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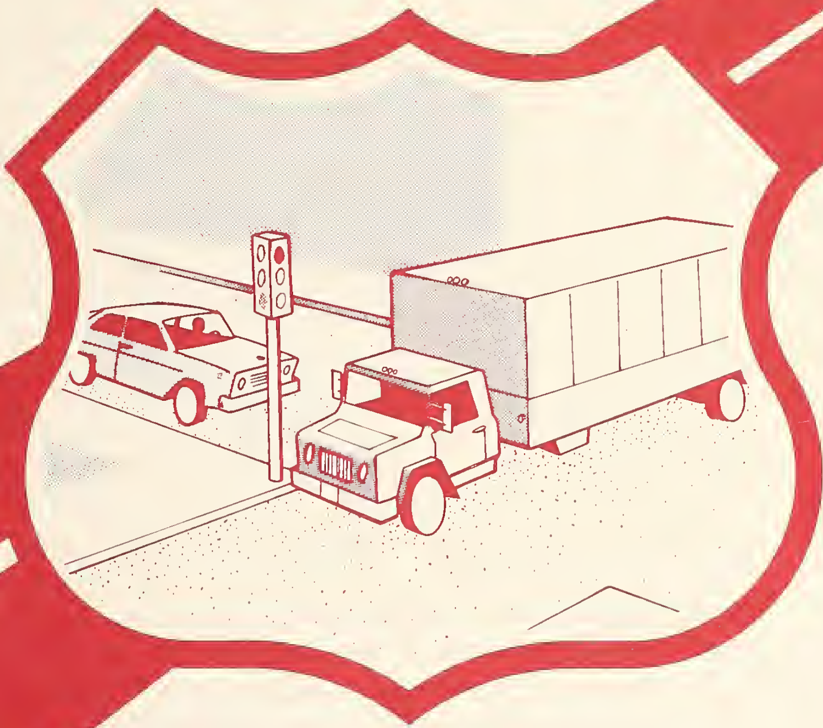
FFECTIVENESS OF ALTERNATIVE SKID REDUCTION MEASURES

Vol. I Evaluation of Accident Rate-Skid Number Relationships
November 1978

Final Report



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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Environmental Division
Washington, D.C. 20590

FOREWORD

This report is part of a final report consisting of an executive summary and four volumes. The executive summary provides a synopsis of the research. Volume I describes the evaluation of accident rate-skid number relationships; Volume II describes the development of the benefit-cost model; Volume III presents the computerized benefit-cost model and instructions for its use; and Volume IV summarizes methods of measuring and achieving macrotexture. It will interest those concerned with pavement surface characteristics and the selection of accident reduction measures.

This research is included in Project 1H, "Skid Accident Reduction" of the Federally Coordinated Program of Research and Development. Mr. George B. Pilkington II is the Project Manager and Mr. Philip Brinkman is the Task Manager.

One copy of this report is being distributed to each FHWA regional office.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract

Relationships were developed between wet-pavement accident rate and skid number for various combinations of highway type, area type (urban/rural) and traffic volume. Accident rate, skid number and related data were collected for two one-year periods on 428 highway sections located in 16 states. An extensive statistical analysis of the data was conducted using matched-pair comparisons, regression analysis and analysis of covariance. The analysis found a small, but statistically significant, influence of skid number on wet-pavement accident rate. A linear relationship with skid number explained the variation in wet-pavement accident rate as well, or better, than any simple logarithmic or polynomial function. The differences in the slope of this linear relationship for various highway type-area type-traffic volume combinations were not statistically significant, so a single common slope was used. It was found that the slope of the wet-pavement accident rate-skid number relationship is sensitive to the dry-pavement accident rate. This sensitivity was quantified to further explain the relationship between wet-pavement accident rate and skid number. The relationships developed in this volume have been incorporated in a computerized benefit-cost model for wet-pavement accident countermeasures, described in Volumes II and III of this report.

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PREFACE

This draft final report was prepared by Midwest Research Institute for the Federal Highway Administration under Contract No. DOT-FH-11-8120. Mr. Charles P. Brinkman of the Office of Research, Federal Highway Administration was the Contract Manager.

The project benefited from the comments and suggestions of several other members of the staff of the Office of Research of FHWA including Mr. Ronald Giguere, Mr. George Pilkington, Ms. Julie Anna Fee, and Mr. Burton Stephens. In addition, the Data Systems Division of FHWA wrote all of the computer programs and made all computer runs for the project. We wish to thank Mr. William Mellott, Ms. Sandy Wallenhorst, Ms. Kathy Centeno, and Ms. Mary Robinson of that division for their invaluable contributions.

We also wish to acknowledge the contributions of 16 state highway and transportation departments and the following individuals who served as principal contacts for the project: Mr. Dave Henry of the California Department of Transportation, Dr. Charles E. Dougan of the Connecticut Department of Transportation, Mr. William C. Walters of the Louisiana Department of Highways, Mr. Wilbur Dunphy of the Maine Department of Transportation, Mr. F. Stanley Kinney of the Maryland State Highway Administration, Mr. Francis W. Holden of the Massachusetts Department of Public Works, Mr. Fred Copple of the Michigan Department of State Highways, Mr. Paul Teng of the Mississippi State Highway Department, Mr. Lee Webster of the North Carolina Department of Transportation, Mr. Leon O. Talbert of the Ohio Department of Transportation, Mr. John G. Hopkins III of the Pennsylvania Department of Transportation, Mr. Robert Fruggiero of the Rhode Island Department of Transportation, Mr. Billy R. Gibson of the South Carolina State Highway Department, Mr. R. V. LeClerc of the Washington State Highway Commission and Mr. John R. O'Leary of the West Virginia Department of Highways. Many other individuals in these agencies provided invaluable assistance which is gratefully acknowledged.

The work reported herein was carried out in the Engineering and Economics and Management Science Divisions, under the administrative direction of Dr. William D. Glauz. Mr. Robert R. Blackbrun, Manager, Driver and Environment Section; and Mr. A. D. St. John, Senior Advisor for Analysis, served as principal investigators for the study. Messrs. Blackburn and St. John, together with Mr. Douglas W. Harwood, Associate Traffic Engineer, and Mr. Michael C. Sharp, Senior Statistician, were co-authors of this report.

Present and past members of the MRI staff who also contributed to the project include: Mr. Jerry L. Graham, Dr. L. Bruce McDonald, Mr. Donald R. Kobett, Mr. Duncan I. Sommerville, Mr. Ahmed Morsi, Ms. Cathy J. Wilton, and Mr. Patrick J. Heenan.

Approved for:

MIDWEST RESEARCH INSTITUTE

A. E. Vandegrift, Director
Economics and Management Science
Division

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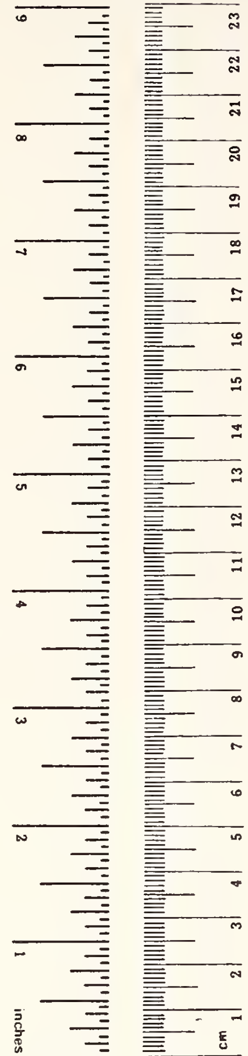
METRIC CONVERSION FACTORS

Approximete Conversions to Metric Meesures

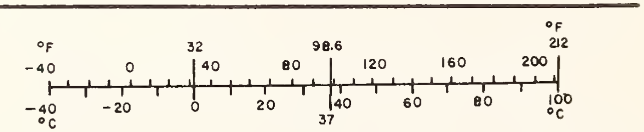
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximete Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



I. INTRODUCTION

Slippery pavements have existed since the advent of the paved highway, but the causes of slipperiness, its measurement, and its influence on traffic accidents were not of great concern before 1950. Although reliable data have been difficult to find, recent research suggests that skidding accidents are increasing rapidly and are reaching proportions that can no longer be ignored. One researcher[1/] has indicated that skidding accidents account for more than one-third of all vehicle accidents in some geographical areas. This trend is undoubtedly a reflection of increased vehicle speeds and traffic volumes.

Each year our highways are used by more vehicles traveling at increased speeds. The increased traffic volumes have reduced the average headway between vehicles, and this reduction, in combination with increased speed, has reduced the time and distance available to the driver to avoid collison circumstances.

More rapid accelerations, higher travel speeds, and more severe braking made possible by modern highway and vehicle designs have raised the frictional demands on the tire-pavement interface. Larger forces are required to keep the vehicle on its intended path. On the other hand, for wet pavements, the frictional capability of the tire-pavement interface decreases with increasing speed. In addition, higher traffic volumes and speeds promote a faster degradation of the frictional capability of the pavement.

The tire-pavement friction level at which skidding is imminent depends mainly on the speed of the vehicle, the cornering path, the magnitude of acceleration or braking, the condition of the tires, and the characteritics of the pavement surface. On wet pavements, speed is the most significant parameter, not only because frictional demand increases with the square of the speed, but also because the skid resistance of the tire-pavement interface decreases with increasing speed.

Skidding accidents constitute a significant traffic safety problem, especially on highways with high vehicle speeds and high traffic volumes. Timely steps should be taken on such highways to ensure compatibility between frictional demands and available skid resistance. From the technological standpoint, the skidding accident problem is amenable to solutions that either reduce the frictional demand (such as improved geometric design and wet-weather speed limits), or increase the skid resistance (improved pavement texture and drainage, improved tire design, and more strigent vehicle inspection controls).

The Federal Highway Administration is cognizant of the skidding accident problem and has undertaken a multidirectional safety research effort aimed at the reduction of wet-pavement accidents. The Administration is coordinating complementary research directed at: (1) evaluating the mechanical interaction of the tire-pavement interface, (2) determining the frictional demands of traffic, (3) relating wet-pavement accident rates to available skid resistance, and (4) combining all traffic, engineering, and economic factors in a cost-benefit model. This coordinated approach has promise to successfully achieve its goal of establishing comprehensive skid resistance requirements that can be implemented to compare locations and select appropriate countermeasures subject to funding constraints.

This is the final report on a project (Contract No. DOT-FH-11-8120) concerned with the third and fourth of the above goals of the FHWA approach to the wet-pavement accident problem. The project consists of two phases, corresponding to the two major objectives of the project:

1. To develop the relationships between pavement skid number and wet-pavement accidents for a variety of highway and traffic conditions (Phase I).

2. To define and evaluate, on a cost-effectiveness basis, a range of alternative solutions to the problem of maintaining the frictional requirements of drivers during wet weather (Phase II).

The final report is divided into four volumes. Volume I describes the work conducted and results obtained under Phase I; Volume II pertains to the work performed under Phase II; and Volume III is a user manual describing the cost-benefit model developed under Phase II and the instructions for the model use by state highway departments. Volume IV is a guide to the subject pavement macrotexture. It discusses the importance of pavement macrotexture in reducing skidding accidents and describes the methods of measuring pavement macrotexture and the techniques for providing macrotexture in new pavements and restoring macrotexture in existing pavements. Volume IV also applies a simplified version of the benefit-cost approach presented in Volumes II and III to the evaluation of alternative pavement macrotexture improvements.

The results reported in this volume cover the Phase I activities. This phase involved a cooperative effort with 16 states in collecting a wide variety of data, analyzing that data, and drawing conclusions regarding the relationships between wet-pavement accidents and skid numbers, and a variety of other parameters.

This volume is organized in the following manner. Section II describes the experimental plan for Phase I and the selection of highway sections for study. The collection of field data, skid resistance, accident and rainfall data for the study sections is presented in Section III. Section IV describes the preparation of the data for the analyses and the computer programs that were written for the project. The statistical analyses used to determine the relationship between wet-pavement accident rate and skid number is described in detail in Section V. Finally, the conclusions of the study are given in Section VI.

II. EXPERIMENTAL PLAN

This section describes the overall experimental plan for Phase I of the project. First, the general structure of the experiment design, statistical analysis, and data requirements for the study are discussed. Then, the role of the cooperating states in providing project data is discussed. And, finally, criteria for selection of study sections and determination of the before and after periods are presented.

A. General Plan

The objective of the Phase I experiment was to determine the relationship between wet-pavement accident rate and skid number for different highway environments. The project test sections were highway sections that were resurfaced during the study period. Resurfacing of the test sections enabled the project to examine each highway at two levels of skid number without any major modification of geometric or traffic characteristics. Because temporal changes in accident rate are not uncommon, some form of experimental control was needed to assure that a general trend in accident rates was not mistaken for an effect of resurfacing. Therefore, a matched-control section, similar in physical and traffic characteristics, was selected for each test section. No alteration was made to pavement surface of the control sections during the study period.

Preliminary contact with the cooperating state highway departments found that the number of resurfacing projects suitable for use as test sections was quite limited. Furthermore, the effect of the energy crisis on vehicle speeds and travel was expected to increase the variability of accident data. Therefore, to assure that an adequate sample size was available and that the range of all relevant variables (particularly skid number) was spanned, data were also obtained for a number of unmatched-control sections. These sections were not resurfaced and were not matched to any particular test section. There were 142 test sections, 142 matched-control sections, and 144 unmatched-control sections available for the project analysis.

Several kinds of data with a known or postulated relationship to accident experience or pavement surface characteristics were collected for each section. These included:

- Highway type
- Area type (urban/rural)
- Average daily traffic volume
- Wet-pavement accident rate
- Pavement type
- Skid number
- Skid number-speed gradient

- 85th percentile speed of traffic
- Exposure to wet-pavement conditions
- Geometrics (curves, grades, intersections)

Two study periods were used in the project--before and after resurfacing of the test sections. Those data that were time dependent were determined for each section for both the before and after period. The selection of dates for the before and after periods for each section are discussed below in Section II-B.

Two experimental designs were used in the statistical analysis: matched-pair analysis and analysis of covariance. The strengths and weaknesses of the two approaches and the reasons why each was chosen are discussed below.

A before-after matched-pair analysis was used to examine the data for an effect of resurfacing on wet-pavement accident rate. The matched-pair analysis was employed (1) to calculate the change in the mean wet-pavement accident rate for test sections (controlled for any changes in the control sections), (2) to determine if the observed change was statistically significant and, if it was, (3) to attribute the observed change in mean accident rate to the observed change in mean skid number. This matched-pair analysis is a useful first step in the overall statistical analysis, because it is simple to perform and because it can take advantage of the autocorrelation of wet-pavement accident rate on each section with itself in time to increase the power of the analysis. However, the matched-pair approach has several disadvantages, such as:

1. The matched-pair analysis considers resurfacing as a treatment applied to the test sections, but it does not consider skid number explicitly. This limitation is obvious when one considers that the analysis treats a section where resurfacing resulted in an increase in skid number of 20 no differently than a section where resurfacing resulted in an increase in skid number of only two; or, for that matter, no differently than a section where resurfacing resulted in a <u>decrease</u> in skid number;

2. The matched-pair analysis uses only the matched test and control sections and ignores the unmatched control sections (1/3 of the available sample); and

3. The matched-pair analysis can produce only one universal accident rate-skid number relationship. It cannot explicitly examine other factors that may influence the accident rate-skid number relationship.

Clearly, a more sophisticated approach is necessary to consider explicitly the relationship of skid number and other variables to accident rate. One common approach is multiple regression analysis. However, this approach has several drawbacks. First, although the objective of the project was to examine the relationship between accident rate and skid number, many variables such as traffic volume are obviously much more highly related to accident rate than skid number. Any multiple regression relationship with accident rate as the dependent variable would be dominated by variables other than skid number. Second, several important variables that influence accident rate, such as highway type and area type, are non-quantitative and, thus, cannot be accounted for explicitly by multiple regression analysis.

Another approach is analysis of covariance. It considers the relationship between a quantitative dependent variable and one or more quantitative independent variables (known as covariates) within cells defined by levels of one or more non-quantitative factors. Analysis of covariance was chosen as the second analysis approach because it does not share the drawbacks of multiple regression analysis identified above. It can isolate the effect of skid number on wet-pavement accident rate by using skid number as the only covariate and using all other variables as factors. The analysis can explicitly examine the influence of these factors on the accident rate-skid number relationship, including non-quantitative factors such as highway type and area type.

Section V (Data Analysis) presents the results of the matched-pair analyses and the analyses of covariance applied to the data for the test and control sections.

B. Cooperating State Highway Departments

The project was accomplished with the assistance of 16 cooperating states: California, Connecticut, Florida, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Washington and West Virginia. These states played a key role in the assembly of data for the project analysis. Each state provided a list of resurfacing projects used for the inital selection of test sections. These selections are discussed below in Section C. Data on the physical features and geometrics of each test and control section were obtained directly by MRI in a field inventory. However, all other data for the project analysis were provided by the cooperating state highway or transportation departments. These data included information about the resurfacing project carried out on each test section, and accident data, ADT, and skid test results for both the before and after periods. A detailed description of the data provided by the cooperating states is found in Section III.

C. Selection of Study Sections

This section presents the criteria used to select test, matched-control, and unmatched-control sections for the project.

An initial analysis was conducted to determine the desired minimum length of study sections. Each study section should be long enough to assure that it has enough yearly wet-pavement accidents to carry out these statistical analysis. A minimum length of 4 miles was established from accident studies for sections on highways with ADT over 5,000. Sections as short as 2 miles were used on highways with ADT much greater than 5,000. In some states very few sections with ADT over 5,000 were resurfaced, so it was necessary to select projects where the ADT was less than 5,000. Minimum section lengths up to 6 miles may be required in these cases.

