grooved sections, both before and after grooving and during both wet and dry conditions, were read for any mention of "wobbles". Two accident reports before and seven reports after grooving did mention wobbling. All of the after accidents involved other factors - one flat tire, one stall, and five traveling at higher speeds. Of the higher speeds, three were at estimated speeds of 60 to 65 mph, one in excess of 65 mph, and one identified only as high speed. Only one report mentioned the grooves. The officer's conclusion in this case was that the vehicle went into a wobble for unknown reasons while traveling at an unsafe speed for conditions. The officer did not attribute the accident to the grooves.

C. Types of Collisions

Table 5 is a summary of accidents by types of collisions for the grooved PCC pavement sections. The collision types are: rear end, head on, hit object, sideswipe, and miscellaneous. The miscellaneous

Table 5

TYPES OF COLLISIONS
GROOVED PCC PAVEMENT
(Fatal plus Injury Accidents)

Pavement Condition	Accidents			*Rates		
	Before	After	% Change	Before	After	% Change
WET						
Rear End	161	46	- 71%	1.85	0.67	- 64%
Head-On	14	7	- 50	0.16	0.10	- 37
Hit Object	228	41	- 82	2.62	0.59	- 77
Sideswipe	70	9	- 87	0.80	0.13	- 84
Misc.	55	23	- 58	0.63	0.33	- 48
Totals	528	126	- 76	6.07	1.83	- 70
MVM	87	69	- 23			
DRY						
Rear End	1,197	1,028	- 14%	0.28	0.24	- 14%
Head-On	24	16	- 33	0.006	0.004	- 35
Hit Object	609	506	- 17	0.14	0.12	- 14
Sideswipe	302	212	- 30	0.07	0.05	- 29
Misc.	275	219	- 20	0.07	0.05	- 29
Totals	2,407	1,981	- 18	0.57	0.45	- 21
MVM	4,225	4,362	+ 4			
WET + DRY						
Rear End	1,358	1,074	- 21%	0.31	0.24	- 23%
Head-On	38	23	- 39	0.009	0.005	- 41
Hit Object	837	547	- 35	0.19	0.12	- 37
Sideswipe	372	221	- 41	0.09	0.05	- 44
Misc.	330	242	- 27	0.08	0.05	- 38
Totals	2,935	2,107	- 28	0.68	0.48	- 29
MVM	4,312	4,431	+ 4			

Notes: * Rates are accidents per million vehicle miles.

category includes broadside, overturn, auto-pedestrian, and unclassified accidents.

Under wet pavement conditions, the largest decreases were in sideswipe and hit object accidents. These large decreases could be attributed to the tracking effect of grooves (7).* This effect helps keep a vehicle from sliding sideways from its lane. The next largest decrease is in rear end accidents. Stopping distance tests have shown that in a braked stop from 40 mph, the vehicle skidded between 80 and 100 feet on wet, grooved pavement and over 140 feet on wet, ungrooved pavement. In the same test on dry pavement, the difference in stopping distances was much less - 69 feet on grooved pavement and 58 feet on ungrooved pavement. The smallest reductions are in head-on and miscellaneous accidents.

Only eight of the collisions coded as head-on were due to wrong way or cross median movements. These eight accidents were all on dry pavement. All the other head-on collisions occurred when a vehicle braked or swerved suddenly, spun around and was hit by a following vehicle. This latter type of accident decreased from 18 to 14 (22%) on dry pavement and 14 to 7 (50%) on wet pavement. This is another indication that grooving aids vehicle control on wet pavement.

*Tracking is a phenomenon whereby a vehicle is partially guided by the grooves, such as when a vehicle is caught in streetcar tracks.

During dry pavement conditions, the largest decreases were in head-on, sideswipe and miscellaneous accidents. The smallest reductions were in hit object and rear end accidents. There appears to be no ready explanation for the pattern of accident reductions by collision type on dry pavement.

IV. INTERPRETATION AND PREDICTION

A. Interpretation

Table 1, page 9, shows that the F+I wet pavement accident rates decreased 70% on grooved pavement and 2% on the control sections. The dry pavement accident rates decreased 21% and 24% on the grooved sections and control sections, respectively. At the same time, the F+I accident rates on all Los Angeles freeways decreased 23%.

The question is: How much of the wet pavement accident rate reduction on grooved pavement can be attributed to the grooving, and how much to other factors? The normal procedure when control sections are used is to assume that any accident change on the treated sections that is in excess of that experienced on the control sections is caused by the treatment (grooving). This is the interpretation given to the results of this study. The 70% reduction in wet pavement accident rates on the grooved sections in the face of the 2% reduction on the control sections means that the grooving produced a 69% reduction in wet pavement accident rates on these projects.

Another question should be asked: Why did the wet pavement accident rates on the control sections decrease less than the dry pavement accident rates? There are two possible answers to this question: 1) the pavement surface deteriorated over time, or 2) accidents "moved down the road". The first possibility is not related to the grooving. However, if the second case is true, the net benefits of grooving given above are overstated. Accident data on some freeways in Los Angeles indicate that wet accident rates increase substantially over time as traffic wear reduces the surface friction (8). Here the degradation of the surface can be offsetting the reductions in fatal and injury accidents that are occurring over time through improved vehicles, traffic operational improvements, etc. It is also possible that wet pavement accidents have "moved down the road" from the grooved sections to the control sections (and other roads). It is at least conceivable that with a given combination of tire tread, tire pressure and speed that a vehicle which would not lose control on grooved pavement will lose it at other locations where the surface friction factor is not as high.

If it is assumed that wet pavement accidents did move down the road (i.e., the rates would have decreased 24% without grooving), then the reduction that can be attributed to grooving is 60%, rather than the previously calculated 69%.