Test sections were selected from lists of resurfacing projects provided by each of the cooperating states. A candiate resurfacing project was suitable for use as a test section if: (1) resurfacing was scheduled during 1973 or 1974; (2) results of skid tests made before resurfacing were available; and (3) the section was at least 4 miles in length for ADT of 5,000 or greater (more than 4 miles was required if ADT was less than 5,000). Sections were selected in each state to span a broad range of highway types, area types and traffic volumes.

A matched-control section was selected for each test section. The control section was matched to the test section in highway type, area type, and ADT. The highway type and area type of matching test and control sections were identical and the ADT were matched within 20%. Finally, whenever possible the control section was at least as long as its matching test section.

A number of unmatched-control sections were selected in each state. At the outset of the project it was expected that parts of the skid number range, particularly the high end of the range, might be underrepresented in the sample of test sections. Where this problem was found, unmatched-control sections representing the high end of the skid number range were selected. Additional unmatched-control sections were obtained because a number of test and unmatched-control sections had to be eliminated for various reasons such as postponement or cancellation of resurfacing on the test section. When complete project data were available for such sections, they were used as unmatched-control sections. The unmatched-control sections were used to increase the available sample size for the analysis.

The sections chosen in the initial selection process and used for the field inventory were referred to as macrosections. Preliminary boundaries for these macrosections were established at the time of the field inventory. These sections, however, contained many non-homogeneous elements such as small lengths of a contrasting highway type. These non-homogeneous elements were included because it was most convenient in the field to inventory a continuous length of highway. At a later stage of the project, a careful review of each macrosection was made to define the final section boundaries to be used for analysis. The sections defined by these final boundaries were referred to as microsections. The process of selecting microsections by eliminating the non-homogeneous elements of the macrosections is presented in Section IV.

Many resurfacing projects used as test sections were long enough to provide two or more microsections longer than the required minimum length discussed above. It was our initial intention to subdivide such sections and thereby increase the total sample of sections available for the statistical analysis. However, an examination of the requirements for the statistical analysis revealed that more power could be retained by making sections as long as possible, and thus increasing the expected number of yearly wet-pavement accidents, than could be obtained by subdividing longer sections into several sections 5 miles in length. Therefore, macrosections were not subdivided into more than one microsection unless this was required by non-homogeneity of the section.

In summary, a six-step process was used to select the sections and to define the final section boundaries. First, an initial list of macrosections was established after reviewing the list of resurfacing projects provided by each cooperating state. In the second step, this list was reviewed by each state to determine if the selected sections were suitable for use in the project. Third, any substitutions of sections recommended by the cooperating states were made. The field inventory of each section was then conducted. Preliminary macrosection boundaries were established at this time. When the resurfacing projects had been completed, the cooperating states provided data on the actual limits of resurfacing work. Finally, this resurfacing data and the field inventory data were used to establish the boundaries of the final microsections that were used in the analysis.

D. Selection of Before and After Periods

Dates were established for 1-year study periods both before and after resurfacing of the test sections. These dates were needed to define requests for accident data and for weather records used to estimate wet-pavement exposure. Each control section had the same before and after periods as its matching test section. However, because of the variation in resurfacing dates among the test sections, various 1-year periods had to be used for different test sections.

Another major constraint in the selection of study periods was the energy crisis or gasoline shortage that began to have a pronounced effect on highway transportation in the United States during the Fall of 1973. This shortage resulted in a nationwide reduction of speed limits to 55 mph in late 1973 and early 1974, and was accompanied by a marked reduction in nationwide accident experience, especially fatalities. The initial effect of the gasoline shortage on travel and accident experience was probably not uniform throughout the 16 cooperating states because of regional differences in the price and availability of gasoline and in the date of the speed limit reduction. For this reason, it was decided to collect no accident data for any section for the period between July 1, 1973 and June 30, 1974. All before data for the project, including accident data, were collected for a period before July 1, 1973. All after data were collected for a period after June 30, 1974.

The before period for each test section was a 12-month period during the 24 months immediately prior to resurfacing. Considerations in selecting the before period for a section were: (1) the date when resurfacing work began, and (2) the date for which skid data were available.

After data were collected for a 1-year period beginning 2 months after the completion of resurfacing work on each test section. The 2-month pause was intended as a settling-down period to allow the new pavement some initial exposure to traffic before skid data or accident data were collected. However, as stated above, no after period was begun before July 1, 1974. For this reason, the after period for some test sections did not begin until longer than 2 months after the completion of resurfacing. No after period for any section extended beyond December 31, 1975.

The before and after periods for unmatched control sections were defined by the dates of the available skid tests. However, as with the matched test and control sections, no data were collected for the period between July 1, 1973 and June 30, 1974.

III. DATA COLLECTION

Seven basic categories of data were collected for this project: (1) field inventory data, (2) resurfacing data, (3) skid resistance data, (4) accident data, (5) ADT data, (6) speed data, and (7) exposure data. This section of the report is correspondingly in seven parts, each part presenting the reason the category of data was collected, the elements in the data category, and the manner in which each data element was collected.

A. Field Inventory

The purpose of the field inventory was to obtain data on the geometrics, traffic control features, and pavement surface characteristics of the study sections. A photographic technique was developed to obtain pavement texture measurements. Because the photography required a field visit to each study section, it was decided to collect all of the necessary geometric and traffic control data in the field, rather than from office documents.

1. General inventory procedure: All field inventory data were collected from a moving survey vehicle by a three- or four-man crew. The crew collected three kinds of data on each inventoried section: (1) visual observations of roadway and roadside features, (2) readings from instruments used to determine percent grade, and radius and superelevation of horizontal curves, and (3) obliquely-lighted photographs of the pavement surface in the left wheel path of the vehicle. Each kind of data is discussed below in detail.

The survey vehicle was a specially equipped E-200 Ford Econoline van. The van instrumentation included a fifth wheel odometer and speedometer, a surveying altimeter, an electric gyrocompass, and a lateral accelerometer (U-tube manometer). Several runs over each section were needed to collect the required data.

A common coordinate system was needed to define locations of both the field inventory data and the data in other categories provided by state highway departments. The individual coordinate systems of the 16 cooperating states were unsuitable for three reasons. First, not all of the states have field markers (e.g., mileposts) identifying coordinate locations. Second, some states identify locations in mileage coordinates and others identify locations in stations (1 station = 100 ft). Finally, three states did not use a milepost system or a stationing system, but rather used a link-node or grid coordinate system for accident and/or skid data. Therefore, we established our own coordinate system for each section in the field, at the time of the inventory. The beginning point of the first run on each section was assigned an initial coordinate (usually zero) and the coordinates increased along the section until the end of the run. The direction of this first run is referred to as the forward direction and the coordinates defined above are referred to as forward inventory coordinates. Coordinates were measured in miles using the fifth wheel odometer. All project data were either recorded initially in this coordinate system or were later converted to this system manually or during computer processing.

2. Visual observations: The survey crew made visual observations of 25 geometric and traffic control features and recorded their observations manually on specially-developed forms. Data were recorded for three highway types during the field inventory: two-lane highways, multilane highways with uncontrolled access, and multilane highways with controlled access. Separate forms were developed for each highway type, because each presents different features to be recorded and different densities of features. Three types of forms were used for two-lane and multilane, uncontrolled access highways and two types were used for multilane, controlled access highways. Each form contained a group of features that could be recorded by one person on one pass over the highway section. The data items contained on each inventory form are identified and discussed in Appendix B.

Table 1 lists the 25 data items recorded by visual observation during the field inventory. The table identifies the highway types for which each data item was recorded and whether the item was recorded in one or both directions of travel. Detailed definitions of each data item and the codes used are found in Appendix B.

3. Geometrics: Quantitative data were recorded for two kinds of geometric features, grades and horizontal curves.

Grade data were obtained with a surveying altimeter. This instrument can detect the small changes of atmospheric pressure associated with changes of elevation. Once set to the local elevation, the instrument will display directly the elevation of any point along the highway. The scale of the altimeter used permits elevation readings to the nearest 5 ft. The altimeter was read by a crew member in the moving survey vehicle. Because the altimeter is pressure sensitive, its readings can be influenced by air currents caused by motion of the van. Experimentation established that the most consistent readings were obtained with the van windows slightly open.

The normal operating procedure for making altimeter readings was to set the altimeter for the approximate local elevation before the beginning of a run. The altimeter was then read at the beginning of the inventoried section and at 0.2-mile intervals throughout the section. A sample of the form used to record these observations manually is found in Appendix A. Differences between consecutive altimeter readings were used to calculate the average percent grade over 0.2 mile intervals as follows:

TABLE 1

VISUAL OBSERVATIONS RECORDED FOR EACH HIGHWAY TYPE

Data Item	Two-Lane Highways	Multilane Uncontrolled Access Highways	Multilane Controlled Access Highways
Highway Type	O	B	B
Lane Width	O	B	B
Pavement Type	O	B	B
Special Lanes	B	B	B
Shoulder Type and Width	B	B	B
Curb	B	B	B
Meidan Type	N	O	O
Median Width	N	O	O
Median Openings	N	O	O
Overpasses	N	N	B
Intersection Type	O	O	N
Intersection Contol	O	O	N
Intersection Channelization	O	O	N
Interchange Type	N	B	B
Interchange Ramp Length	N	B	B
Railroad Crossings	O	O	N
Drives	B	B	N
Pedestrian Crosswalks	O	B	N
No Passing Zones	O	N	N
Legal Speed Limit	O	B	B
Advisory Speed Limit	O	B	B
Bridges	O	O	B
Guardrail	O	B	B
Roadside Obstacles	B	B	B
Embankment Requiring Guardrail	B	B	B

Key:

N = Not recorded for this highway type
O = Recorded in only one direction for this highway type
B = Recorded in both directions for this highway type

$$\text{Percent Grade} = \frac{(100)\Delta E}{(5280)\Delta L} = 0.0189 \frac{\Delta E}{\Delta L}$$

where ΔE = Elevation difference over interval (ft), and

ΔL = Interval length (miles).

The radius and superelevation of each horizontal curve were determined from the following readings, made in the order given:

(1) Direction of curve (left or right)

(2) Y_B = Azimuth of back tangent (degrees)

(3) PC = Coordinate of point of curvature (miles)

(4) A = Accelerometer reading, ratio of lateral acceleration to acceleration of gravity (dimensionless)

(5) V_A = Speed of survey vehicle at time of accelerometer reading (mph)

(6) PT = Coordinate of point of tangency (miles)

(7) Y_F = Azimuth of forward tangent (degrees)

The locations where these readings are made are illustrated in Figure 1. A sample of the form used to record these data is given in Appendix A.

The procedure used to determine the radius and superelevation of a curve from the above readings is as follows:

Let L_c = Length of curve (miles), then

$$L_c = |PT - PC|$$

The change in heading (ΔY) in degrees for a curve is the smaller of the two quantities $|Y_F - Y_B|$ and $360 - |Y_F - Y_B|$.

Then,
$$R = \frac{5280\ (57.296) L_c}{\Delta Y}$$

where R = Radius of curvature (feet).

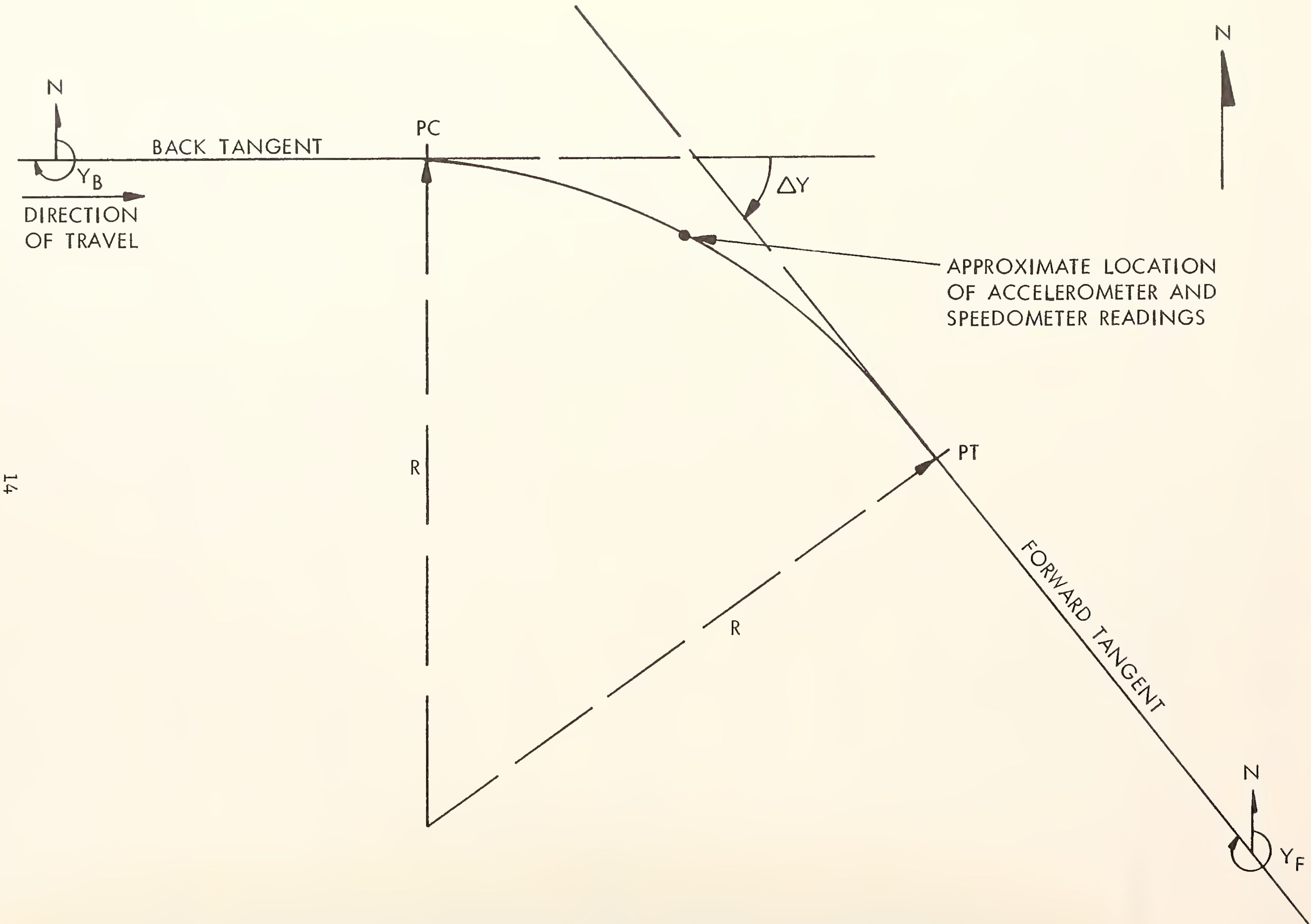


Figure 1 - Plan View of a Horizontal Curve Showing Curve Parameters

The superelevation is determined as $e = \frac{(1.4667\ V_A)^2}{gR} - A$ for a left curve and $e = \frac{(1.4667\ V_A)^2}{gR} + A$ for a right curve.

where e = superelevation (ft/ft), and

g = acceleration of gravity = 32.2 ft/sec^2

The constant in the equation, 1.4667, makes the units consistent by converting the vehicle speed from miles per hour to feet per second.

The instrument readings used to calculate the radius and superelevation of curves were obtained in the following manner.

The azimuth of the back and forward tangents, respectively, were read from an electric gyrocompass before entering and after leaving each curve. This instrument was checked for accuracy each day by driving the van through a 360° circle and observing whether the gyrocompass registered 360°. The coordinate of the PC and PT for each curve was recorded from the fifth wheel odometer to the nearest 0.01 mile.

A U-tube manometer containing colored water was used to measure lateral acceleration, to assist in the calculation of the superelevation of each curve. The manometer was graduated in units of the ratio of lateral acceleration to acceleration of gravity. The manometer fluid was suitably damped to obtain as steady a reading as possible under normal roadway conditions. The manometer and fifth wheel speedometer were read simultaneously near the center of each curve. The manometer reading is the resultant of two components. One is the displacement of the manometer fluid due to the centripetal acceleration of the van following a horizontal curved path along the highway; the other is rotation of the manometer due to superelevation of the roadway. The centripetal acceleration can be evaluated because the speed and radius of curvature are known. The remainder of the reading is due to the superelevation. Two potential sources of error in the manometer readings are present. The first is rotation due to lack of alignment between the horizontal axis of the manometer and the horizontal axis of the survey vehicle. This source of error was controlled by parking the survey van on a level surface each day and leveling the horizontal axis of the manometer. The other potential source of error is rotation due to roll by deflection of the springs of the survey vehicle. This source of error was controlled as much as possible by loading the van the same way each day.

The calculated values of superelevation are less accurate than the calculated values of radius of curvature. The inaccuracy of superelevation measurement results partly from the difficulty of obtaining a steady manometer reading in the field and partly because it is essentially impossible for the survey van (or any other vehicle) to track the curve following a path with constant radius of curvature. In addition, some imprecision in measurement is inevitable because the "as built" superelevation varies throughout a curve, even in the center portion of a curve where superelevation is nominally constant.

4. Photographic macrotexture data: An important accomplishment of the project was the development of a technique to estimate the rate of change of skid number with speed, the skid number-speed gradient, from photographs of a pavement surface taken from a moving vehicle.

Skid number is typically measured at 40 mph. However, it is postulated that the skid number measured at a higher speed, closer to the speeds at which most skidding accidents occur, is a more appropriate variable to relate to accident experience. To convert the skid number at 40 mph to skid number at some other speed, we must know the skid number-speed gradient.

Because the skid number decreases as speed increases, it is conventional to define the gradient as a positive number by taking the negative of the slope of the skid number-speed curve. For this project, the gradient was defined as:

$$SNG = - \frac{SN40 - SN60}{(40 - 60)}$$

where
SN40 = Skid-number at 40 mph,
SN60 = Skid-number at 60 mph, and
SNG = Skid number-speed gradient (SN/mph).

This form of skid number-speed gradient is most appropriate for adjusting skid numbers measured at 40 mph to a higher speed. Thus, the skid number at a higher speed, V , is

$$SNV = SN40 - SNG(V-40).$$

For example, if we know that the skid number of a pavement at 40 mph is 45 and the gradient is 0.50, then the skid number at 60 mph is:

$$SN60 = 45 - 0.50 \times (60-40)$$

$$= 45 - 10$$

$$= 35$$

The most obvious method of obtaining the gradient for a section of pavement is to measure the skid number at various speeds and determine it empirically. However, this is an expensive procedure and the cooperating states have only a limited budget available for skid testing. Consequently, gradients have been determined from multiple-speed skid tests for only a small number of pavement sections.

Several research projects have been directed toward alternate methods of determining the speed gradient of selected pavements. The most pertinent study was that of Schulze and Beckman.[2] They found that the skid number gradient from 20 to 60 km/hr was correlated with the mean width of surface voids. Larger void widths produce a flatter speed gradient, caused primarily by better water drainage. Their method of obtaining the mean void width was described by Schulze.[3] Stereo photographs were taken of pavement sections and magnified 25 to 1. The outline of each individual void was traced onto paper and the width of each void measured. Needless to say, this procedure would be overwhelmingly expensive for any major speed-gradient inventory.

Gillespie[4] found mean void widths using pavement profile traces obtained with an electromechanical roughness meter. The mean void width was defined as the mean distance between peaks of the trace. When mean void width was compared to the known speed-gradient from 37.5 to 50 mph, the correlation with the Schulze and Beckman curve was excellent.

Goodman[5] proposed several techniques for pavement texture measurement from a moving vehicle involving photography, although his validation was limited to laboratory tests. A narrow slit of light was projected vertically onto the surface of the pavement and the resulting line was photographed from an angle of 30° to the horizontal. In the resulting photograph, the strip of light delineated the peaks and valleys along the strip very well. The mean number of peaks per inch (reciprocal of mean void width) from the photographic technique agreed well with the results from an electromechanical roughness meter applied to the same strip of pavement.

The gradient estimation technique developed for this project draws upon all of the above work. We elected to use a photographic approach, because it appeared to offer the highest probability of success.

A sketch of the photographic equipment configuration is shown in Figure 2. It consists of four parts: a projection system, a camera system, a light shroud, and an auxiliary equipment package.* The projection system projects a high-intensity, short-duration shadow-bar pattern on the pavement surface. The projection is made at a shallow angle (20°) with the pavement surface to enhance the visibility of surface texture. The camera is aimed perpendicular to the highway surface and synchronized with the projector to obtain photographs of the projected shadow-bar pattern as it appears on the non-planar surface. An example of the projected shadow-bar pattern is given in Figure 3. The function of the light shroud is to block out most (but not all) of the ambient light. A small amount of ambient light was found to increase the quality of the photographs. The auxiliary equipment package consists of power supply and automatic control equipment.

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* The auxiliary equipment package is not shown in Figure 2.

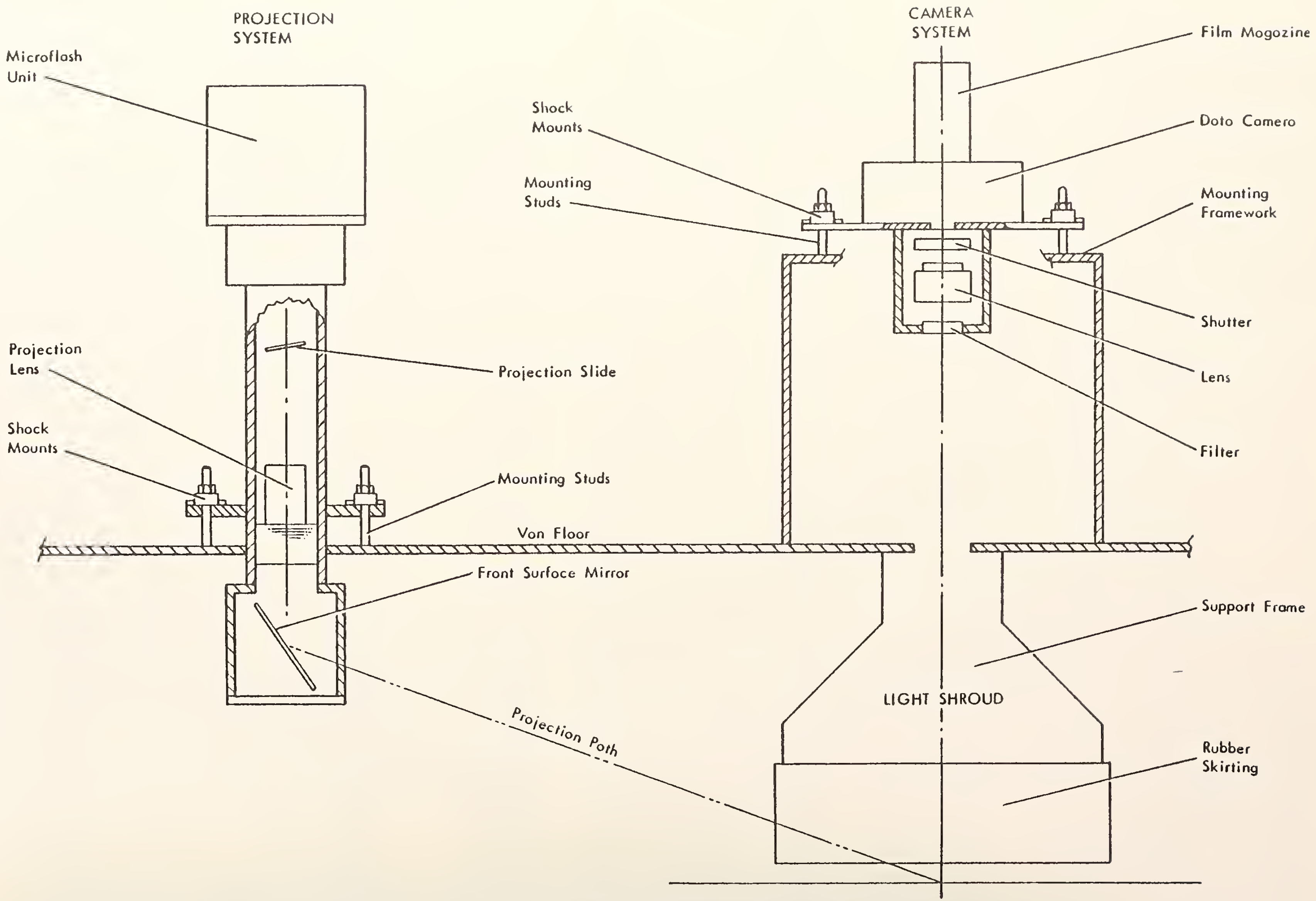

Figure 2 - Principal Components of Photographic System

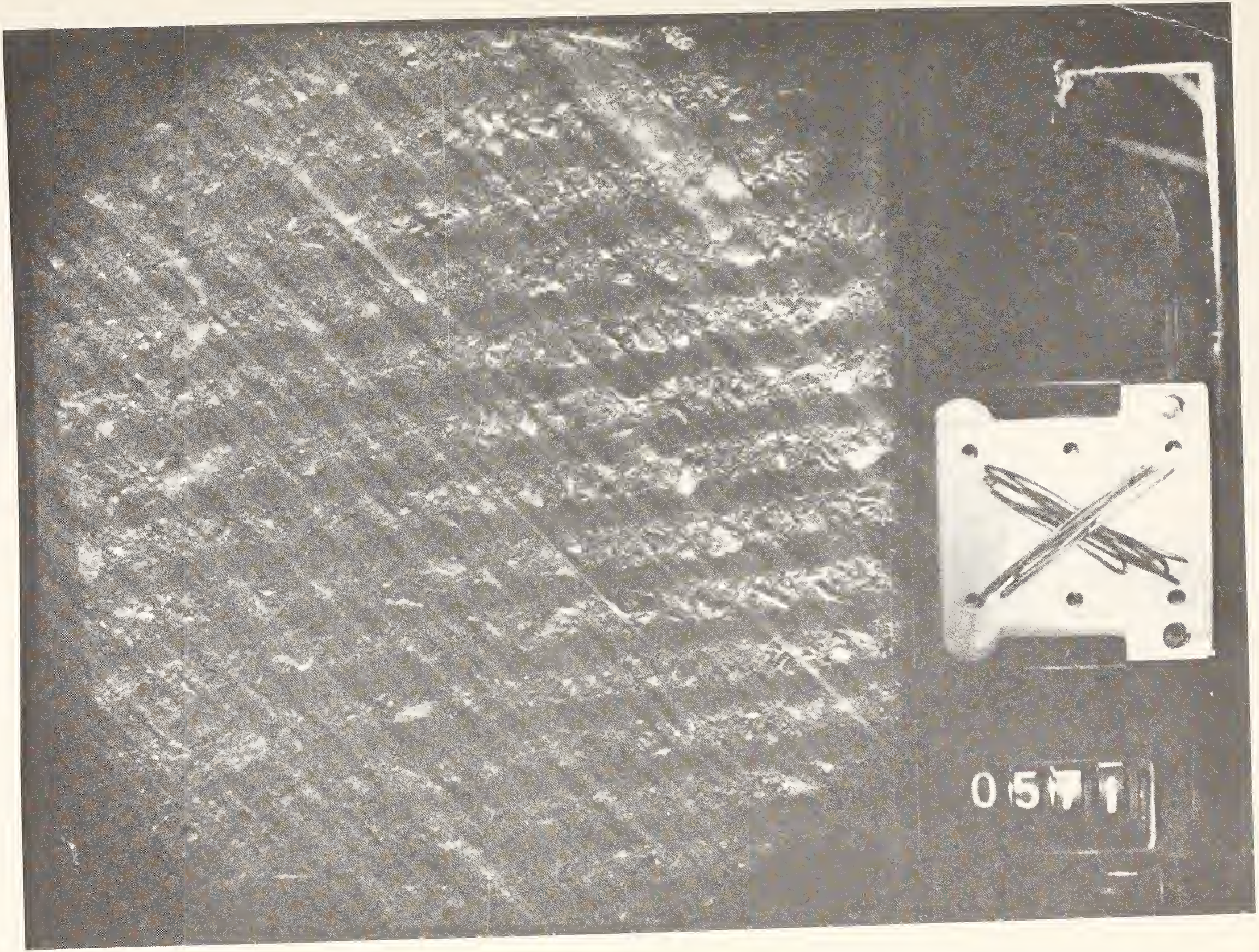

Figure 3 - Example of Pavement Photograph with Projected Shadow-Bar Pattern

In operation, a push-button triggering switch initiates an event sequence which included firing the synchronized camera and projector, illuminating the camera data chamber, and advancing the film. A more detailed description of the components of the photographic system is in Appendix C.

The photographic system was used throughout the field inventory. Over 32,000 photographs were made of the inventoried highway sections. Approximately five photographs per mile were made in the travel (right) lane. Two-lane pavements were photographed in one direction of travel only, while multilane pavements were photographed in both directions of travel.

In addition, a special series of macrotexture photographs and pavement impressions were made on "in-service" pavements in Ohio, Pennsylvania, Florida and Louisiana during the field inventory. Similar data were also obtained from the five standard surfaces used for skid trailer calibration at the Eastern States Field Test and Evaluation Center in East Liberty, Ohio. These data were used to develop an evaluation technique for the pavement photographs.

Five photographs of surfaces with known gradient were selected as standards for use in rating the photographs. These five photographs were assigned standard rating values of 1 through 5 in order of descending gradient. All available photographs of known gradient surfaces were rated by comparison with the five standard photographs. A regression analysis developed the relationship between standard rating (on the 1 to 5 scale) and gradient as

$$SNG = 0.52 - 0.06\ R$$

where SNG = Skid number-speed gradient (SN/mph)

R = standard rating

A detailed discussion of the development of this rating relationship is in Appendix C.

Each of the over 32,000 photographs obtained in the field was rated by a trained observer, by comparison with the five standard photographs. The observer assigned an integer rating of 1 to 5 to each field photograph. The location of each photograph and its standard rating were encoded and keypunched for processing with other project data. The mean standard rating of all photographs on a section was used to estimate the average skid number-speed gradient and to adjust the measured skid number to speeds other than 40 mph (see Section III-C).

The above approach was used to obtain the skid number-speed gradients for all control sections. However, for the test sections, 44% were photographed before resurfacing and 56% were photographed after resurfacing. Only one inventory trip could be made to each test section, so gradients could be estimated directly for either the before or the after period, but not for both. Therefore, gradient estimates were also developed for each pavement type from the field data that were available.

To deal with uninventoried sections in the before period, a sample of older sections with asphalt concrete (AC) and portland cement concrete (PCC) pavements was identified in the project data. Sections about to be resurfaced at the time the photographs were taken were selected, so that these photographs would be typical of older pavements such as the unphotographed test sections. This sample included 906 photographs on AC pavements and 655 photographs on PCC pavements. The mean and variance of the gradient ratings (1 to 5 scale) for these photographs were:

	Older AC Pavements	Older PCC Pavements
Mean Gradient Rating	2.1	1.9
Variance of Gradient Rating	1.07	0.48

The difference between the ratings for AC and PCC pavements was statistically significant, so separate values were used for the two pavement types. The mean ratings correspond to gradients of 0.39 and 0.41 SN/mph for AC and PCC pavements, respectively. These estimates were used for all test sections that were not photographed before resurfacing.

A similar analysis was made for test sections that were not photographed after resurfacing. A set of 520 photographs made on AC pavements within 1 year after resurfacing was obtained.* The mean rating of these photographs was 1.5, corresponding to a gradient of 0.47 SN/mph. This value was used as an estimate of the gradient for all test section pavements not photographed after resurfacing. It was surprising that a larger gradient was found for new than for older asphalt pavements. It had been expected that the older pavements would be worn smoother and would therefore have a larger gradient. However, the difference between the old and new asphalt pavements, while statistically significant, is almost trivially small--amounting to a skid number change of 1.2 at 60 mph for pavements with the same skid number at 40 mph.

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* All resurfacing was asphaltic.

B. Resurfacing Data

Two hundred twelve (212) test macrosections were included in the field inventory. The cooperating states were requested to provide several different kinds of data about each resurfacing project for use in defining further analyses. The following information was requested:

1. Updated project boundaries: The state provided the actual limits of resurfacing work. These limits frequently differed from the resurfacing project boundaries available at the time of the field inventory. Only those portions of each test macrosection that were actually resurfaced were included in a test microsection.

2. Actual start and completion dates: The actual start and completion dates of resurfacing work, rather than the letting and acceptance dates, were obtained. These dates were used to establish before and after study periods for each test microsection and its matching control microsection.

3. Type of pavement surface before resurfacing: The states identified the pavement surface before resurfacing as either asphalt concrete or portland cement concrete. This information was used in the estimation of the skid number-speed gradient for test microsections where no photographs were taken before resurfacing.

4. Material and mix used for resurfacing: The states identified the material and mix used for resurfacing each test microsection, usually with reference to their standard specifications.

5. Cost of resurfacing: The states provided the actual cost of each resurfacing project including any overrun or underrun of the bid price.

6. Improvements other than resurfacing: The states identified any work carried out on the test microsection in addition to resurfacing. For example, shoulder improvements were carried out in conjunction with many resurfacing projects. The test microsections were pre-screened to assure that they did not include major reconstruction work such as reconstructing curves, adding additional lanes, etc. Such major reconstruction might produce a confounding effect on accident rates that could be mistaken for a skid number effect.

C. Skid Resistance Data

The following section describes the skid resistance data provided by the cooperating states and the skid resistance measures obtained from these data.

1. Candidate measures of skid resistance: The most commonly used measure of skid resistance is the skid number. This number is the coefficient of sliding friction multiplied by 100. Possible values of skid number range from 0 to 100.

The skid number of a pavement depends on the speed at which skid number is measured. A standard testing speed of 40 mph is used by each of the cooperating states in accordance with ASTM Specification E-274. Thus, the skid number at 40 mph, SN40 , is one candidate measure of skid resistance used on the project.

Most vehicles on high-type facilities travel at speeds substantially higher than 40 mph. Therefore, it was postulated that the skid number at a more appropriate (higher) speed might show a stronger correlation with accidents than SN40 . The skid number at the 85th percentile speed of traffic, SN(85) , is the second candidate measure of skid resistance that was considered. The skid number-speed gradient (i.e., the slope of the skid number-speed curve) was estimated from the photographs of the pavement surface taken in the field inventory described in Section III-A. The estimated skid number-speed gradient was used to adjust SN40 to SN(85) .

2. Skid resistance data requested from the cooperating states: The cooperating states were requested to provide the results of skid number measurements made both before and after resurfacing of each test section. Some states were able to schedule skid tests at our request during the period immediately before resurfacing. In other states the test sections were resurfaced before the collection of data began. These states were able to provide skid number measurements of the before condition from their files.

The cooperating states were also requested to make skid number measurements on the test sections after resurfacing. No such skid number measurements were made during the first 2 months after the resurfaced pavement was opened to traffic, to allow for some initial wearing of the surface and to allow the skid number of the new surface to have a chance to stabilize. Due to delays encountered by the states in scheduling skid tests, the skid resistance of some test sections was not measured until 18 to 24 months after resurfacing. The actual date of the skid test was one factor in the selection of the before and after study periods. This assures a correspondence between the skid number and accident data used in the analysis.

The cooperating states were requested to make skid number measurements on all of the control sections during the same periods when the test sections were skid tested. Thus, two sets of skid tests were made on each control section, corresponding to the before and after periods, even though no modification was made to the pavement surface between the measurements. These two measurements were intended to enable controlling for the expected variation in skid number from sources such as degradation due to traffic wear.