The two possibilities are shown in the following table:

Wet Pavement Accident Rates*

Before Rate	Expected Reduction	Expected After Rates	Actual After Rate	Percent Reduction
6.07	2%	5.95	1.83	69%
6.07	24%	4.61	1.83	60%

*All rates are accidents per million vehicle miles.

As stated previously, the interpretation is that grooving produced a 69% reduction in the wet pavement accident rates. However, the possibility that this overstates the benefits of grooving should be recognized. In either case, the reductions, whether 69% or 60%, are substantial and statistically significant.

This average reduction of 69% cannot, of course, be expected on all future grooving projects. All of the study sections were on high volume, urban freeways and these results reflect the condition of the pavement surface and rate of pavement wear. Methods of predicting accident reductions on future projects are given in the next section.

B. Predicting Reductions

The average reduction in wet pavement accident rates of 69% from these 23 projects is not adequate for predicting reductions to be expected from future projects. The original study developed the following predictive equation:

$$WAR_A = 1.32 + 3(DAR_B) \qquad \text{(Eq. 1)}$$

where:

WAR_A = Wet accident rate after grooving
DAR_B = Dry accident rate before grooving

This equation included PDO accidents. Since about 40% of the accidents in that study were fatal or injury, the equivalent equation for F+I accident rates is:

$$WAR_A = 0.54 + 1.2\ (DAR_B) \qquad \text{(Eq. 2)}$$

The best fit linear equation with the current data gives:

$$WAR_A = 0.70 + 1.66\ (DAR_B) \qquad \text{(Eq. 3)}$$

The coefficient of correlation (r) for this equation is 0.35, and the adjusted standard error of estimate ($\overline{s}$) is 1.19.

The trouble with using the dry accident rate before grooving (DAR_B) in the predictive equation is that it builds in the accident rate trends found on the particular freeway sections chosen for this study. A major finding in this study is that the wet pavement accident rate after grooving will be about four times the dry pavement rate. (See Table C-6, Appendix C.) The dry accident rate after grooving (DAR_A) is a better predictor of the wet accident rate that can be expected after grooving.

The best fit equation using (DAR_A) as a predictor is also linear:

$$WAR_A = 0.30 + 3.17\ (DAR_A)^* \qquad \text{(Eq. 4)}$$

This is also a better fit ($r = 0.58$, $\overline{s} = 1.03$) than Equation 3.

This line, along with data points for the 23 projects, are plotted on Figure 4.

The most accurate way of predicting the benefits from grooving on new projects is to account for any trends in wet and dry pavement accident rates separately. Trends in wet and dry rates can be extrapolated from past records for the particular project. The predicted wet pavement accident rates should then be calculated from Equation 4 above. Using the projects in this study as an example, the analyses is shown schematically in the diagram on page 26. (The service life of PCC grooving is assumed to be ten years.) The total benefit is represented by the shaded area.

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*Note that DAR_A is the expected dry accident rate <u>after</u> grooving, and that it is determined by an extrapolation of dry accident rates in the past. See chart on page 27.