It was not possible for the cooperating states to skid test each study section during the same season of the year in both the before and after periods. This was unfortunate, because pavement skid numbers are known to vary with the season of the year. The highest skid number values are observed in the spring months and the lowest values in the fall. Extreme seasonal variations in skid number as high as 30 have been reported, with more typical variations in the range of 5 to 15.[18/] This phenomenon is presumed to result from variations in precipitation, temperature or some combination of both. An analysis of skid data for the test sections, presented in Appendix G, concludes that no reasonable model of seasonal variations in skid number could conceivably result in a significant effect on the mean change of skid number with resurfacing. Thus, seasonal variation of skid number does not appear to introduce an overall bias into the data set. However, it is not known to what extent seasonal variation of skid number might influence the coefficients of the accident rate-skid number relationships developed from these data.

Due to budget and manpower limitations, the cooperating states were unable to skid test all of the sections that we requested. Those test and control sections for which skid number data were not available for either the before or after period were dropped from the analysis.

3. State skid testing procedure: The basic procedure for skid testing of pavement surfaces is contained in ASTM Specification E-274. The essential points of the ASTM procedure are as follows: Testing is done with a two-wheel trailer towed by a truck at 40 mph. A layer of water 0.02 in. thick is placed on the pavement by nozzles located just in front of the trailer wheels. This requires a flow rate of 3.6 gal/min/in. of wetted width at 40 mph. The trailer brakes are activated to lock one or both of the trailer wheels on the wetted surface. A trace of the wheel torque is made and later interpreted to obtain the frictional force and the skid number. The conversion relationship used to obtain skid number from the friction force depends on the geometry of each individual skid trailer.

The tires used for skid testing must meet specifications established by ASTM. In the past, 14-in. tires meeting ASTM Specification E-249 have been used for skid testing. However, a changeover to 15-in. tires meeting ASTM Specification E-501 was made during this project. The comparisons between the tires that were initially available showed that the 15-in. tires produced skid number readings slightly lower than 14-in. tires for surfaces with skid number above 50.[67] More recently, the results of a complete analysis by the Federal Highway Administration have shown that the 15-in. tire produces skid number readings approximately 4% higher than the 14-in. tire at 40 mph.[19] For purposes of this study, the difference between the skid test tires was assumed to be negligible.

Table 2 describes the procedures and equipment used by each state to gather skid resistance data for this project. The table includes the testing speed, wheelpath and testing interval used by each state. It also gives details of each state's skid trailer such as the number of wheels, the manufacturer, and the availability of calibration equations from one of the three National Field Test and Evaluation Centers. The procedures and equipment used by most of the cooperating states were in at least rough conformance with the ASTM Specification described above. The major exception is Pennsylvania, which used a one-wheel trailer design originated by the Penn State University. Five of the cooperating states had more than one skid trailer. It was not possible to schedule all testing in these states with only one trailer, so several trailers were used to collect the skid data in each of these states.

Most skid testing was done at 40 mph. However, many states conduct tests at speeds other than 40 mph, particularly in congested areas where testing at 40 mph is considered unsafe. Individual test results from speeds other than 40 mph were corrected to 40 mph using the photo-estimated gradient, so that these data could be combined with data collected at 40 mph. Several of the states have developed "rules of thumb" to correct skid test results obtained at other speeds to 40 mph. Whenever possible, we "uncorrected" the data supplied by the state to obtain the raw skid number and then used the photo-estimated gradient to adjust to 40 mph. This procedure assures that the data from all 16 states are adjusted on a common basis.

Another area of variation in procedure among the states is the wheel path that is tested. The left wheel path is generally regarded to be most exposed to traffic wear and, therefore, to have the lowest skid resistance. Twelve (12) of the 16 cooperating states routinely test by locking the left wheel only. However, the State of California considers the right wheel path to have the lowest skid resistance and routinely tests with the right wheel only. The State of Maine tests alternately with the right and left wheels and one of the trailers owned by the State of Michigan, as well as the West Virginia trailer, tests by locking both wheels simultaneously. Because of these variations, data supplied by the states had to be used regardless of the wheel path tested.

TABLE 2

SKID TESTING PROCEDURES FOR CONTRACT DOT-FH-11-8120

State	Usual Testing Speed (mph)	Wheel Path Tested	Testing Interval (Miles)	Skid Trailer: Unit No.	No. of Wheels	Manufacturer	Calibrated at NTC	Correction Equation Used: Before Data	After Data
California	40	Right	0.3-0.5	A	2	K. J. Law	Yes Arizona - 1975	Yes	Yes
California	40	Right	0.3-0.5	B	2	Unknown	No	No	No
Connecticut	40	Both	a/	1	2	Testlab	Yes Ohio - 1975	Yes	Yes
Florida	40	Left	0.2	1	2	K. J. Law	Yes Texas - 1974	Yes	Yes
Florida	40	Left	0.2	3	2	Unknown	No	b/	No
Louisiana	40	Left	1.0	1	2	Unknown	Yes Texas - 1973	Yes	c/
Maine	40	Left and Right d/	0.25	1	2	Maine DOT	Yes Ohio - 1974	Yes	Yes
Maryland	40	Left	0.5	1	2	Maryland DOT	Yes Ohio - 1975	Yes	Yes
Maryland	40	Left	0.5	2	2	K. J. Law	Yes Ohio - 1975	b/	Yes
Massachusetts	40	Left	0.3-0.5	1	2	Stevens Institute	Yes Ohio - 1974	Yes	c/
Michigan	40	Both	a/	1	2	Michigan SHD	No	No	No
Michigan	40	Left	e/	2	2	K. J. Law	Yes Ohio - 1975	No	Yes
Mississippi	40	Left	1.0	1	2	Soiltest	Yes Texas - 1974&75	Yes	Yes
North Carolina	40	Left	0.2	1	2	North Carolina DOT	No	No	No
Ohio	40	Left	0.5	1	2	K. J. Law	Yes Ohio - 1974	Yes	Yes
Pennsylvania	40	Left	0.33	f/	1	f/	No	No	No
Rhode Island	40	Left	0.5-1.0	1	2	K. J. Law	Yes Ohio - 1974	g/	g/
South Carolina	40	Left	0.3-0.4	1	2	Soiltest	No	No	No
Washington	40	Left	1.0	1	2	Soiltest	Yes Arizona - 1975	No	No
Washington	40	Left	1.0	2	2	K. J. Law	Yes Arizona - 1975	No	No
West Virginia	h/	Both	0.5	1	2	Soiltest	Yes Ohio - 1975	Yes	Yes

a/ Testing interval unknown for Connecticut data. Locations of individual skid tests were not identified.
b/ No skid data for before period collected with these trailers.
c/ After-period skid data from Louisiana and Massachusetts not used because after-period accident data were not available.
d/ Maine conducted skid test alternately with the left and right wheels.
e/ Michigan skid tests were not conducted at a predetermined interval. Instead, several skid tests were conducted at each of 2-5 sites on each section.
f/ Pennsylvania has five one-wheel skid trailers. The first was built by Penn State, the second by Wald Industries, and the remainder by Soiltest.
g/ Rhode Island skid data were not used because accident data were not available.
h/ West Virginia conducted skid tests at three speeds (25 mph, 40 mph and 55 mph) on each section. Seven tests at 25 mph were conducted on the first third of the section; seven tests at 40 mph on the second third; and seven tests at 55 mph on the final third.

Eleven of the 16 cooperating states conducted skid tests for the project in both directions of travel on two-lane pavements. The states of Florida, Massachusetts, Pennsylvania, South Carolina and West Virginia conducted tests in one direction only on two-lane highways. All 16 states tested multilane highways in both directions of travel. On multilane highways, only skid tests conducted in the travel (right) lane were used in the subsequent analysis.

4. Form of data provided by the cooperating states: Skid test results were provided by the states in several forms. Separate data formats were established for encoding each form of the data.

Most of the states conducted a series of tests along a section at an established testing interval. The data included the result of each individual test, the location of the test, the test speed, and the wheel used for testing. All of this information was encoded. Separate data formats were used for skid tests conducted at equally-spaced intervals and at irregular intervals.

A few states reported a series of skid number values resulting from repeated tests at selected sites within the section. The individual values of skid number were encoded together with their test speed and wheel and their common location. A special format was used for data in this form.

Finally, one state reported only the average value of several tests conducted on each section. The state had tabulated average skid number values for various highway sections but the individual skid numbers had not been retained. A special coding format was also needed for these data.

5. Skid trailer calibration results: Thirteen of the 16 cooperating states sent their skid trailers to be calibrated during 1974 or 1975 at one of the three Field Test and Evaluation Centers established by FHWA in Ohio, Texas and Arizona. Calibration relationships established at these centers were used to correct the raw skid data supplied by these states. No correlations between the calibrations from the three national centers were available in time to be used in the initial data analysis. However, calibration relationships between the three centers and the National Bureau of Standards (NBS) trailer were obtained at a later date, after the analyses reported in this volume were completed. At that point, a test was made to determine if the lack of correlations between the three centers invalidated the earlier analyses. All skid data collected with calibrated trailers were corrected to values consistent with the NBS trailer. Upon reanalysis of the data, no significant differences in the analysis results due to this correction were found. Therefore, the lack of calibration corrections between the three centers does not affect the validity of the analysis results reported in this volume.

Two correlation studies are made on each skid trailer during calibration. The first correlation is made by comparing the state's trailer in the "as arrived" condition with known skid numbers for several reference surfaces. The results are given as a series of regression equations that can be used to adjust skid measurements made prior to calibration. The 40 mph correction equations were used for this project and are of the following form:

$$SN40\ (Standard) = a + b\ SN40\ (State)$$

An identical study, known as the second correlation, is performed after any needed adjustments are made to each state's skid trailer. The regression equations obtained from this study are of the same form as above and are appropriate to correct measurements made after the calibration.

The calibration relationships caused a substantial adjustment of the measured skid number in several cases. For example, an observed skid number of 40 could be adjusted to as high as 45.6 or as low as 34.8, depending on the trailer. These are extreme cases, however, and most adjustments were smaller. The average magnitude (absolute value) of calibration correction for a measured skid number of 40 for all trailers was 2.42.

Calibration corrections were made only for those trailers identified in Table 2 as having been calibrated at one of the three centers. No correction was made to skid measurements made by trailers that were not calibrated.

6. <u>Calculation of average SN for a section</u>: The average skid number for a section in both the before and after periods was determined in the following manner. A computer program examined all skid test data provided by the state for each study section and selected for analysis only those tests located within the final section boundaries in the travel (right) lane. Skid data from both directions of travel were used when available. If any skid tests were conducted at speeds other than 40 mph, these individual test results were converted to 40 mph as follows:

$$SN40 = SNT - (40 - V_T)(0.52 - 0.06\ \bar{R})$$

where $SN40$ = Skid number adjusted to 40 mph,

SNT = Skid number at test speed,

V_T = Test speed (mph), and

$\bar{R}$ = Mean gradient rating for the section (photo-estimated).

The quantity $0.52 - 0.06\ \bar{R}$ is the estimated skid number-speed gradient. The derivation of this quantity is briefly discussed in Section III-A and presented in detail in Appendix C.

Next, all skid tests made with trailers calibrated at one of the three Field Test and Evaluation Centers were adjusted with the trailer calibration results, as described above. The mean skid number at 40 mph ($\overline{SN40}$) was calculated using all of the above data. This quantity is the first of the candidate measures of skid resistance used in the analyses.

The second candidate measure of skid resistance is the skid number adjusted to the 85th percentile speed of each microsection. This quantity was determined as:

$$\overline{SN(85)} = \overline{SN40} - (V_{85} - 40)\ (0.52 - 0.06\ \bar{R})$$

where $\overline{SN(85)}$ = Mean skid number at 85th percentile speed,

$\overline{SN40}$ = Mean skid number at 40 mph,

V_{85} = Estimated 85th percentile speed for the section (mph), and

$\bar{R}$ = Mean gradient rating for the section (photo-estimated).

The estimation of the 85th percentile speed for each study section is discussed in Section F.

D. Accident Data

A major effort was needed to collect accident data for the project. Initial planning for this effort identified those aspects of accident experience that were required to explore the accident rate-skid number relationship. Accident data for each test and control section were then obtained from the cooperating state highway departments.

Wet-pavement accidents are those accidents which are reported as occurring under wet-pavement conditions by the police officer who investigates the accident and files the accident report. Wet-pavement accidents do not necessarily involve skidding. An early decision was made to study all wet-pavement accidents rather than just those accidents identified as involving skidding. Only five of the 16 cooperating states were able to identify whether or not accidents involved skidding on their computer-generated accident data. Furthermore, there are obvious questions as to the completeness of the reporting of skidding involvement, even in those states which use this item. On the other hand, pavement conditions at the time of the accident are easily observed and universally reported.

Although the study of wet-pavement accident experience was the focus of the project, dry-pavement accident experience was also analyzed for comparative purposes as described in Section V (Data Analysis).

A careful study was made to determine the most appropriate measure of wet-pavement accident experience for use in the statistical analyses. Because of the varying lengths and traffic volumes of the study sections, a simple comparison of the number of wet-pavement accidents for each section would be misleading. Previous researchers including Rizenbergs et al.,[14] have used the ratio of wet-pavement accidents to dry-pavement accidents or total accidents as a measure. However, the highway sections used in this study are located in a variety of climates with contrasting wet-pavement exposure times. The differences in exposure time cannot be easily incorporated in the wet-to-dry and wet-to-total accident ratios. Instead, a wet-pavement accident rate was computed for each section using three factors to normalize the observed accident experience: (1) section length, (2) exposure to wet-pavement conditions, and (3) traffic volume. The latter two factors are discussed in Sections III-E and III-G. The accident rate per million vehicle-miles is determined using the expression presented below in the discussion of processing the accident data.

The general structure of the experiment used in the project was a before and after comparison of accident experience on sections, some of which were resurfaced and some of which were not. Therefore, accident data were gathered separately for the before and after periods. One year of accident data was used for each period. Different dates were used for the accident periods for each matched pair of test and control sections, because there was a different resurfacing schedule for each test section. The selection of dates for the study periods is discussed in Section II. The 1-year before period occurred within a 2-year period prior to resurfacing of each section; and the 1-year after period did not begin until at least 2 months after the completion of resurfacing on the test section.

1. Request to cooperating states: All accident data were provided by the cooperating states. The before data were requested soon after the field inventory, when preliminary section boundaries were established. The after data were obtained at a later date.

Each state was asked to provide detailed data on each accident that occurred on each section during both the before and after study periods. In most cases the states were able to provide this data in computer printout form. These data were keypunched directly from the computer printout. In a few cases hard-copy accident data had to be used. These accident data were manually encoded prior to keypunching.

Most of the accident data that we requested from the cooperating states were provided. The State of Rhode Island was unable to provide accident data for the before period, because Rhode Island did not have a computerized accident records system at that time and hard-copy accident data were unavailable. After accident data were not obtained from the states of Louisiana and Massachusetts because routine processing of 1975 accident data by these states was not completed in time for analysis. All other accident data requested by the project were obtained.

Data were provided in the printout form routinely used by the states at the time of the request. The states of Michigan and Massachusetts provided accident data in two different formats. In Michigan, a special format was required for accidents that occurred within the City of Detroit. In Massachusetts, different formats were required for accidents recorded with the Department of Public Works and with the Registry of Motor Vehicles. Also, some states modified the format in which they provided data between the time of the before and after accident requests. These changes in format increased the complexity of the data processing effort, but did not reduce the availability of any data needed for the project.

A detailed discussion of the accident data items obtained is given below.

2. Accident data items used: The list of data items to be obtained from the cooperating states was determined before the initial accident requests were submitted. Preliminary indications of data availability from the cooperating states and potential accident correlates from the literature were used to help determine the list. The following data items were collected from each state where they were available:

- Location (used to identify whether the accident occurred within the final section boundaries);
- Date (day, month and year in which the accident occurred);
- Accident type (based on the National Safety Council classification system in most states);
- Manner of collision (head-on, rear end, etc.);
- Accident severity (number of dead, number of injured, number of injuries in each injury class, and estimate of property damage);
- Number and type of vehicles involved;

- Light condition;
- Direction of travel;
- Vehicle speed;
- Skidding involvement;
- Vehicle condition;
- Geometry (used to determine if a curve, grade, or intersection was involved in an accident); and
- Pavement condition (used to determine whether the pavement surface was under wet, dry or ice and snow conditions at the time of the accident).

Table 3 identifies those states for which each data item was available. Those items which were available from only a limited number of states were not included in the overall analyses. However, the basic data items needed for the analysis--date, location and pavement surface condition--were available for all states and were used.

3. Data processing: The accident data were processed to obtain the accident rate under wet- and dry-pavement conditions for each test and control section. The first step in this process was to determine the number of accidents under wet- and dry-pavement conditions for each section during the before and the after periods. The data for each accident were examined to determine if it was within the final section boundaries, whether it occurred in either the before or after period, and whether it occurred under wet- or under dry-pavement conditions. The analysis excluded accidents that occurred on roads that intersected the study section and accidents that occurred on interchange ramps, whenever such accidents could be identified. Such accidents were not included in the study because (1) no skid tests were conducted on either crossroads or interchange ramps, and (2) traffic volumes for crossroads and ramps were not available.