PREDICTIVE EQUATION
PCC GROOVING
WAR_A vs DAR_A

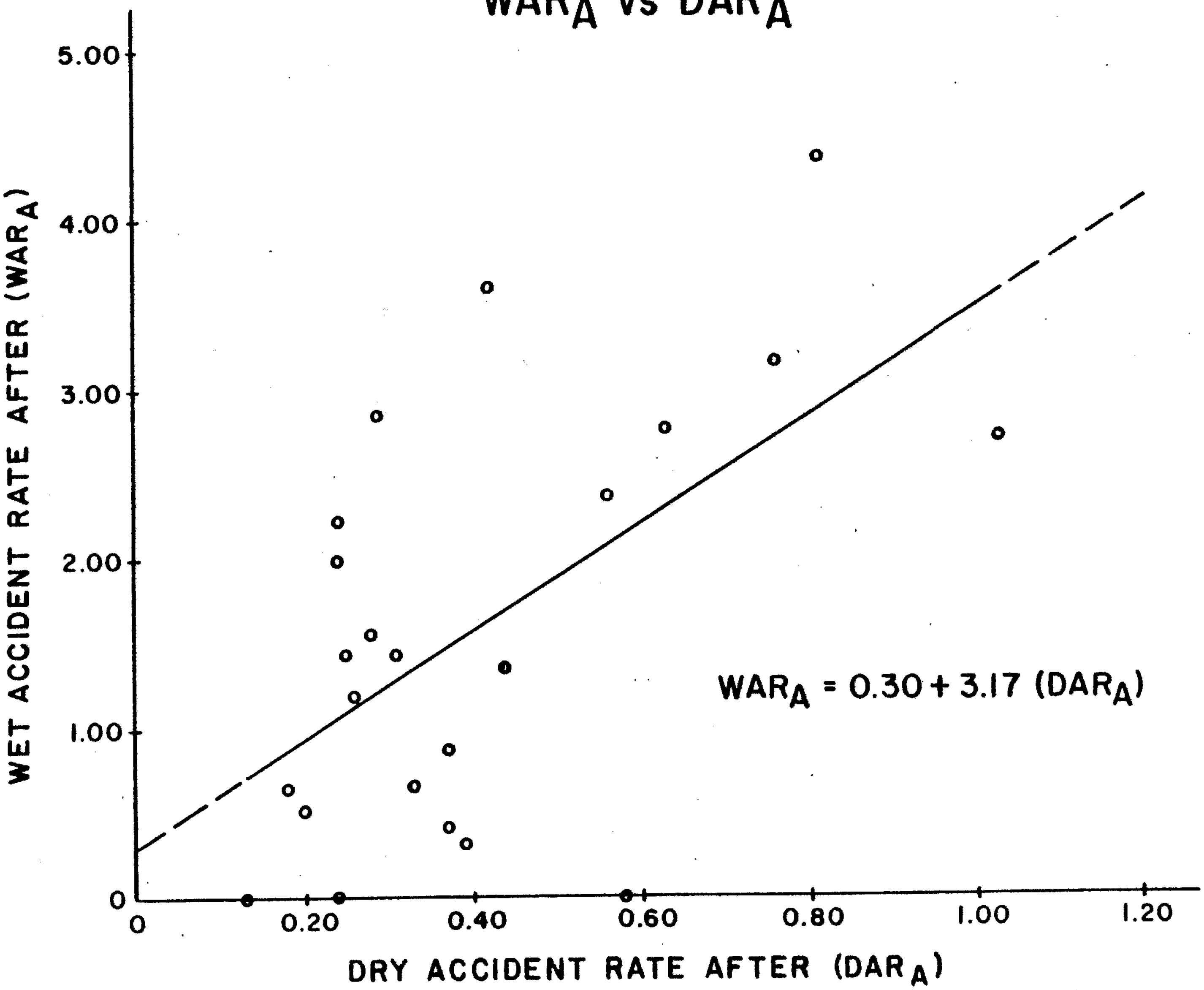
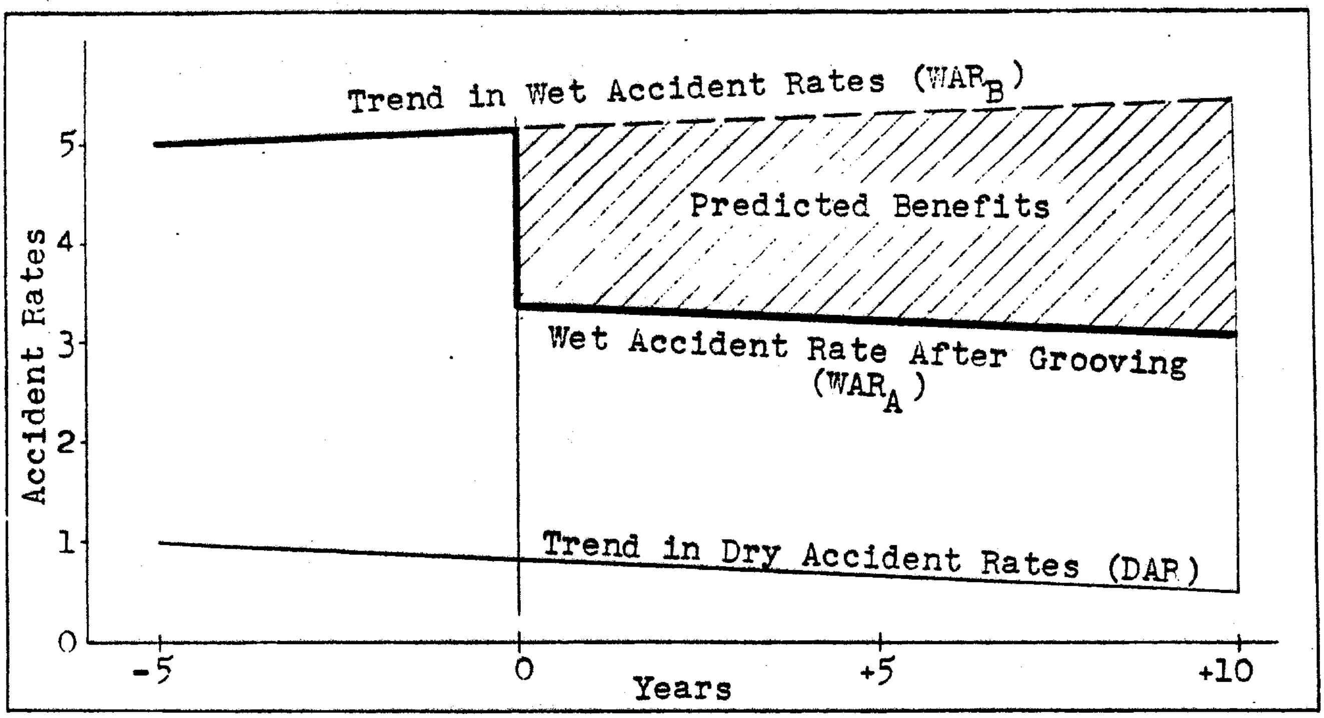


Figure 4

Accident rates are converted to numbers of accidents by using estimated future traffic volumes and calculating wet pavement exposure using the formula on page 7.

Predicted Benefits of Grooving



The analyses is simplified if both the wet and dry pavement accident rates have been relatively constant in the past. This may indeed be the case for many projects, and could be sufficiently accurate for most project estimates.

The dramatic results of a 69% reduction in wet pavement accident rates found on these PCC grooving projects could lead to unwarranted grooving and low pay-off projects unless care and judgment is exercised. These reported results, strictly speaking, apply only to high volume urban freeways (60,000 to 200,000 ADT) and where, not so incidently, the pavement surface had been polished to a certain degree. Skid number tests had been conducted on seven of the projects before grooving. About one-half the readings (SN_{40}) were 30 (f = 0.18) or below. Readings of as high as 46 were obtained on other segments, even though all the roads had a high incidence of wet pavement accidents. The predictive method outlined above may be applied to other road types and other areas, but these limitations should be recognized.

The results of this study indicate that unless the wet pavement accident rate is greater than four times the dry pavement accident rate, little or no improvement will be experienced. Therefore, as a general rule, grooving is not warranted and should not be done unless this condition is met. Even if the rule is met, the project may still not be warranted if the estimated savings in accident costs is less than the cost of grooving.

V. REFERENCES

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9. Michaels, Richard M., "Two Simple Techniques for Determining the Significance of Accident-Reducing Measures", Traffic Engineering, September 1966, pp. 45-48.

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VI. APPENDICES

APPENDIX A

EVALUATION OF MINOR IMPROVEMENT STUDIES

A. General

Data from some 500 minor improvement projects were gathered for the ten parts of the "Evaluation of Minor Improvements" series. The previous publications are:

Part	Title	Date Published
1.	Flashing Beacons	May 1967
2.	Safety Lighting	May 1967
3.	Delineation	Jul 1967
4.	Guardrail	Jul 1967
5.	Left-turn Channelization	Oct 1967
6.	Signs	May 1968
7.	Traffic Signals	Apr 1970
8.	Grooved Pavements	Dec 1972
9.	Open Graded Ashpalt Concrete Overlays	Jan 1972
10.	Miscellaneous	Jan 1972

The current report, Part 8, Grooved Pavements (Supplemental), is the last part planned for this series.

B. Study Objectives

The three objectives of the "Evaluation of Minor Improvements" series were:

1. To determine the effectiveness of minor improvements in reducing traffic accidents.

2. To determine what conditions are susceptible to improvement.
3. To determine methods and measures for predicting the magnitude of accident reductions of proposed minor improvement projects.

No attempt has been made in this series to present cost-effectiveness or cost-benefit data. Procedures are available by which the predictive methods of this series can be combined with current costs to calculate the effectiveness or benefit measures.

C. Study Methodology

The "before and after" study approach was used throughout this series. The accident rates were based on million vehicle miles of travel, except for spot improvements or intersection improvements where million vehicles or the sum of all entering vehicles in millions were used, respectively.

In before and after studies, the possibility always exists that a project may be initiated because of an unusual short time accident experience. This may be due to a temporary roadway or other condition in the before period or it may merely be a random fluctuation in accidents. In such cases, even if nothing had been done, an accident reduction could have been observed in the after period (regression to the mean theory).

In this supplemental study of grooved pavements, two years of before and two years of after accident data were used. Since grooving projects tend to be constructed soon after one year of high wet pavement accident rates have been observed, the addition of one earlier year in the before period should reduce, or average out, any random accident peak in the before period. Nevertheless, the possibility remains that the benefits of grooving, or any minor improvement project for that matter, are somewhat overstated because of this phenomena of random accident fluctuations.

Control sections (used in this report) afford the opportunity of "cancelling out" other effects. For example, the fatal plus injury accident rate on Los Angeles urban freeways has been declining about 10% per year (from 0.67 in 1968 to 0.38 in 1973). This decline is undoubtedly due to a large number of factors, including improved freeways, safer automobiles and perhaps better drivers. Any change in accident rates above that experienced on the control sections is assumed to be due to the treatment (i.e., grooving).

The original grooving report considered accidents within 0.2 mile downstream of the study sections (those grooved in the after period) as having occurred within the nominal limits of the sections. A vehicle can lose control and continue on some distance before becoming involved in a collision. The point of impact or collision is the reported location of the accident. Earlier practice was to limit grooving to the immediate area of the wet pavement accident concentrations. Experience has indicated that grooving should begin some distance upstream and extend downstream of the apparent accident concentration location. The new practice is to do this, and this had been done on the projects reported in this study. Therefore, it was not considered necessary to extend the limits downstream for the projects in this supplemental study.

D. Significance Testing

Statistical tests are used to determine whether observed changes in accidents are large enough to be ascribed to some change that has been introduced, or whether they are due to chance factors (random variations). A Bureau of Public Roads publication discusses the appropriateness of two statistical distributions; the poisson and the chi-square (9). Both distributions have limitations and neither is universally valid for all accident studies.

Both distributions are plotted in Figure A. Note that the chi-square is more conservative than the poisson distribution. That is, a higher reduction is required for significance at the 10% level with the chi-square test than is required with the poisson test at the 5% level. (A normal distribution curve has been plotted at the end of the poisson curve for more than 25 expected accidents.)

The more conservative chi-square statistical test, at a 90% level of confidence, was selected for use in this study. (The Yates Correction for Continuity would have made the significance testing even more conservative, but as a matter of practicality the correction was not considered necessary, and was not applied).