Once the number of accidents that occurred under wet-pavement conditions was determined, the accident rate was computed as follows:

$$AR = \frac{N_w (24)(10^6)}{(L)(E_w)(ADT)}$$

where AR = Wet-pavement accident rate (accidents/10^6 vehicle-mile)

N_w = Number of wet pavement accidents during study period

L = Section length (miles)

TABLE 3

AVAILABLE ACCIDENT DATA ITEMS FROM 16 COOPERATING STATES

	CA	CT	FL	LA1/	ME	MD	MA2/	MA3/	MO4/	MO5/	MS	NC	OH6/	OH7/	PA	RI8/	SC	WA	WV	Total Number of States With Data Item Available
Location	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Day	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	14
Month	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Year	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Pavement Surface Condition	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Accident Type	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Manner of Collision	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Accident Severity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	15
Number of Deaths	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	15
Number of Injuries	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	15
Number of "A" Injuries		X			X							X		X						4
Number of "B" Injuries		X			X							X		X						4
Number of "C" Injuries		X			X							X		X						4
Property Damage Estimate					X	X					X	X			X		X	X	X	8
Number of Vehicles Involved	X	X	X	X	X	X	X			X	X9/		X	X	X			X	X	13
Number of Cars Involved	X	X		X	X	X				X	X9/				X			X	X	10
Number of Trucks Involved	X	X		X	X	X				X	X9/				X			X	X	10
Number of Other Vehicles	X	X		X	X	X				X	X9/				X			X	X	10
Light Condition	X	X	X	X	X	X	X	X			X	X	X	X	X		X	X	X	14
Direction of Travel	X	X			X	X	X	X	X			X			X			X	X	10
Vehicle Speeds				X								X								2
Skidding Involvement		X					X	X	X								X	X		5
Vehicle Condition				X						X										2
Curve Involvement		X	X	X	X				X				X	X	X		X	X		9
Grade Involvement		X	X	X	X								X	X	X		X	X		8
Intersection Involvement	X		X	X	X	X			X		X9/		X	X			X	X	X9/	11

1/ Louisiana accidents available for before period only
2/ Massachusetts accidents listed with Department of Public Works - available for before period only
3/ Massachusetts accidents listed with Registry of Motor Vehicles - available for before period only
4/ Michigan accident format for all accidents except before accidents within the City of Detroit
5/ Michigan accident format for before accidents within the City of Detroit
6/ Ohio accident format for 1972 before accidents
7/ Ohio accident format for 1973 before accidents and 1974 and 1975 after accidents
8/ Rhode Island accident data not available
9/ Data item available for before period only

E_w = Exposure to wet pavement conditions during study period (hours)

ADT = Average Daily Traffic (vehicles)

The purpose of the two constants in the expression for wet-pavement accident rate is to place the accident rate in the desired units--accidents per million vehicle-miles. The first constant, 24, converts the wet-pavement exposure time from hours to days and the second constant, 10^6, converts the entire expression from accidents per vehicle-mile to accidents per million vehicle-miles. The dry-pavement accident rate was computed analogously as:

$$DAR = \frac{N_d (24)(10^6)}{(L)(E_d)(ADT)}$$

where DAR = Dry-pavement accident rate (accidents/10^6 vehicle-mile)

N_d = Number of dry-pavement accidents in study period

E_d = Exposure to dry-pavement conditions during study period (hours)

E. ADT Data

Average daily traffic (ADT) data were needed both to calculate accident rates and to stratify the study sections for the statistical analysis. Because traffic volumes usually change with time, the ADT for each test and control section was obtained for both the before and after periods. The sources of these data were ADT maps, log books, and other information provided by the cooperating states.

Most of the test and control sections carry two-way traffic. The two-way ADT was used in calculating accident rates for these sections. However, six of the study sections consisted of one roadway of a divided highway. For these sections, the one-way ADT (estimated as half of the two-way ADT) was used.

The data provided by the cooperating states showed that ADT often varies along a section. Such sections were divided into zones and a weighed-average ADT, as shown below, was used in the calculation of accident rates:

$$ADT = \frac{\sum_{i=1}^{n} (ADT_i)(L_i)}{L}$$

where ADT = Weighted average ADT (vehicles)

ADT_i = ADT of i^{th} zone (vehicles)

L_i = Length of i^{th} zone (miles)

$$L = \sum_{i=1}^{n} L_i = \text{section length (miles)}$$

n = Number of zones.

F. Speed Data

The energy crisis that began in the late Summer and Fall of 1973 produced some changes in highway travel characteristics that were expected to have an impact on the results of the matched-pair, before-after experimental design employed in the analysis. The primary change expected was a reduction in vehicle speeds. Because of the concern about these potential effects, the original analysis plan was modified to separate the effects of the energy crisis from the effects of a change in skid number. This amounted to expanding the experimental design to include in the analysis an estimate of the appropriate wet-pavement operating speed for each study section. This operating speed would be used two ways in the analysis of the wet-pavement accident rate-skid number relationships: (1) to adjust the skid numbers obtained at a reference speed (usually 40 mph) to the skid numbers experienced by vehicles operating on wet pavements; and (2) as another concomitant variable in the covariance design along with the value of the skid number obtained at the reference speed.

Since the skid number normally decreases as vehicle speed increases, the region of higher vehicle speeds is more critical in the analysis of wet-pavement accidents and skid number. Therefore, the 85th percentile of the wet-pavement speed distribution was postulated as the most appropriate speed for use in the analysis.

Speed studies under wet-pavement conditions were not available from any of the cooperating states. Therefore, dry-pavement speed data were obtained from each state for typical highway sections in that state. Such data were available from 11 states for the before period and from 12 states for the after period. These data were used to estimate the 85th percentile speed of traffic on dry pavement for each test and control section. The collection of these general speed data is discussed in Appendix D.

A special study was conducted to determine the relationship between traffic speeds on wet and dry pavements. The details of this study are presented in Appendix D. It was found that wet-pavement speeds are 1.19 $\pm$ 0.58 mph lower than dry-pavement speeds. Highway type and area type did not produce any variation in this wet-dry speed correction. Therefore, this single correction factor was used to adjust all of the estimated dry pavement speeds, so that they were representative of operating speeds under wet-pavement conditions.

G. Wet-Pavement Exposure Determination

One of the key ingredients used in the determination of the accident rate-skid number relationships is wet-pavement accident rate. The wet-pavement accident rate for each of the test and control sections is dependent on the exposure of the section to wet-pavement conditions. It is important that this variable be taken into account because climatic conditions vary greatly due to the geographic separation of the sections and the temporal separation of the before and after study periods. Wet-pavement exposure was determined using weather records assembled for an area near each section during both the before and after periods. These records were used to estimate the annual number of hours of exposure of each section to wet-pavement conditions. No attempt was made to use the records to determine the actual weather conditions on a section at any specific date and time. The exposure estimate for each study section was made for the same period as the accident data for that section.

The most detailed weather information available nationwide for preparing an estimate of exposure is the U.S. Environmental Data Service Local Climatological Data (LCD) reports published monthly for major weather reporting stations around the country. These data include records of hourly precipitation amounts in addition to weather condition by 3-hr periods. Weather records from 70 LCD stations were used to estimate the exposure times for all geographic areas where the test and control sections were located. Each macrosection was assigned to one of the 70 LCD stations. This assignment was based on geographical proximity and similarity of climate.

A technique previously developed by MRI as part of an NCHRP Project[7/] was adapted to estimate the number of hours of exposure to wet-pavement conditions for each station during both the before and after periods. This technique classified an hour as wet time if:

1. A measurable amount (0.01 in. or greater) of nonfrozen precipitation occurred during the hour; or

2. A trace amount (less than 0.01 in.) of nonfrozen precipitation occurred during the hour, except that periods of precipitation composed entirely of trace amounts are not counted; or

3. Fog occurred during the hour; or

4. The hour immediately followed a period of precipitation (frozen or nonfrozen) in which a measurable amount of precipitation occurred in at least 1 hr.

In applying Rule 2, trace amounts were counted which were part of a longer period (two or more consecutive hours) of precipitation during which a measurable amount of precipitation occurred in at least 1 hr.

Rules 1 through 3 above accounted for wet time due to rain or fog. A listing of the hours during which rain or fog occurred was available directly from the Local Climatological Data reports. Rule 4 was included to account for the period of time after precipitation had stopped, when the pavement was still wet. No information was found in the literature concerning typical pavement drying times. The estimate of 1 hr for pavement drying time after a period of precipitation was based on field observations made in eastern Iowa during the 1971-1972 winter. The entire technique was validated for eastern Iowa using hourly weather records for Cedar Rapids and data from a moisture sensor implanted in a bridge deck on an Interstate highway.

The above rules of thumb for estimating exposure to wet pavement conditions were thoroughly reviewed to assure that the technique was applicable to a wide range of climatic conditions. Because the hours of rain and fog are well documented in weather records, we concentrated our efforts on the estimation of pavement drying time. Differences in pavement drying time from section to section could occur because of differences in evaporation rate or differences in traffic volumes. The evaporation rate at a site is influenced by many factors including temperature, relative humidity, wind velocity and cloud cover. Annual evaporation rates, based on measurements with a Class A evaporation pan, are available from published weather data. The passage of traffic increases the rate at which a wet pavement becomes dry by forcing water from beneath the tires and speeding the evaporation process. Observations of wet pavement indicate that the wheel paths are the first areas to dry completely.

A comparison was made between observed highway drying times in Ohio and Louisiana and expected drying times using the estimated evaporation rate recorded for the same month at the nearest Class A pan location. For the purpose of this comparison the depth of water on the pavement was assumed to be 0.02 in., the depth used for the standard skid test. This comparison, illustrated in Table 4 indicated that highway pavements dry far more rapidly than would be expected solely from pan evaporation rates. It was concluded from this analysis that the effect of the passage of traffic would tend to minimize any regional differences in pavement drying times due to the variation of evaporation rates.

TABLE 4

PAVEMENT DRYING OBSERVATIONS

Location	Highway Type	ADT	Observed Drying Time for Wheel Paths	Estimated Drying Time at Pan Evaporation Rate
Ohio	Four-lane Interstate	20,000	20 min	156 min
Louisiana	Two-lane	2,000	30 min	220 min
Louisiana	Two-lane	4,000	50 min	220 min

The observed drying times listed in Table 4 are all less than the 1 hr estimate used previously. Based on this data and engineering judgment developed through observation of wet pavement during the field inventory, a modification of the estimation technique to include only 1/2 hr for pavement drying time was proposed. This modification will produce a more conservative (smaller) estimate of exposure time. The sensitivity of wet pavement exposure times to the proposed change was evaluated by applying the original and modified technique to actual weather records at five stations representative of a wide range of climates. The results of this comparison are shown in Table 5. At only one station does the reduction in the drying time estimate reduce the total exposure time by more than 3.5% in comparison with results from the original method. Such differences are small compared to the errors inherent in any estimate of exposure from published weather data. In the case of the one exception, West Palm Beach, Florida, the 9.5% reduction is due to the pattern of short, frequent rainstorms.

TABLE 5

SENSITIVITY OF WET-PAVEMENT EXPOSURE TIME TO MODIFICATION OF PAVEMENT DRYING ESTIMATE

Station	Annual Precipitation (in.)	Annual Evaporation (in.)	Annual Wet Time (hr) Original 1 Hour Drying Time	Annual Wet Time (hr) Modified 1/2 Hour Drying Time	Percent Reduction
Detroit, Michigan	30.8	41	1,848	1,792	3.0
Columbia, South Carolina	44.8	56	1,694	1,634	3.5
Worcester, Massachusetts	45.4	35	1,682	1,649	2.0
West Palm Beach, Florida	61.7	63	846	768	9.2
Astoria, Oregon	71.4	25	3,168	3,059	3.4

The small reductions found in this comparison reconfirm our judgment that it would not be productive to develop a relationship between ADT and pavement drying times, based on limited data that vary over a range of only 30 min. Therefore, the estimation technique presented above was modified as follows:

1. An hour is classified as wet time if a measurable amount (0.01 in. or greater) of nonfrozen precipitation occurred during the hour; or

2. If a trace amount (less than 0.01 in.) of nonfrozen precipitation occurred during the hour, except that periods of precipitation composed entirely of trace amounts are not counted; or

3. If fog occurred during the hour;

4. Also, a half-hour is classified as wet time if it immediately follows a period of precipitation (frozen or nonfrozen) in which a measureable amount of precipitation did occur in at least 1 hr.

In the overall analysis of the accident rate-skid number relationships, accident rates were also computed for dry-pavement conditions for comparison with the wet-pavement conditions. The exposure times of ice and snow conditions were computed by applying Rules 1 and 2 of the estimation technique to frozen precipitation. Dry-pavement exposure times were determined as the difference between an entire year and the sum of the wet-pavement and ice and snow exposure times.

The annual number of hours of intense rainfall was also computed from the LCD data for each macrosection and study period. An hour of intense rainfall was defined as an hour which satisfies Rule 1 of the exposure estimation technique and is one in which 0.5 in. or greater of precipitation was recorded.

IV. DATA PROCESSING

A. Overview

The project data base consists of over 100,000 80-character records. This raw data had to be processed before any analysis could be conducted. The processing was accomplished in four distinct stages: preparation, keypunching, editing, and final processing. Each of these stages is discussed below.

1. Preparation: All project data, including the field inventory data and the data received from the cooperating states, had to be prepared prior to keypunching. In the case of the field inventory data, this stage involved a manual review of each data sheet to assure that the data were as complete and accurate as possible. Data from the cooperating states that were in the form of computer printouts were marked so that special templates could be used to keypunch directly from the printouts. Data in forms other than computer printout were manually encoded for keypunching.

2. Keypunching: Because automated data processing techniques were used with the project data, all data had to be keypunched. Eleven different kinds of cards (records) were used. These kinds of cards fall into two general categories. The first, which includes cards that reference specific highway sections, consists of the following:

- Microsection Boundary Cards--these contain the final boundaries of each section, the 85th percentile speed of traffic on each section, and other general section information.
- Macrosection Description Cards--these contain overall length of section, information tying the section to a particular set of weather data, and other general section information.
- General Inventory Cards--these contain all information gathered during the field inventory except altimeter, curve, and photographic data.
- Curve Cards--these contain information describing each horizontal curve of each section inventoried.
- Altimeter Cards--these contain altimeter readings every 0.2 miles over the road sections inventoried.
- Photograph Cards--these contain gradient ratings for the road sections inventoried. These ratings were determined from pavement macrotexture photographs.
- ADT Cards--these contain average daily traffic.
- Skid Number Cards--these contain skid numbers measured by the cooperating states. Four different formats were required for skid data provided by the cooperating states in four different forms.

- Accident Cards--these contain detailed information on each accident on each study section. A different format was used for the data provided by each cooperating state. Several states required more than one format.

The second general category of cards are those which do not reference specific highway sections. It includes:

- Precipitation Cards--these contain hourly precipitation for specific weather stations.

- Weather Cards--these contain three-hourly indications of weather conditions to be used in determining whether precipitation recorded on the Precipitation Card is rain, snow, hail, etc.

Over 100,000 cards were keypunched and verified for the project. The punched cards were then placed on magnetic tape for ease of processing.

3. Editing: In any data collection effort of this magnitude, errors and inconsistencies in the data base are inevitable, due to both errors in the original data and keypunching errors. Therefore, the data base was subjected to careful editing and updating using specially developed computer programs described below. Errors and inconsistencies were identified by the computer program, the source of each error was located manually, and appropriate updating of the data files was accomplished.

4. Final processing: The final processing of the data was accomplished using the updated files and the computer programs described below.

B. Computer Programs

Seven major computer programs were needed for the project. These were (1) Error Identification Program, (2) Microsection Selection Program, (3) Exposure Estimation Program, (4) Microsection File Program, (5) Bias Analysis Program, (6) Matched-Pair Analysis Program, and (7) other Statistical Analysis Programs. The purpose of each of these programs is explained below.

1. Error Identification Program: The error identification program was used to identify errors and inconsistencies in the data files. Certain errors, either in the contents or the ordering of the records, could prevent the proper operation of data analysis programs. Any such errors obviously had to be identified and corrected. Other kinds of errors might not prevent subsequent programs from running, but might result in the loss

of some of the information gathered. It is obviously desirable to identify and correct these kinds of errors as well.

An Error Identification Program was written to accomplish this task. This program performed three kinds of checks for the data for each test and control section. These were (1) checks to establish that all necessary data were present, (2) checks of quantitative data to determine whether each value was in an acceptable range, and (3) checks of coded data to assure that only "legal" codes were used. The program generated a printout identifying the nature of each error that was located and listing the 80-column record that contained the error.

A correct value was determined manually for each error identified. An update program, written especially for the project, was then used to insert the corrected values into the data file. Two or three iterations of identifying errors and updating the files were needed for the processing of both the before and after data.

2. Microsection Selection Program: Many of the inventoried test and control sections contained foreign elements which made them nonhomogeneous. Such portions were included in the inventoring of the sections because it was most efficient in the field to inventory continuous lengths of highway. This made it necessary to define final section boundaries, such that nonhomogeneous portions of the sections were eliminated.

The first step in the microsection selection process was to eliminate foreign elements in the test macrosections. Any portion of a test macrosection that was not, in fact, resurfaced was excluded from the test microsection. Short segments of one highway type, within a macrosection which was predominately another highway type, were eliminated, because study sections should contain only one highway type. Small towns within an otherwise rural section were also eliminated. Such towns were identified in the data by a depressed speed limit (usually 25 to 35 mph) within a section where the predominant speed limit was 50 to 55 mph. Although the ADT of each section was screened in the original selection process, a final check was made at this stage to assure that the range of ADT on any section was as small as possible, so that the weighted average ADT was representative of the entire section. After these checks, the remaining portion of each test macrosection was used as a test microsection.

The second step in the selection process was to screen the control macrosections in a similar manner. This screening excluded nonhomogeneous portions of control sections, which should not be included in the control microsections.

The third step was to assign a matching control microsection to each test microsection. Each control microsection has physical and traffic characteristics similar to its matching test microsection. Specifically, the control microsection was of the same highway type and area type (urban or rural) as the test microsection. The ADT of the two sections were similar. The length of the control microsection was as great or greater than the length of the test microsection, whenever possible. After each test microsection had been assigned a matching control microsection, all remaining sections were used as unmatched control microsections.

The section selection and matching necessarily required a great deal of judgment. It could not, therefore, be accomplished entirely by automated techniques. However, computer processing of the data was used to assist the process. A Microsection Selection Program was used to generate a printout displaying the distribution of each of the following parameters on each section:

- Average daily traffic,
- Highway type,
- Intersections (classified by type),
- Interchange ramps,
- Special lanes,
- Pavement type, and
- Legal speed limit,

The final section boundaries identified from this printout were punched on Microsection Boundary Cards and used in subsequent programs to control processing of the data.

3. Exposure Estimation Program: Section III describes the technique to estimate exposure to different pavement conditions. This technique was applied to at least 12 months of weather data for 70 weather stations located near the study sections. An Exposure Estimation Program was written to estimate the exposure to various pavement conditions for each month at each weather station. The four types of exposure calculated for each month of data are: (1) exposure to wet-pavement conditions, (2) exposure to dry-pavement conditions, (3) exposure to ice and snow conditions, and (4) exposure to high-intensity rainfall.

The exposure estimates were developed from hourly records collected at a weather station near each study section. Hourly weather records contained on the Local Climatological Data reports of the U.S. Environmental Data Service were punched on two kinds of cards: (1) Precipitation Cards and (2) Weather Cards. Precipitation Cards identified the amount of precipitation that occurred in each hour of each day considered. Weather Cards were organized by corresponding 3-hr periods, and identified the type of precipitation, if any, that occurred. The Exposure Estimation Program processed these data and estimated the total number of hours of each of the four types of exposure for each month at each weather station. These results were placed in a file for use by subsequent programs. The Microsection File Program, described below, selected from the exposure estimate file the months corresponding to the period for which accident data were collected for each study section. The exposure estimates were used in the calculation of wet- and dry-pavement accident rates.

4. <u>Microsection File Program</u>: This was the most complex single program written for the project. It processed the raw data collected in the field inventory and from the cooperating states, and calculated 72 parameters that describe each section. These parameters fall into 10 categories:

(1) General
(2) Accidents
(3) Exposure
(4) Skid Numbers
(5) Pavement and Cross Section
(6) Access Points
(7) Traffic Control
(8) Obstacles
(9) Curves
(10) Grades

Table 6 identifies the specific parameters calculated for each general category of data. Definitions of each parameter are presented in Appendix E.

Three kinds of input data were used for the Microsection File Program: (1) the Macrosection File (containing field inventory data and data gathered from the cooperating states), (2) the Exposure Estimate File, and (3) the Microsection Boundary File containing the final section boundaries. The output of the program was a Microsection File containing the 72 parameters listed in Table 6 for each study section. This file provided all of the input data required for subsequent statistical analysis programs.

5. <u>Bias Analysis Program</u>: The objective of the bias analysis is to compare the wet-pavement accident rates of the matched pairs of test and control sections to determine whether the sections are well matched. The information needed to make this comparison includes: (1) the means and variances of wet-pavement accident rate for both test and matched control sections, (2) the correlation coefficient of wet-pavement accident rate between test and control sections, and (3) the results of statistical tests for symmetry and outlying observations in the set of matched test and control sections. The actual statistical analysis was performed manually, but a computer program, known as the Bias Analysis Program, was used to present the data in a convenient format to expedite these calculations. This program used input data directly from the Microsection File.

TABLE 6

MICROSECTION FILE PARAMETERS

Parameter
General
State
Type of Microsection
Microsection Number
Microsection Length
Highway Type
Urban or Rural
One-Way or Two-Way
Weighted Average ADT
Microsection Segment Code
Accidents
First month of period
Last month of period
Number of wet accidents by month
Total number of wet accidents in period
Number of ice and snow accidents by month
Total number of ice and snow accidents in period
Number of dry and other accidents by month
Total number of dry and other accidents in period
Wet-pavement accident rate
Exposure
Number of hours of wet-pavement exposure by month
Total hours of wet exposure in period
Number of hours of ice and snow exposure by month
Total hours of ice and snow exposure in period
Number of hours of dry-pavement exposure by month
Total hours of dry exposure in period
Number of hours of exposure to high-intensity rainfall by month
Total hours of exposure to high-intensity rainfall in period
Mean annual number of days with thunderstorms
Skid Numbers
Mean gradient rating
Mean skid number at 40 mph

Parameter

Skid Numbers (concluded)

Standard deviation of skid number at 40 mph
Month and year of skid test
85th percentile speed
Mean skid number at 85th percentile speed

Pavement and Cross Section

Percent of length with paved shoulder
Percent of length with shoulder over 6 ft wide
Percent of length with asphalt pavement
Percent of length with lane width under 10 ft
Percent of length with lane width 12 ft or over
Percent of length with paved median
Percent of length with curbed median
Percent of length with median width under 10 ft
Percent of length with median width over 30 ft

Access Points

Number of residential drives
Number of commercial drives
Number of industrial drives
Number of minor intersections
Number of intermediate intersections
Number of major intersections
Number of interchange ramps
Number of median openings
Density of access points

Traffic Control

Legal speed limit
% no-passing zones - forward direction
% no-passing zones - reverse direction

Obstacles

Number of roadside obstacles - forward direction
Number of roadside obstacles - reverse direction
Percent of length with guardrail or bridge rail - forward
Percent of length with guardrail or bridge rail - reverse
Percent of length with barrier curb
Percent of length with mountable curb

TABLE 6 (Concluded)

Parameter
Curves
Number of curves on microsection
Percent of length on curves
Mean demand skid number at 85th percentile speed including curves only
Standard deviation of demand skid number at 85th percentile speed including curves only
Maximum demand skid number
Mean traction margin including curves only
Minimum traction margin
Mean traction margin including both curves and tangents
Standard deviation of traction margins including both curves and tangents
Grade
Percent of length on significant grade
Number of sag vertical curves

The following information was displayed on the printed output for each matched pair of test and control sections:

- Microsection number,
- State where test section is located,
- Area type of test section,
- Highway type of test section,
- ADT of test section,
- State where control section is located,
- Area type of control section,
- Highway type of control section,
- ADT of control section,
- Wet-pavement accident rate for test section,
- Wet-pavement accident rate for control section, and
- Difference between wet-pavement accident rate for test section and wet-pavement accident rate for control section.

These sections were arranged on the printout in descending order of wet-pavement accident-rate difference. This arrangement allowed for efficient application of the Dixon-Massey Outlier test.

The following information was calculated by the program for the entire set of matched test and control sections:

- Mean and variance of wet-pavement accident rate for test sections,
- Mean and variance of wet-pavement accident rate for control sections, and
- Mean and variance of the differences between test and control section accident rates.

The program also had the capability to perform the same calculations for mean skid number at the 85th percentile speed, SN(85), and for mean skid number at 40 mph, SN40, as for wet-pavement accident rate. Two separate bias analyses were conducted--one for the before data and one for the after data. The details of the analysis are discussed in Section V.

6. Matched-Pair Analysis Program: A matched-pair analysis was conducted to examine the differences between before and after accident rates for the test and control sections. The objective of this analysis was to determine if there was any time trend in the test or control section accident rates. A Matched-Pair Analysis Program, similar to the Bias Analysis Program, was written to assist this analysis. This analysis was the first in the project to make use of both before and after data. Again, the actual statistical analysis was performed manually, while the Matched-Pair Analysis Program was used to display the data in a convenient printout format to expedite the analysis. The following information was displayed on the printed output for each matched pair of test and control sections:

- Microsection number,
- State where test section is located,
- Area type of test section,
- Highway type of test section,
- State where control section is located,
- Area type of control section,
- Highway type of control section,
- Accident rate for test section in after period,
- Accident rate for test section in before period,
- Accident rate for control section in after period,
- Accident rate for control section in before period, and
- Difference in test section accident rates adjusted for difference in control section accident rates.

The sections were arranged on the printout in order of descending accident rate difference for efficient application of the Dixon-Massey Outlier Test.

The following information was calculated by the program for the entire set of matched test and control sections:

- Mean and variance of test section accident rates for after period,
- Mean and variance of test section accident rates for before period,

- Mean and variance of accident-rate differences between before and after periods for test sections,

- Mean and variance of control section accident rates for after period,

- Mean and variance of control section accident rates for before period,

- Mean and variance of accident-rate differences between before and after periods for control sections, and

- Mean and variance of the differences of test section accident rates between the before and after periods adjusted for the differences of control section accident rates between the before and after periods.

The Matched-Pair Analysis Program has the capability to analyze both wet- and dry-pavement accident rates. A detailed discussion of the analysis of both accident rates is found in Section V.

7. Other Statistical Analyses: The remaining statistical analyses did not require specially written analysis programs, but were accomplished using the Statistical Package for the Social Sciences (SPSS), Release 6.02, available through the Transportation Computing Center of the U.S. Department of Transportation located in Washington, D.C. The two major kinds of statistical analyses performed were linear regressions and analyses of covariance. These were accomplished using SPSS Subprograms REGRESSION and ANOVA. Many other SPSS subprograms were used in the analyses including CONDESCRIPTIVE, SCATTERGRAM, CROSSTABS, PEARSON CORR, PARTIAL CORR, and ONE-WAY.[8/] A complete description of the statistical analyses is found in Section V.

V. DATA ANALYSIS

This section describes the statistical analyses of the data and the results obtained. The objective of the analyses was to develop the relationships between wet-pavement accident rate and skid number for the range of highway conditions spanned by the study sections.

In the first step, a bias analysis was performed to determine whether the test and control sections were adequately matched with respect to wet-pavement accident rate. This analysis is described in Section V-A. No bias was found in either the before or the after data. Section V-B identifies the skid number at 40 mph (SN40) as the most appropriate measure of skid resistance for use as an independent variable. Then, the form of the relationship between wet-pavement accident rate (AR) and skid number is investigated in Section V-C. It was established that a linear AR-SN40 relationship fits the data as well or better than any other simple, monotonic function.

The before-after matched-pair analysis is described in Section V-D. No effect of resurfacing on the wet-pavement accident rate of the test sections was found. This negative finding could mean that there is no relationship between wet-pavement accident rate and skid number or it could merely reflect the fact that resurfacing did not have a significant effect on the mean skid number of the test sections.

A more sophisticated approach, an analysis of covariance, was used to resolve this inconclusive result. The results of this approach are presented and explained in Section V-E. A small, but statistically significant relationship between wet-pavement accident rate and skid number was found. Highway type, area type and ADT were found to have significant effects on this relationship. Quantitative AR-SN40 relationships are presented for 12 cells defined by three levels of highway type, two levels of area type, and two levels of ADT.

A further analysis, presented in Sections V-F and V-G, established that the slope of the AR-SN40 relationship is sensitive to the dry-pavement accident rate. This finding was extremely useful in the development of the Phase II benefit-cost model.

The influence of pavement texture, exposure to high-intensity rainfall, and several geometric variables on the AR-SN40 relationship are examined in Sections V-H, V-I and V-J. None of these variables, as defined, was found to have a significant effect in the analyses of the available data. A relationship between pavement texture and wet-pavement accident rate is developed indirectly in Section V-I. Section V-K summarizes the accident rate-skid number relationships used in the computerized benefit-cost model described in Volume II. Section V-L discusses the predictive accuracy of the AR-SN40 relationships and Section V-M compares the results of these analyses with work reported by other researchers.

A. Bias Analysis

The objective of the bias analysis was to compare the wet-pavement accident rates of the test and control sections to determine whether the sections were well-matched. Let:

T_i = Wet-pavement accident rate for the i^{th} test section

C_i = Wet-pavement accident rate for the i^{th} control section

The bias analysis conducted consists of applying the following five tests:

a. Calculate an F-Ratio to determine whether the T and C distributions differ in variance;

b. Use the Dixon-Massey outlier test to identify and discard any outlying observations;

c. Determine whether the Z distribution, where $Z_i = T_i - C_i$, is symmetrical;

d. Determine whether the correlation between T and C is significant; and

e. Determine whether the average wet-pavement accident rate for test sections is significantly different from that for control sections.

A bias analysis of skid number was also conducted. Although the planned analyses did not require that test and control sections be matched with respect to skid number, the use of skid number as a covariate in an analysis of covariance does require an overlap between the two skid-number populations.

Table 7 presents the means and standard deviations of wet-pavement accident rate (AR), skid number at 40 mph (SN40) and estimated skid number at the 85 percentile speed, SN(85). The bias analyses of the matched test and control sections for the before period are described below. This is followed by a discussion of an after period data analysis.

1. Before data: There were 142 matched pairs of test and control sections available for the bias analysis of the before data. The results of this analysis of the wet-pavement accident rates are:

a. T and C do not differ in variance ($F(141,141) = 1.69$).

b. The Dixon-Massey outlier test confirms that there are no outliers in the before data.

TABLE 7

MEANS AND STANDARD DEVIATIONS FOR MATCHED TEST AND CONTROL SECTIONS

	Number of Sections	Wet-Pavement Accident Rate (Accidents/MVM)		SN(85)		SN40	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Before Period							
Test Sections	142	3.26	3.26	40.95	8.37	47.91	7.55
Matched Control Sections	142	2.96	2.51	39.17	8.75	46.57	8.30
After Period							
Test Sections	130	3.06	3.10	41.91	9.21	47.97	8.98
Matched Control Sections	130	2.97	3.40	38.84	9.55	44.83	9.29

c. The Z distribution is symmetrical.

d. The correlation between T and C is significant ($r = 0.642$); i.e., Z has less variance than the combined variance of T and C , by a significant amount.

e. The average wet-pavement accident rate for the test sections does not differ significantly from that of the control sections (t_1 (141) = 1.13, t_2 (141) = 1.15) .*

In summary, the matching of test and control sections is unbiased with respect to wet-pavement accident rate, and the matching process itself produces a significant correlation between the test and control accident rates, as it should.

A bias analysis of SN(85) was also conducted for the before data. The mean SN(85) for the test sections is significantly higher than for the control sections (t_1 (141) = 2.31, $p < 0.05$) . As stated above, this difference in skid number will not adversely affect the analysis. The test and control sections are almost completely overlapped with respect to SN(85). No formal bias analysis was conducted for SN40. However, the test and control sections are also overlapped with respect to SN40.

2. After data: A bias analysis was also performed with 130 matched test and control section pairs in the after period. Normally, a bias analysis of the after period conditions would not be performed since matching of the test and control sections in that period is not a requirement in the matched-pair analysis. A bias analysis of the after period data was performed to determine if any differences between wet-pavement accident rates of the test and control sections could be detected.

The results of the after period analysis were similar to the before period findings:

a. T and C do not differ in variance ($F(129,129) = 1.20$) ;

b. There are no outliers;

c. The Z distribution is symmetrical;

---

* The test for a difference between the average wet-pavement accident rates of the matched test and control sections could be made with Ho: $\mu(Z) = 0$ (test statistic t_1) or Ho: $\mu(T) = \mu(C)$ (test statistic t_2) . The choice of test statistic depends on the correlation between T and C . In this case, t_1 and t_2 are almost equally powerful and both are non-significant.

d. The correlation between T and C is significant ($r = 0.602$); and

e. The difference between the average wet-pavement accident rate of the test and control sections is not significant ($t_1(129) = 0.30$) .

The distributions of both SN(85) and SN40 were considered in the analysis of the after data. A significant difference between the matched test and control sections exists for both mean SN(85) ($t_1(129) = 3.78$, $p < 0.01$) and for mean SN40 ($t_1(129) = 4.00$, $p < 0.01$) . The distributions of after skid numbers for both the test and control sections are almost completely overlapped.

3. Summary: The pairs of test and control sections are well-matched with respect to wet-pavement accident rates in the before period. The bias analysis of the after data showed that the difference between the wet-pavement accident rate of the test and control sections is not significant even though the test section surfaces, in the after period, were altered through resurfacing. Small, but significant differences between the test and control sections exist in both SN(85) and SN40. However, these differences present no impediment to a successful analysis of covariance, because the skid number populations for test and control sections are almost completely overlapped.

B. Selection of Skid Resistance Measure

A linear regression analysis was conducted to determine the most useful form of the independent variable in the accident rate-skid number relationship. This independent variable is to be used as the covariate in the analysis of covariance. Since the overall objective of the analysis was to determine the relationship between wet-pavement accident rate and skid resistance, the best available measure of skid resistance should be used as the covariate. The influence of all variables other than skid resistance was examined by using these variables as factors in the analysis of covariance.

Three candidate measures of skid resistance were considered for use as independent variables: (1) mean skid number at the 85th percentile speed, SN(85); (2) mean skid number at 40 mph, SN40; and (3) a linear combination of 85th percentile speed, U, and skid number at 40 mph, SN40. It was postulated that SN(85) would correlate better with accidents than SN40, because the 85th percentile speed is more typical of the speed at which accidents occur than is 40 mph. However, because the skid number-speed gradient used to determine SN(85) had to be estimated, we also decided to explore the possibility that a linear combination of SN40 and U might be a better measure of skid resistance than SN(85). As explained below, the actual results of the linear regression analysis of the candidate skid resistance measures were quite different from these postulates. From this analysis, it was concluded that SN40 is the most appropriate measure of skid resistance for use as the independent variable in the remainder of the analyses. The details of the regression analysis are given below.

1. <u>Linear regression analysis of before data</u>: The three forms of the accident rate-skid number relationship tried in the linear regression analysis of the before data were:

$$AR = b\ SN(85) + a,$$

$$AR = b\ SN40 + a, \text{ and}$$

$$AR = b_1\ U + b_2\ SN40 + a,$$

where AR = Wet-pavement accident rate (acc/million vehicle miles),

SN40 = Mean skid number at 40 mph,

SN(85) = Mean skid number at 85th percentile speed, and

U = 85th percentile speed (mph).

Six regressions were calculated for each of the three forms of the relationship. The cases considered were: (1) test sections only, (2) matched control sections only, (3) unmatched control sections only, (4) test and matched control sections, (5) matched and unmatched control sections, and (6) all sections. The total number of sections with data available for the before period is 428; 142 test sections, 142 matched control sections and 144 unmatched control microsections.