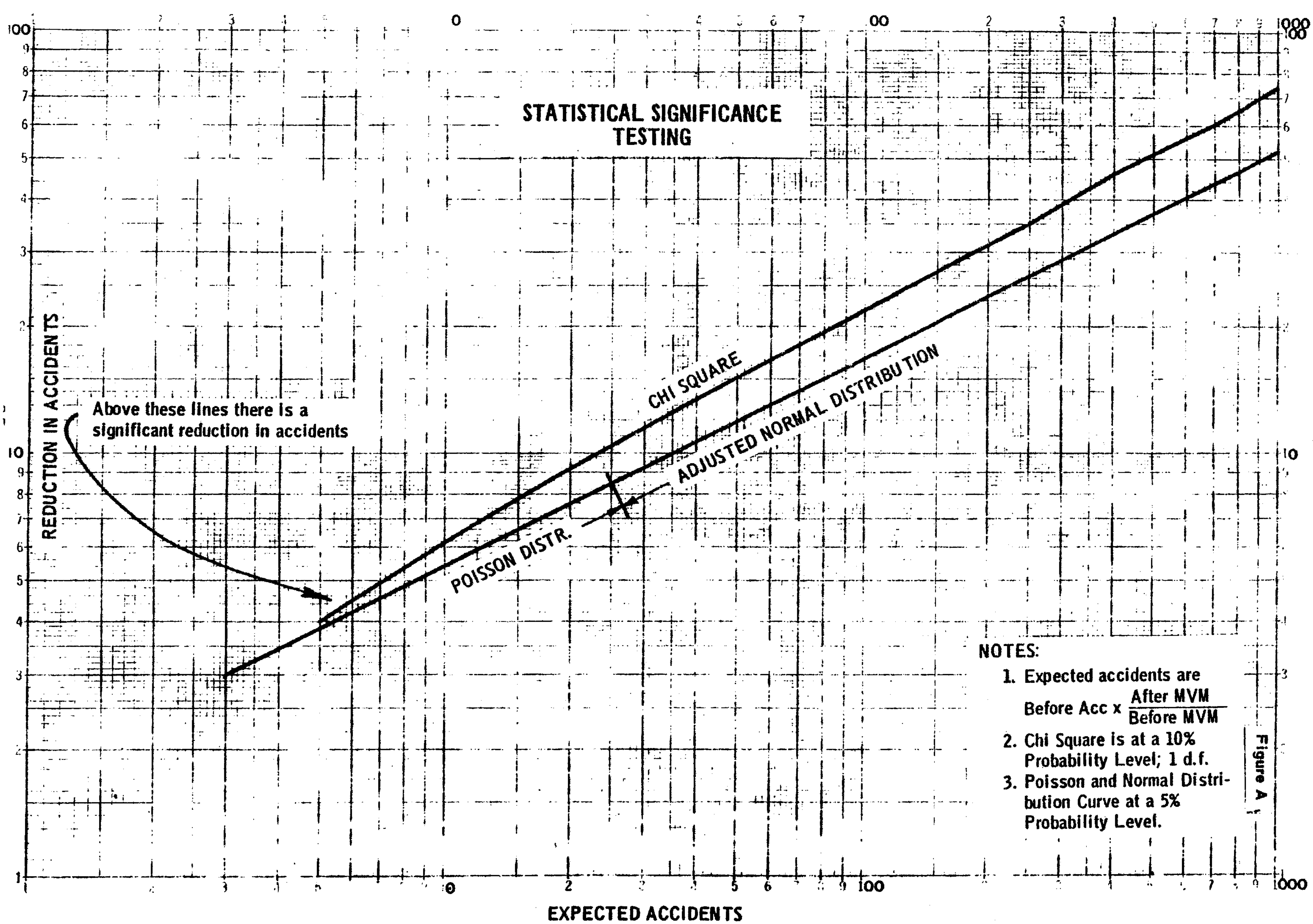
STATISTICAL SIGNIFICANCE TESTING
Above these lines there is a significant reduction in accidents
CHI SQUARE
ADJUSTED NORMAL DISTRIBUTION
POISSON DISTR.
REDUCTION IN ACCIDENTS
EXPECTED ACCIDENTS
NOTES:
1. Expected accidents are Before Acc x After MVM / Before MVM
2. Chi Square is at a 10% Probability Level; 1 d.f.
3. Poisson and Normal Distribution Curve at a 5% Probability Level.

Figure A

The chi-square test evaluates the independence of the after sample to that of the before sample. A contingency table composed of cells representing all the possible combinations of outcomes works well as long as there are no less than 5 events in any one cell (10). Before and after studies can be set up in a 2 x 2 contingency table format as shown below.

CONTINGENCY TABLE FORMAT

Observed Before Accidents	Before Non-Accidents	Before Vehicles
Observed After Accidents	After Non-Accidents	After Vehicles
Observed Total Accidents	Total Non-Accidents	Total Vehicles

The above contingency table was the basis for the following chi-square (χ^2) equations:

$$\chi^2_{(1)} = \frac{\left[O_B - \left(O_T \times \frac{V_B}{V_T}\right)\right]^2}{\left(O_T \times \frac{V_B}{V_T}\right)} \qquad \text{(Eq. A-1)}$$

$$\chi^2_{(2)} = \frac{\left[O_A - \left(O_T \times \frac{V_A}{V_T}\right)\right]^2}{\left(O_T \times \frac{V_A}{V_T}\right)} \qquad \text{(Eq. A-2)}$$

$$\chi^2_{(3)} = \frac{\left[B_N - \left(T_N \times \frac{V_B}{V_T}\right)\right]^2}{\left(T_N \times \frac{V_B}{V_T}\right)} \qquad \text{(Eq. A-3)}$$

$$\chi^2_{(4)} = \frac{\left[A_N - \left(T_N \times \frac{V_A}{V_T}\right)\right]^2}{\left(T_N \times \frac{V_A}{V_T}\right)} \qquad \text{(Eq. A-4)}$$

Where: O_B = Observed Before Accidents
O_A = Observed After Accidents
O_T = Observed Total Accidents = $(O_B + O_A)$
B_N = Before Non-Accidents
A_N = After Non-Accidents
T_N = Total Non-Accidents = $(B_N + A_N)$
V_B = Before Vehicles
V_A = After Vehicles
V_T = Total Vehicles = $(V_B + V_A)$

$$\chi^2 = \chi^2_{(1)} + \chi^2_{(2)} + \chi^2_{(3)} + \chi^2_{(4)} \qquad \text{(Eq. A-5)}$$

The terms $\chi^2_{(3)}$ and $\chi^2_{(4)}$ are extremely small values since there is always a large number of non-accidents. Also, exposure or travel can be substituted for vehicles, since the before and after project lengths are the same. In that way, the chi-square equations can be expressed in terms of accidents and accident exposure. Terms involving exposure are nondimensional and could be expressed in either MV or MVM. Adding Equations A-1 and A-2 and substituting exposure for vehicles gives:

$$\chi^2 = \frac{\left[O_B - \left(O_T \times \frac{MVM_B}{MVM_T}\right)\right]^2}{\left(O_T \times \frac{MVM_B}{MVM_T}\right)} + \frac{\left[O_A - \left(O_T \times \frac{MVM_A}{MVM_T}\right)\right]^2}{\left(O_T \times \frac{MVM_A}{MVM_T}\right)} \qquad \text{(Eq. A-6)}$$

Where: MVM_B = MVM of Travel Before
MVM_A = MVM of Travel After
MVM_T = Total MVM of Travel = $(MVM_B + MVM_A)$

When the before and after exposures are equal, the above equation reduced to:

$$\chi^2 = \frac{4(O_B - \frac{1}{2}O_T)^2}{O_T} \qquad \text{(Eq. A-7)}$$

or

$$\chi^2 = \frac{4(O_A - \frac{1}{2}O_T)^2}{O_T} \qquad \text{(Eq. A-8)}$$

since $\left[(O_B - \frac{1}{2}O_T)\right] = \left[(O_A - \frac{1}{2}O_T)\right]$