Table 8 gives the results of the 18 linear regressions run with the before data. The value of r, the correlation coefficient, ranges from 0.02 to 0.36. Such low r values can be expected because this regression analysis does not explicitly include the influence of factors such as area type, highway type, and ADT that are known to strongly influence accident rate.

It was our original expectation that the most useful form for the accident rate-skid number relationship would be developed using SN(85) since this skid number is based on SN40 with a correction to a more appropriate speed. However, this form of the relationship had the worst (almost non-existent) fit of the three forms tried. There is a reasonable explanation for the poor correlation, which is reinforced by the results of the other two forms.

TABLE 8

LINEAR REGRESSIONS WITH BEFORE DATA

	AR = b SN(85) + a	AR = b SN40 + a	AR = b_1 U + b_2 SN40 + a
Test Sections Only	b = +0.00797 a = +2.93730 r = 0.02045	b = -0.05385 a = +5.84358 r = 0.12463	b_1 = -0.09815 b_2 = -0.04854 a = +11.26589 r = 0.30579
Matched Control Sections Only	b = -0.06227 a = +5.40003 r = 0.21727	b = -0.09486 a = +7.37911 r = 0.31397	b_1 = -0.05197 b_2 = -0.08672 a = +10.05603 r = 0.36145
Unmatched Control Sections Only	b = -0.00835 a = +3.20345 r = 0.02544	b = -0.05357 a = +5.32183 r = 0.15371	b_1 = -0.11580 b_2 = -0.04104 a = +11.57047 r = 0.36026
Test and Matched Control Sections	b = -0.02656 a = +4.17612 r = 0.07846	b = -0.07414 a = 6.61470 r = 0.20259	b_1 = -0.07847 b_2 = -0.06595 a = +10.80450 r = 0.31577
Matched and Unmatched Control Sections	b = -0.03249 a = +4.17668 r = 0.10500	b = -0.07192 a = +6.23285 r = 0.21966	b_1 = -0.08517 b_2 = -0.06089 a = +10.73666 r = 0.34188
All Sections	b = -0.01807 a = +3.74747 r = 0.05428	b = -0.06413 a = +6.02761 r = 0.17932	b_1 = -0.09120 b_2 = -0.05487 a = +10.93149 r = 0.32632

The regressions of wet-pavement accident rate with SN40 have much better (higher) correlation coefficients than those using SN(85). Further, the wet-pavement accident rates exhibit a sensitivity to SN40 that indicates skid number has a practical effect on accident rate. (The coefficients of SN40 indicate that a reasonable increase in SN40 can cause an appreciable decrease in accident rate.)

The third form tried employed both SN40 and 85th percentile speed as independent variables. The idea here was that the effect of speed on skid number, and thus accident rate, could be incorporated without a formal correction of skid number to the facility speed. This form yielded the highest correlation coefficients. However, the analyses showed that wet-pavement accident rates were inversely related to the 85th percentile speeds. This finding has opposite sense to that expected and, indeed, it destroys the usefulness of a linear combination of SN40 and U as a measure of skid resistance.

Clearly, the negative correlation between accident rate and 85th percentile speed must arise from the relationship of speed to other highway parameters such as highway type and area type. Table 9 illustrates the trend of this relationship for the data collected. Note that the lowest accident rates are generally found on multilane facilities with controlled access, the same facilities that have the highest speeds. Thus, in a regression where all highway types are lumped without distinction, it is not surprising to find that accident rates are negatively correlated with speeds.

The proxy effect of highway type and area type is probably also responsible for the poor correlations between wet-pavement accident rates and skid numbers corrected to the 85th percentile speeds. It should be recognized that SN(85) as used, is developed from a linear combination of SN40 and U, where the coefficient of U is determined by the skid number-speed gradient, rather than through a regression analysis. For a two-lane highway the 85th percentile speed is relatively low and its skid number is decreased only a moderate amount by the speed gradient correction. This highway type, however, has a relatively high accident rate. In contrast, a controlled access highway has a low accident rate and a high 85th percentile speed; skid number is reduced considerably in the speed gradient correction. The speed gradient corrections to adjust skid number to the 85th percentile speeds are systematic and tend to yield high skid numbers for highway types with large accident rates and low skid numbers for highways that frequently have low accident rates. The systematic adjustment apparently eliminated the correlation between wet-pavement accident rates and adjusted skid number when all highway types were included without distinction.

The above analysis indicates a stronger direct relationship between accident rate and SN40 than between accident rate and SN(85). These overall regression results also provide some indication that wet-pavement

TABLE 9

MEAN WET-PAVEMENT ACCIDENT RATES AND 85TH PERCENTILE SPEEDS FOR BEFORE PERIOD

Area Type and Highway Type	Mean Wet-Pavement Accident Rate (Accidents/MVM)	Mean 85th Percentile Speed (mph)
Rural, Multilane, Controlled Access	0.84	67.9
Rural, Multilane, Uncontrolled Access	3.09	62.1
Urban, Multilane, Controlled Access	2.13	61.3
Rural, Two-Lane, Uncontrolled Access	3.12	57.6
Urban, Multilane, Uncontrolled Access	8.09	47.9
Urban, Two-Lane, Uncontrolled Access	3.62	43.3

accident rates may be correlated with SN40 with a sensitivity of practical importance. The results also confirmed our initial concept that it is essential to treat variables such as highway type, area type, and ADT as factors.

2. Linear regression analysis of after data: A linear regression analysis of the after data was also conducted. Eighteen regression equations were computed in a manner entirely analogous to the before-data analysis. The total number of sections with data available for the after period is 378; 130 test sections, 130 matched control sections and 118 unmatched control sections.

Table 10 gives the results of the 18 linear regressions run with the after data. These regressions exhibit the same characteristics as the before regressions. The correlation coefficients range from 0.02 to 0.53. The correlation between accident rate and SN40 was again larger in the after period than the correlation between accident rate and SN(85). The same negative correlation between accident rate and 85th percentile speed was observed in the after data. Therefore, the same reasoning presented above implies that SN40 is the most useful form of the independent variable for use in accident rate-skid number relationships.

3. Comparison of SN40 and SN(85) as covariates: It was suggested in the above discussion that the correlation between accident rate and SN(85) would be improved when the influence of factors such as highway type and area type was accounted for. The possibility that the use of these factors would make SN(85) a better covariate than SN40 was examined in a pair of analyses of covariance. The details of the two analyses are presented in Tables 35 and 36 of Appendix F. The two analyses differ only in the covariate used: SN40 in Table 35 and SN (85) in Table 36. Highway type (HTYP) and area type (ATYP) were used as factors and wet-pavement accident rate (AR) was the dependent variable. The contributions of each covariate to explaining the variation in wet-pavement accident rate are compared below:

Covariate	Sum of Squares Explained By Covariate	F-Ratio	Significance of F
SN40	133.339	18.258	0.001
SN(85)	60.023	8.119	0.005

This comparison indicates that SN40 explains more of the variation in accident rate than SN(85). This finding was observed consistently in similar comparisons for other paired runs.

TABLE 10

LINEAR REGRESSIONS WITH AFTER DATA

	AR = b SN(85) + a	AR = b SN40 + a	AR = b_1 U + b_2 SN40 + a
Test Sections Only	b = +0.00623	b = -0.03969	b_1 = -0.17976
	a = +2.80178	a = +4.96666	b_2 = -0.02176
	r = 0.01850	r = 0.11492	a = +13.91188
			r = 0.41564
Matched Control Sections Only	b = -0.08293	b = -0.10538	b_1 = -0.11181
	a = +6.38807	a = +7.89312	b_2 = -0.09598
	r = 0.18720	r = 0.23138	a = 13.66251
			r = 0.28371
Unmatched Control Sections Only	b = -0.02072	b = -0.05689	b_1 = -0.26061
	a = +3.22618	a = +4.97844	b_2 = -0.04295
	r = 0.06887	r = 0.18272	a = +19.00400
			r = 0.53644
Test and Matched Control Sections	b = -0.03985	b = -0.07252	b_1 = -0.14851
	a = +4.72312	a = +6.47962	b_2 = -0.06041
	r = 0.10207	r = 0.18115	a = +14.08024
			r = 0.31981
Matched and Unmatched Control Sections	b = -0.05205	b = -0.08204	b_1 = -0.17959
	a = +4.83021	a = +6.49647	b_2 = -0.06960
	r = 0.13588	r = 0.20761	a = +15.95445
			r = 0.35725
All Sections	b = -0.03030	b = -0.06441	b_1 = -0.18056
	a = +4.10729	a = +5.85977	b_2 = -0.05228
	r = 0.08321	r = 0.17182	a = +15.29630
			r = 0.36967

The results obtained from using SN(85) as a covariate were very disappointing. The determination of this quantity for each microsection required a considerable amount of effort. As defined, SN(85) was calculated from SN40, the 85th percentile of the wet-pavement speed distributions for the section, V_{85} , and the skid number-speed gradient for the section, SNG. Both V_{85} and SNG had to be estimated from the collection and analysis of special data. V_{85} was calculated in a straightforward manner by drawing upon data obtained through the assistance of the cooperating states. The estimation of SNG, on the other hand, was not straightforward. First, it required the development of a reliable system that would obtain photographs of a pavement surface taken from a moving vehicle. Then, it required the formulation of a method to relate the macrotexture photographs to the rate of change of skid number with speed.

It is unfortunate that the gradient data obtained could not be used beneficially in the development of a covariate. The photographic technique assembled, however, is an important accomplishment of the project and is one that can be used by other researchers in need of economically estimating the skid number-speed gradient of pavements.

4. Summary: Both simple linear regressions and paired analyses of covariance indicate that SN40 is the most useful independent variable because it explains a larger portion of the variation in wet-pavement accident rate than SN(85) and it is not confounded by the effects of other factors. Therefore, SN40 is used as the independent variable in the remainder of the analyses.

C. Investigation of Nonlinearity of the Accident Rate-Skid Number Relationship

After SN40 was established as the best measure of skid resistance, the next step was to establish the form of the relationship between accident rate and SN40 for use in the analysis of covariance. We used a series of simple regression analyses to determine if a linear relationship could be used or whether the relationship was significantly nonlinear.

First, we examined possible log, log-log and polynomial forms of the accident rate-skid number relationship. To avoid confounding these analyses with the effects of highway type and area type, only the rural two-lane highway sections for the before period were used. There are 275 such sections, the largest sample size of any highway type-area type combination. The cell with the largest sample size offers the most power in the statistical tests. None of these three forms improved the correlation coefficient of the accident rate-skid number relationship substantially.

Next, we examined the nature of the accident rate-skid number relationship by two approaches. The first approach investigated the effect on the slope of the relationship of extending the range of skid number to higher values. This analysis used three sets of before data: (1) all the rural and urban sections, (2) all rural sections, and (3) all rural, two-lane sections. The second approach subdivided the skid number range into several strata to examine any differences in the sensitivity of accident rate to skid number. This latter analysis used rural, two-lane data.

1. Log and log-log relationships: The objective of this analysis was to identify the functional form of the accident rate-skid number relationship. A plot is given in Figure 4 of accident rate versus skid number for the rural, two-lane sections in the before period. This plot is representative of scatter found for the other highway type-area type combinations.

The simple, linear regression relationship for the rural, two-lane before data is:

$$AR = -0.08449 \text{ SN40} + 7.201399$$

and

$$r = 0.23075.$$

The logarithmic regression relationship for the same data set is:

$$AR = -9.41747 \log \text{SN40} + 18.92225$$

and

$$r = 0.23990.$$

The use of a logarithmic relationship produced only a marginal improvement in the correlation coefficient over the linear relationship. This improvement is not significant.

A log-log relationship was also computed for the same data set used above:

$$\log AR = -0.91307 \log \text{SN40} + 1.90802$$

and

$$r = 0.20108.$$

This relationship has a smaller correlation coefficient than the linear relationship.

Neither the log nor the log-log form of the accident rate-skid number relationship fits the data significantly better than the simple linear form.

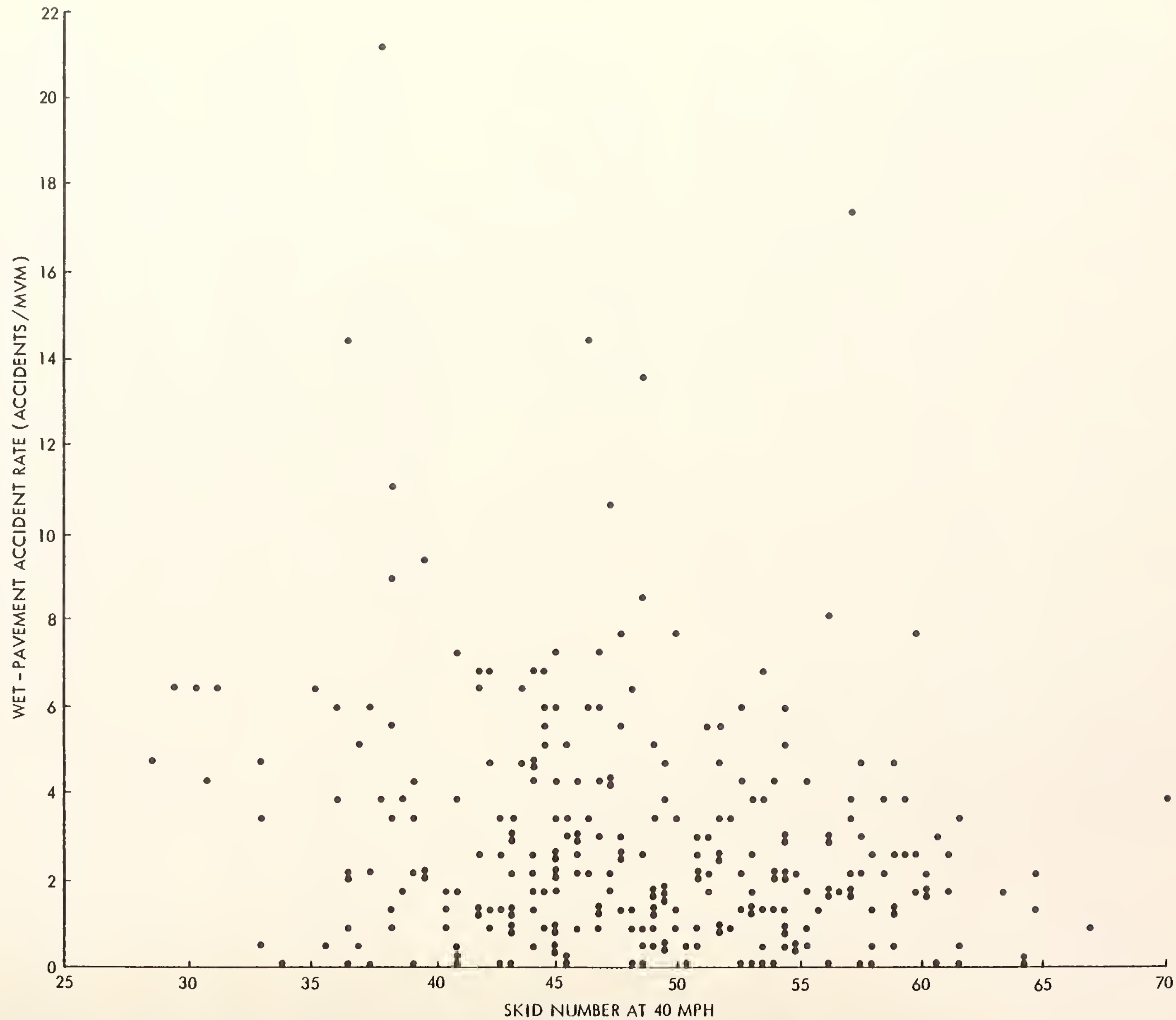

Figure 4 - Scatter Plot of Wet-Pavement Accident Rate vs. Skid Number at 40 mph for Rural, Two-Lane Sections in the Before Period

2. Polynomial relationships: A polynomial relationship between wet-pavement accident rate and skid number was also considered. A one-way analysis of variance was used to examine the contribution of various polynomial terms to explaining the variation in wet-pavement accident rate. The contribution of linear, quadratic, cubic, and quartic terms was examined, using the polynomial trends feature of Subprogram ONEWAY of the Statistical Package for the Social Sciences (SPSS).

The rural, two-lane before data were stratified into eight levels of the independent variable, SN40. Equally-spaced levels of the independent variable must be used for this type of analysis. The boundaries of the eight chosen class intervals are shown in Table 11, together with the analysis of variance results. The quadratic, cubic, and quartic terms make virtually no contribution to explaining the variation of wet-pavement accident rate. On the other hand, the linear term is highly significant. The F-Ratio for the linear term is 9.357 which is significant at the 99% confidence level. This analysis provides strong evidence that the relationship between wet-pavement accident rate and SN40 is linear, at least in the range of skid numbers spanned by the before data for rural, two-lane highways.

The results above indicate that it is appropriate to use a linear relationship in the analyses of covariance. However, because of the importance to the project of understanding the nature of the relationship between accident rate and skid number, we explored this relationship further.

3. Use of dry-pavement accident rate to represent high SN conditions: The range of skid numbers was extended to higher values to investigate this influence upon the slope of the accident rate-skid number relationship. Wet-pavement accident rate data were not well represented in the high skid number range (SN40 $\geq$ 60). Therefore, dry-pavement accident rate data were used to represent high skid number conditions.

A regression analysis was used to compare the wet-pavement accident rate-skid number relationship with the relationship for a combined set of wet- and dry-pavement accident data. Based on NCHRP Report 37,[9/] an estimated skid number of 80 was used for all pavements under dry conditions, and the observed skid number was used for each pavement under wet conditions. The regression relationships for the wet-pavement data were compared with the relationships for the combined data for three groups of highway sections: (1) all 275 rural two-lane highway sections, (2) all 378 rural highway sections, and (3) all 428 rural and urban highway sections.