Equation A-7 can be used to derive an approximation of Equation A-6 when the before and after exposures are nearly, but not exactly equal. If it is hypothesized that the treatment is not successful, then the accident rate in the after period would be the same as in the before period and the expected number of accidents in the after period would be:

$$E_A = \left(O_B \times \frac{MVM_A}{MVM_B}\right) \qquad \text{(Eq. A-9)}$$

Equation A-9, along with the observed number of accidents in the after period, can be substituted into equation A-7 to obtain:

$$\chi^2 = \frac{4\left[E_A - \frac{1}{2}(E_A + O_A)\right]^2}{\left(E_A + O_A\right)} \qquad \text{(Eq. A-10)}$$

since $E_A \cong O_B$ when $MVM_A \cong MVM_B$

and $O_T \cong \left(E_A + O_A\right)$

Equation A-10 is an approximation, and has been used only for the visual presentation in Figure 3. The significance testing throughout this report uses the mathematically correct Equation A-6. Note in Figure 3 that a larger change in accidents $\left(E_A - O_A\right)$ is required for significance when $O_A > E_A$.

APPENDIX B

STANDARD SPECIFICATIONS

SECTION 42

GROOVE PAVEMENT

42-1 Grooving

42-1.01 Description - This work shall consist of grooving the surface of asphalt concrete or portland cement concrete pavement and bridge decks as shown on the plans and as specified in these specifications and the special provisions.

42-1.02 Construction - Grooved areas shall begin and end at lines normal to the pavement center line and shall be centered within the lane width. If new concrete pavement is grooved, the grooving in any lane shall cover the full lane width.

Grooving blades shall be 0.095-inch wide ±0.003-inch and shall be spaced 3/4 inch on centers. The grooves shall be cut not less than 1/8 inch nor more than 1/4 inch deep. The grooves on bridge decks shall be cut not less than 1/8 inch nor more than 3/16 inch deep. Grooves over inductive loop detectors shall be cut not less than 1/16 inch nor more than 1/8 inch deep.

The actual grooved area of any selected two-foot by 100-foot longitudinal area of pavement specified to be grooved shall be not less than 95 percent of the selected area. Any area within the selected area not grooved shall be due only to irregularities in the pavement surface and for no other reason.

Residue from grooving operations shall not be permitted to flow across shoulders or lanes occupied by public traffic or to flow into gutters or other drainage facilities. Solid residue resulting from grooving operations shall be removed from pavement surfaces before such residue is blown by the action of traffic or wind.

The noise level created by the combined grooving operation shall not exceed 86 dBA at a distance of 50 feet at right angles to the direction of travel.

42-1.03 Measurement - Pavement grooving on existing pavement will be measured by the square yard. The quantity of pavement grooving to be paid for will be determined by multiplying the width of the grooved area by the total horizontal length of lane grooved.

42-1.04 Payment - The contract price paid per square yard for groove existing concrete pavement shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all work involved in grooving the existing concrete pavement, including removing residue, as shown on the plans, as specified in these specifications and the special provisions, as directed by the Engineer.

APPENDIX C

PROJECT DATA

Table C-1
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

GENERAL

Proj. No.	Location		Length	Wet Time (Hours)		Wet Time (Percent)		AADT (1,000)	
	Route	Postmiles	Miles	Before	After	Before	After	Before	After
1	5	0.20 - 3.40	3.20	457	314	2.61	1.79	63.6	58.4
2	5	3.41 - 3.90	0.49	457	314	2.61	1.79	122.6	118.7
3	5	14.90 - 16.00	1.10	418	254	2.39	1.45	188.7	188.7
4	5	18.50 - 20.80	2.30	418	254	2.39	1.45	135.0	140.8
5	5	28.20 - 30.60	2.40	452	259	2.58	1.48	101.9	103.0
6	5	33.00 - 35.40	2.40	452	259	2.58	1.48	81.1	83.7
7	10	28.20 - 30.80	2.60	392	303	2.24	1.73	137.0	131.0
8	10	39.00 - 40.80	1.80	493	259	2.81	1.48	87.0	78.7
9	11	11.10 - 13.60	2.50	232	291	1.32	1.66	123.9	141.6
10	11	21.60 - 24.00	2.40	259	315	1.48	1.80	181.8	194.2
11	101	0.65 - 2.80	2.15	452	340	2.58	1.94	171.4	172.2
12	101	2.81 - 5.20	2.39	452	340	2.58	1.94	128.6	130.0
13	101	5.21 - 7.70	2.49	452	312	2.58	1.78	128.6	130.0
14	101	17.40 - 17.80	0.40	588	291	3.36	1.66	183.8	191.7
15	101	20.74 - 23.50	2.76	185	366	1.06	2.09	146.7	148.3
16	405	0.70 - 2.10	1.40	482	137	2.75	0.78	148.7	153.5
17	405	2.11 - 3.50	1.39	400	147	2.28	0.84	163.8	167.0
18	405	9.84 - 10.26	0.42	367	147	2.09	0.84	148.1	149.5
19	405	13.20 - 15.00	1.80	348	240	1.99	1.37	154.7	164.2
20	405	15.01 - 16.50	1.49	246	307	1.40	1.75	151.6	162.6
21	405	16.51 - 18.00	1.49	270	166	1.54	0.95	150.1	154.5
22	405	20.00 - 21.00	1.00	327	282	1.87	1.61	167.8	168.5
23	405	36.00 - 39.10	3.10	301	319	1.72	1.82	154.5	160.2

Table C-2
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

ACCIDENTS

Proj. No.	Pavement Condition								
	Wet			Dry			Wet and Dry		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
1	52	1	- 98%	157	49	- 69%	209	50	- 76%
2	3	0	- 100	11	9	- 18	14	9	- 36
3	25	5	- 80	121	83	- 31	146	88	- 40
4	32	3	- 91	125	86	- 31	157	89	- 43
5	32	4	- 88	68	49	- 28	100	53	- 47
6	29	3	- 90	51	45	- 12	80	48	- 40
7	22	6	- 73	81	61	- 25	103	67	- 35
8	15	1	- 93	68	34	- 50	83	35	- 58
9	22	5	- 77	105	67	- 36	127	72	- 43
10	25	16	- 36	389	345	- 11	414	361	- 13
11	30	16	- 47	214	202	- 6	244	218	- 11
12	25	25	0	183	245	+ 34	208	270	+ 30
13	36	11	- 69	136	146	+ 7	172	157	- 8
14	21	0	- 100	18	32	+ 78	39	32	- 18
15	14	8	- 43	114	129	+ 13	128	137	+ 7
16	31	0	- 100	41	21	- 49	72	21	- 71
17	15	3	- 80	53	41	- 23	68	44	- 35
18	7	1	- 86	30	13	- 57	37	14	- 62
19	33	10	- 70	87	89	+ 2	120	99	- 18
20	13	2	- 85	55	31	- 44	68	33	- 51
21	8	3	- 63	52	40	- 23	60	43	- 28
22	10	1	- 90	36	24	- 33	46	25	- 46
23	28	2	- 93	212	140	- 34	240	142	- 41
Totals	528	126	- 76%	2,407	1,981	- 18%	2,935	2,107	- 28%

Table C-3
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

TRAVEL
(Million Vehicle Miles)

Proj. No.	Pavement Condition								
	Wet			Dry			Total		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
1	3.75	2.41	- 35.73	144.82	134.00	- 7.47	148.57	136.41	- 8.18
2	1.10	0.75	- 31.82	42.77	41.72	- 2.46	43.87	42.47	- 3.19
3	3.47	2.12	- 38.90	148.03	149.41	+ 0.93	151.50	151.53	+ 0.02
4	5.36	3.36	- 37.31	221.26	232.96	+ 5.29	226.62	236.32	+ 4.28
5	4.31	2.56	- 40.60	174.15	177.86	+ 2.13	178.46	180.42	+ 1.10
6	3.49	2.11	- 39.54	138.58	144.61	+ 4.35	142.07	146.72	+ 3.27
7	5.66	4.16	- 26.50	254.28	244.54	- 3.83	259.94	248.70	- 4.32
8	3.13	1.50	- 52.08	111.22	101.97	- 8.32	114.35	103.47	- 9.51
9	2.90	4.15	+ 43.10	223.28	254.18	+13.84	226.18	258.33	+14.21
10	4.51	5.93	+ 31.49	313.97	334.33	+ 6.48	318.48	340.26	+ 6.84
11	6.95	5.06	- 27.19	262.03	265.20	+ 1.21	268.98	270.26	+ 0.48
12	6.69	5.73	- 14.35	276.08	300.69	+ 8.91	282.77	306.42	+ 8.36
13	6.13	3.99	- 34.91	227.54	232.30	+ 2.09	233.67	236.29	+ 1.12
14	1.75	0.87	- 50.29	51.91	55.12	+ 6.18	53.66	55.99	+ 4.34
15	2.89	5.94	+105.54	292.75	292.94	+ 0.06	295.64	298.88	+ 1.10
16	4.01	1.17	- 70.82	147.93	155.75	+ 5.29	151.94	156.92	+ 3.28
17	3.64	1.35	- 62.91	162.56	168.15	+ 3.44	166.20	169.50	+ 1.99
18	0.92	0.35	- 61.96	44.49	45.49	+ 2.25	45.41	45.84	+ 0.95
19	3.93	2.78	- 29.26	199.37	212.94	+ 6.81	203.30	215.72	+ 6.11
20	2.25	3.07	+ 36.44	162.64	173.78	+ 6.85	164.89	176.85	+ 7.25
21	2.44	1.50	- 38.52	160.85	166.51	+ 3.52	163.29	168.01	+ 2.89
22	2.21	1.96	- 11.31	120.31	121.01	+ 0.58	122.53	122.97	+ 0.36
23	5.83	6.42	+ 10.12	343.85	356.02	+ 3.54	349.68	362.44	+ 3.65
Totals	87	69	- 20.71%	4,225	4,362	+ 3.24%	4,312	4,431	+ 2.75%

Table C-4
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

ACCIDENT RATES
(Accidents/Million Vehicle Miles)

Proj. No.	Pavement Condition								
	Wet			Dry			Wet and Dry		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
1	13.87	0.41	- 97.0%	1.08	0.37	- 65.7%	1.41	0.37	- 73.8%
2	2.73	0	-100.0	0.26	0.22	- 15.4	0.32	0.21	- 34.4
3	7.20	2.36	- 67.2	0.82	0.56	- 31.7	0.96	0.58	- 39.6
4	5.97	0.89	- 85.1	0.56	0.37	- 33.9	0.69	0.38	- 44.9
5	7.42	1.56	- 79.0	0.39	0.28	- 28.2	0.56	0.29	- 48.2
6	8.31	1.42	- 82.9	0.37	0.31	- 16.2	0.56	0.33	- 41.1
7	3.89	1.44	- 63.0	0.32	0.25	- 21.9	0.40	0.27	- 32.5
8	4.79	0.67	- 86.0	0.61	0.33	- 45.9	0.73	0.34	- 53.4
9	7.59	1.20	- 84.2	0.47	0.26	- 44.7	0.56	0.28	- 50.0
10	5.54	2.70	- 51.3	1.24	1.03	- 16.9	1.30	1.06	- 18.5
11	4.32	3.16	- 26.9	0.82	0.76	- 7.3	0.91	0.81	- 11.0
12	3.74	4.36	+ 16.6	0.66	0.81	+ 22.7	0.74	0.88	+ 18.9
13	5.87	2.76	- 53.0	0.60	0.63	+ 5.0	0.74	0.66	- 10.8
14	12.00	0	-100.0	0.35	0.58	+ 65.7	0.73	0.57	- 21.9
15	4.84	1.35	- 72.1	0.39	0.44	+ 12.8	0.43	0.46	+ 7.0
16	7.73	0	-100.0	0.28	0.13	- 53.6	0.47	0.13	- 72.3
17	4.12	2.22	- 46.1	0.33	0.24	- 27.3	0.41	0.26	- 36.6
18	7.61	2.86	- 62.4	0.67	0.29	- 56.7	0.81	0.31	- 61.7
19	8.40	3.60	- 57.1	0.44	0.42	- 4.5	0.59	0.46	- 22.0
20	5.78	0.65	- 88.8	0.34	0.18	- 47.1	0.41	0.19	- 53.7
21	3.28	2.00	- 39.0	0.32	0.24	- 25.0	0.37	0.26	- 29.7
22	4.39	0.51	- 88.4	0.30	0.20	- 33.3	0.38	0.20	- 47.4
23	4.80	0.31	- 93.5	0.62	0.39	- 37.1	0.69	0.39	- 43.5
Total	6.05	1.82	- 69.9%	0.57	0.45	- 21.1%	0.68	0.48	- 29.4%

Table C-5
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

CHI-SQUARE VALUES

Proj. No.	O_B	O_A	O_T	MVM_B	MVM_A	MVM_T	E_B	E_A	$\frac{(O_B-E_B)^2}{E_B}$	$\frac{(O_A-E_A)^2}{E_A}$	χ^2
1	52	1	53	3.75	2.41	6.16	32.3	20.7	12.015	18.748	30.76
2	3	0	3	1.10	0.75	1.85	1.8	1.2	0.800	1.200	2.00
3	25	5	30	3.47	2.12	5.59	18.6	11.4	2.202	3.593	5.80
4	32	3	35	5.36	3.36	8.72	21.5	13.5	5.128	8.167	13.30
5	32	4	36	4.31	2.56	6.87	22.6	13.4	3.910	6.594	10.50
6	29	3	32	3.49	2.11	5.60	19.9	12.1	4.161	6.844	11.01
7	22	6	28	5.66	4.16	9.82	16.1	11.9	2.162	2.925	5.09
8	15	1	16	3.13	1.50	4.63	10.8	5.2	1.633	3.392	5.03
9	22	5	27	2.90	4.15	7.05	11.1	15.9	10.704	7.472	18.18
10	25	16	41	4.51	5.93	10.44	17.7	23.3	3.011	2.237	5.30
11	30	16	46	6.95	5.06	12.01	26.6	19.4	0.435	0.596	1.03
12	25	25	50	6.69	5.73	12.42	26.9	23.1	0.134	0.156	0.29
13	36	11	47	6.13	3.99	10.12	28.5	18.5	1.974	3.041	5.02
14	21	0	21	1.75	0.87	2.62	14.0	7.0	3.500	7.000	10.50
15	14	8	22	2.89	5.94	8.83	7.2	14.8	6.422	3.124	9.55
16	31	0	31	4.01	1.17	5.18	24.0	7.0	2.042	7.000	9.04
17	15	3	18	3.64	1.35	4.99	13.1	4.9	0.276	0.737	1.01
18	7	1	8	0.92	0.35	1.27	5.8	2.2	0.248	0.655	0.90
19	33	10	43	3.93	2.78	6.71	25.2	17.8	2.414	3.418	5.83
20	13	2	15	2.25	3.07	5.32	6.3	8.7	7.125	5.160	12.29
21	8	3	11	2.44	1.50	3.94	6.8	4.2	0.212	0.343	0.56
22	10	1	11	2.21	1.96	4.17	5.8	5.2	3.041	3.392	6.43
23	28	2	30	5.83	6.42	12.25	14.3	15.7	13.125	11.955	25.08

Notes:

O_B = Observed Accidents Before

O_A = Observed Accidents After

O_T = Observed Accidents Total

E_B = Expected Accidents Before

E_A = Expected Accidents After

MVM_B = Million Vehicle Miles Before

MVM_A = Million Vehicle Miles After

MVM_T = Million Vehicle Miles Total

$$\chi^2 = \frac{(O_B-E_B)^2}{E_B} + \frac{(O_A-E_A)^2}{E_A}$$

$$E_B = \frac{MVM_B}{MVM_T}(O_T) \qquad E_A = \frac{MVM_A}{MVM_T}(O_T)$$

χ^2 = 2.71 (90% Confidence Level)

Table C-6
GROOVED PROJECT DATA
(Fatal plus Injury Accidents)

RATIOS OF WET TO DRY RATES

Project Number	$\frac{WAR_B}{DAR_B}$	$\frac{WAR_A}{DAR_B}$	$\frac{WAR_A}{DAR_A}$
1	12.8	0.4	1.1
2	10.5	0	0
3	8.8	2.9	4.2
4	10.7	1.6	2.4
5	19.0	4.0	5.6
6	22.5	3.8	4.6
7	4.7	4.5	5.8
8	7.9	1.1	2.0
9	16.1	2.6	4.6
10	4.5	2.2	2.6
11	5.3	3.9	4.2
12	5.7	6.6	5.4
13	9.8	4.6	4.4
14	34.3	0	0
15	12.4	3.5	3.1
16	27.6	0	0
17	12.5	6.7	9.3
18	11.4	4.3	9.9
19	19.1	8.2	8.6
20	17.0	1.9	3.6
21	10.3	6.3	8.3
22	14.6	1.7	2.6
23	7.7	0.5	0.8
Weighted Average	10.6	3.2	4.0