The findings of the analyses should be interpreted cautiously because, in combining wet- and dry-pavement accident data, the analysis assumes that the only factor that has an influence on accident rate and differs between wet- and dry-pavement conditions is skid number. Other factors, such as changes in visibility and vehicle speeds are present, but it is a reasonable assumption that the difference in skid number is an important factor.

TABLE 11

ONE-WAY ANALYSIS OF VARIANCE OF POLYNOMIAL COMPONENTS OF AR-SN40 RELATIONSHIP

Dependent Variable	Wet-Pavement Accident Rate
Independent Variable	SN40
Number of Levels of Independent Variable	8
Input Data	Rural Two-Lane Before Data

Level	Number of Cases	SN40 Range	Wet-Pavement Accident Rate (accidents/MVM) Mean	Standard Deviation	Standard Error
1	10	34.5 and under	4.9560	3.2712	1.0344
2	30	34.5 - 39.5	4.5527	4.7019	0.8584
3	48	39.5 - 44.5	2.9608	2.1882	0.3158
4	70	44.5 - 49.5	3.3256	2.9392	0.3513
5	58	49.5 - 54.5	2.6193	1.8835	0.2473
6	38	54.5 - 59.5	2.7334	2.9368	0.4764
7	16	59.5 - 64.5	2.0300	1.9698	0.4925
8	5	over 64.5	1.7640	1.5481	0.6923
Total	275		3.1205	2.8945	0.1745

Source of Variation	Analysis of Variance DF	Sum of Squares	Mean Square	F	Significance Level of F
Between Groups	7	147.8865	21.1266	2.626	0.012
Linear Term	1	75.2642	75.2642	9.357	0.003
Dev. from Linear	6	72.6223	12.1037	1.505	0.176
Quadratic Term	1	2.9017	2.9017	0.361	0.556
Dev. from Quadratic	5	69.7206	13.9441	1.734	0.126
Cubic Term	1	1.8405	1.8405	0.229	0.638
Dev. from Cubic	4	67.8801	16.9700	2.110	0.079
Quartic Term	1	0.1319	0.1319	0.016	0.867
Dev. from Quartic	3	67.7482	22.5827	2.808	0.039
Within Groups	267	2147.6633			
Total	274	2295.5498			

The results of this analysis are presented in Table 12. The slope for the combined wet and dry data was less in magnitude than that for the wet data only for all three highway section groups, significantly less for two of the groups.

A subsidiary analysis resulted in reaching the same conclusion. Rather than assuming a value of 80, a value of the skid number (dry pavement) was calculated that would make the regression lines for the wet data and the combined data coincide. This calculated value is 60. Thus, a difference between the wet and the combined data must exist, because 60 is an unreasonably low estimate of dry-pavement skid resistance.

These findings suggest that the accident rate-skid number relationship may be curvilinear, with a flatter slope at high skid number than at low skid number (i.e., concave upwards).

4. Slope of AR-SN40 relationship in various SN40 ranges: Further evidence of nonlinearity of the accident rate-skid number relationship was uncovered by examining the slope of the relationship in five ranges of skid number defined so that there are relatively equal numbers of sections in each range. The slope of the regression lines for both the before and after periods is given in Table 13. The slopes for the before period appear to be decreasing in magnitude as skid number increases, but the trend is inconsistent. The slopes for the after period vary widely and include two positive values.

A two-way analysis of variance of the slopes was conducted using SN40 level (1-5) and time (before vs. after) as factors. (This statistical technique is valid in this situation because the distribution of slopes approaches normality.) SN40 level was found to be a significant factor, i.e., the differences between slopes are statistically significant. However, both time and the time-skid number interaction were not significant.

The only possible interpretation of these data is that the accident rate-skid number relationship is not linear. Some functional form other than a linear relationship would probably explain more of the variation in accident rate. However, this form would have to be more complex.

5. Summary: It was established through a log and log-log regression analysis and an analysis of variance using polynomial trends, that a linear accident rate-skid number relationship fits the overall data set as well or better than any other simple function. However, further analyses suggest that the relationship may be slightly nonlinear, with a flatter slope at high skid number than at low skid number, but no simple functional form for this relationship could be identified. On the basis of these findings, it was decided to use a linear form of the accident rate-skid number relationship in the analyses of covariance.

TABLE 12

COMPARISON OF ACCIDENT RATE-SKID NUMBER RELATIONSHIPS FOR WET AND COMBINED WET AND DRY ACCIDENT DATA (BEFORE PERIOD)

Form of Relationship: AR = b SN40 + a

All Rural and Urban Sections (N = 428)

Wet:	b = -0.064	a = 6.01714
	σ(b) = 0.01705	r = 0.17895
	N = 428	
Wet and Dry:	b = -0.02775	a = 4.40166
	σ(b) = 0.00475	r = 0.19618
	N = 856	

$$t = \frac{b_W - b_{WD}}{\sigma p} = \frac{0.03625}{0.017699} = 2.05$$

Significant difference between slopes

All Rural Sections (N = 378)

Wet:	b = -0.05171	a = 5.24417
	σ(b) = 0.01691	r = 0.15580
	N = 378	
Wet and Dry:	b = -0.02383	a = 3.98286
	σ(b) = 0.00477	r = 0.17893
	N = 756	

$$t = \frac{0.02788}{0.017569} = 1.59$$

No significant difference between slopes

All Rural Two-Lane Sections (N = 275)

Wet:	b = -0.08449	a = 7.20139
	σ(b) = 0.02156	r = 0.23075
	N = 275	
Wet and Dry:	b = -0.03024	a = 4.68790
	σ(b) = 0.00581	r = 0.21706
	N = 550	

$$t = \frac{0.05425}{0.022329} = 2.43$$

Significant difference between slopes

Key

b = Slope of regression line (W = Wet; WD = Wet and Dry)
a = Intercept of regression line
σ(b) = Standard error of slope estimate
r = Correlation coefficient
σp = Pooled standard error of slope estimates

TABLE 13

SENSITIVITY OF WET-PAVEMENT ACCIDENT RATE TO SKID NUMBER

Dependent Variable	Wet-Pavement Accident Rate
Independent Variable	SN40
Number of Levels of Independent Variable	5
Input Data	Rural Two-Lane Sections

Before Period

Level	SN40 Range	Number of Sections	Slope of AR-SN40 Regression (accident/MVM/SN40)
1	37.5 and under	22	-0.38929
2	37.5 - 43.5	50	-0.63587
3	43.5 - 49.5	85	-0.12930
4	49.5 - 55.5	66	-0.12027
5	Over 55.5	52	-0.17464

After Period

Level	SN40 Range	Number of Sections	Slope of AR-SN40 Regression (accident/MVM/SN40)
1	37.5 and under	33	-0.11666
2	37.5 - 43.5	50	-0.32641
3	43.5 - 49.5	51	+0.13789
4	49.5 - 55.5	59	+0.28632
5	Over 55.5	50	-0.32638

D. Evaluation of Before-After Differences in Accident Rate

An analysis of differences between before and after accident rates for the test and control sections was conducted to determine if there is any time trend in the test or matched control section accident rates. A time trend in the control accident rates was anticipated, because the beginning of the energy crisis and the national speed limit reduction intervened. between the before and after analysis periods. These events are known to have had an effect on nationwide accident rates. A time trend in the test section accident rates (after any trend in the control sections has been corrected for) would indicate an effect of the resurfacing carried out on the test sections. If no time trend is observed in either the test or control section data, then the before and after data can be combined in future analyses of covariance, effectively doubling the size of the available sample.

1. Wet-pavement accident rate: The following procedure was used to test for a time trend in the wet-pavement accident data. Let:

T_{bi} = Test section accident rate for i^{th} section in before period

T_{ai} = Test section accident rate for i^{th} section in after period

C_{bi} = Control section accident rate for i^{th} section in before period

C_{ai} = Control section accident rate for i^{th} section in after period

The first step was to examine the control sections for a time trend using the null hypothesis that the mean change in control section accident rate is zero:

$$Ho: \mu (C_{ai} - C_{bi}) = 0$$

If this hypothesis is not rejected, i.e., if no time trend is found in the control section accident rates, then the test sections are tested for a time trend using

$$Ho: \mu (T_{ai} - T_{bi}) = 0$$

However, if a time trend is found in the control sections, then the test sections are examined for a time trend using

$$Ho: \mu (Z_i) = 0$$

where $$Z_i = (T_{ai} - T_{bi}) - (C_{ai} - C_{bi})$$

The mean wet-pavement accident rates used in the following analysis differ slightly from those shown in Table 7. This difference occurs because only matched pairs of test and control sections with data available in both the before and after periods were included in this analysis; 12 sections had to be discarded for this analysis because only before data were available.

The mean wet-pavement accident rate for matched control sections in the before period is 3.00 accidents per million vehicle-miles; the after period accident rate is 2.97 accidents per million vehicle-miles. The sample mean difference in the before and after period rates is:

$$\hat{\mu}(C_{ai} - C_{bi}) = -0.02 \text{ accidents/MVM}$$

which is not significantly different from zero $(t(129) = -0.09)$. Therefore, there is no time trend in the wet-pavement accident data for the matched control sections. This result indicates that events between the before and after periods, including the energy crisis, did not introduce a bias into the analysis.

The mean wet-pavement accident rate for test sections in the before period is 3.39 accidents/MVM; the after period accident rate is 3.06 accidents/MVM. The sample mean difference in the before and after accident rates is:

$$\hat{\mu}(T_{ai} - T_{bi}) = -0.32 \text{ accidents/MVM}$$

which is not significantly different from zero $(t(129) = -0.86)$ Thus, there is no significant effect of resurfacing on the test-section accident rate when all highway and area types are considered together.

In interpreting these results, it should be kept in mind that there was virtually no change in the mean skid number for test sections from the before to the after period; i.e., on the average the skid number of test sections was not improved by resurfacing. The 130 test sections for which both before and after data are available had a mean skid number of 47.97 in the before period and 48.64 in the after period. This finding is not entirely unexpected, because the test sections were not necessarily selected for resurfacing on the basis of low skid number. Because this finding has possible implications for the management of pavement surface improvement programs, additional analyses were performed to determine whether any of several possible factors could be masking a true improvement in skid number with resurfacing. These additional analyses are reported in Appendix G. However, because the mean skid number did not change with resurfacing, it cannot be determined from the matched pair analysis whether or not there is a significant relationship between wet-pavement accident rate and skid number. Accident rate-skid number relationships can be developed in the analysis of covariance, because that analysis explicitly considers the skid number of each section both before and after resurfacing.

The absence of any time trend in the wet-pavement accident rates suggests that time (before vs. after) will not be a significant factor in the analyses of covariance and, therefore, that the before and after data can be combined, thereby doubling the effective sample size.

2. Dry-pavement accident rate: The same analysis used in the previous section for the wet-pavement accident rates was also applied to the dry-pavement accident rates. The mean dry-pavement accident rate for matched control sections in the before period is 2.39 accidents/MVM; the corresponding mean for the after period is 2.37 accidents/MVM. The sample mean accident rate difference between the before and after periods for control sections is trivially small:

$$\hat{\mu}(C_{ai} - C_{bi}) = -0.01 \text{ accidents/MVM}$$

which is not significant $(t(129) = -0.07)$. As in the wet-pavement case, there is no time trend in dry-pavement accident rate for control sections.

The mean dry-pavement accident rate for test sections in the before period is 2.35 accidents/MVM; the corresponding accident rate for the after period is 2.70 accidents/MVM. The sample mean dry-pavement accident rate difference between the before and after periods for the test sample sections is:

$$\hat{\mu}(T_{ai} - T_{bi}) = +0.35 \text{ accidents/MVM}$$

which is a statistically significant increase in accident rate $(t(129) = 2.68, p < 0.01)$. The variance of accident rate is considerably smaller for dry- than for wet-pavement conditions. Therefore, the available sample is more powerful for discriminating dry-pavement accident rates than wet-pavement accident rates.

There is no obvious explanation for the significant increase in dry-pavement accident rate. We examined the data set carefully and are satisfied that the finding is not caused by a few extremely large changes in accident rate (outliers), but rather represents a consistent trend in the data. This finding cannot be attributed to an overall time trend in accident experience, because no significant change (in fact, virtually no change at all) was observed for the control sections. The observed effect must be attributed to (1) an effect of resurfacing such as an increase of vehicle speeds or (2) some unique characteristic(s) of sections that are resurfaced that is not present in the control sections.* These findings, while unexpected, do not prevent merging of the before and after data because wet (not dry) accident rate is the response to be used in analyses of covariance.

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* Care was taken to assure that neither the before nor the after period overlapped the time when resurfacing or follow-on work, which might influence accident rates, was in progress.

3. <u>Analysis of covariance of before-after differences</u>: A direct comparison of matched pairs of test and control sections yielded no significant evidence of before-after changes in wet-pavement accident rate. This same effect can be examined with analysis of covariance. Analysis of covariance has a theoretical advantage because it explicitly accounts for the magnitude of the covariate (skid number) before time effects are evaluated. Two analyses of covariance approaches are available to evaluate before-after differences in wet-pavement accident rate: (1) using time (with levels before and after) as a factor in the analysis of covariance framework or (2) using before-after accident rate differentials as the response. It was not clear a priori which approach would be more powerful so both were tried with several frameworks.

The results of three analyses of covariance that use time as a factor are found in Tables 37, 38, and 39 in Appendix F. In these three analyses, time is used together with factors of highway type and area type, highway type and ADT, and area type and ADT, respectively. Time is not a significant factor in any of these frameworks. However, the covariate, SN40, is significant in all three analyses. The slope of the accident rate-skid number relationship in the individual cells of each of the three analyses was investigated and found not to be significantly different. This finding is further evidence that there are no differences that prevent merging of the before and after data.

Before-after differences in accident rate and skid number were used as the response and covariate, respectively, in the analysis of covariance results given in Tables 40, 41, 42, 43, and 44 of Appendix F. The analyses results from all test and control sections are presented in Tables 40, 41, and 42; the results for test sections only are presented in Tables 43 and 44. In each of the five analyses, the factors (highway type, area type and ADT, used two at a time) remove enough of the autocorrelation between the before and after responses that they are less powerful than the analyses that explicitly use time as a factor (Tables 37, 38, and 39).

Altogether eight analysis of covariance models with direct or indirect capability to identify a before-after effect for test and/or control sections were analyzed. The before-after effect was not significant in any of these cases.

4. <u>Summary</u>: No significant before-after effect was found for wet-pavement accident rates for either test or control sections. A significant increase in dry-pavement accident rate was found for test sections, but not for control sections. It was concluded that the before and after data can be merged for analyses of covariance where wet-pavement accident rate is the response.

The following evidence supports this conclusion:

a. There is no significant difference in the mean wet-pavement accident rate between the before and after periods;

b. There is no significant difference in the variance of wet-pavement accident rate between the before and after periods;

c. The slope of the accident rate-skid number relationship is not significantly different between the before and after periods; and

d. Time was not a significant factor when used explicitly in several analyses of covariance frameworks.

E. Influence of Highway Type, Area Type and ADT on the Accident Rate-Skid Number Relationship

It was anticipated that highway type, area type (urban/rural), and ADT would have important effects on wet-pavement accident rate. Several analyses of covariance were made to examine these effects. The first analyses were made, when only the before data were available, to take a preliminary look at the effects of these factors. Later the before and after data were merged (see justification above in Section V-D) and analyses of covariance were made with the entire data set.

The accident experience of the study sections for both the before and after periods is summarized in Appendix A. The study sections tabulated in Appendix A are classified by area type and highway type and the accident experience is summarized separately for each area type-highway type combination.

1. Analysis of covariance with before data: The structure of an analysis of covariance framework that could be used to examine highway type (HTYP), area type (ATYP) and ADT was limited by the available sample. Only 50 of the 428 sections available in the before period are located in urban areas. Because of the small number of urban sections, it was not possible to construct a three-way analysis of covariance framework of any power, i.e., the three-way interaction of the factors cannot be evaluated explicitly. Instead, the factors were considered two at a time, in all possible combinations, and thus, all three two-way interactions were evaluated. Three analyses were conducted as follows: (1) highway type and area type are used as factors in Table 45 of Appendix F; (2) highway type and ADT are used as factors in Table 46; and (3) area type and ADT are used as factors in Table 47. The input data used and the levels of each factor are identified in each table.

Area type, highway type, and their interaction had statistically significant effects in each case where they were examined. ADT was a significant variable when used with highway type, but not when used with area type. The covariate, SN40, had a statistically significant effect in all three cases. This is strong evidence that skid number does influence accident rates. However, the correlation coefficients for the analyses range from 0.26 to 0.42, indicating that much of the variation in accident rate is not explained by skid number or the other variables examined.

The analysis of covariance determines an overall "common" slope for each framework. If the slopes of the AR-SN40 regression lines in the individual cells of a framework are tested and no significant difference is found, the common slope is the best estimate of the true slope in each cell. The common slopes for the three frameworks discussed above are -0.060, -0.063 and -0.055, respectively. In each case, the results indicate that the common slope should be used in each cell; i.e., the accident rate-skid number relationship has the same slope, but not necessarily the same intercept, in each cell. It should also be pointed out, that the small sample size of urban sections makes inferences about urban AR-SN40 relationships weak. The rural relationships tend to overpower the urban relationships in this data set.

In the previous analyses, ADT had two levels: greater than 10,000 and less than 10,000. All highway sections with ADT less than 10,000 were grouped together, because there were not enough urban sections to subdivide this group. We were not completely satisfied with this treatment of ADT. Therefore, we also ran a one-way analysis of covariance using only the data for rural two-lane highways to test the significance of ADT when more levels are used. This analysis of covariance framework is illustrated in Table 48 of Appendix F. ADT was not a significant variable in this framework. Therefore, it was decided to proceed with the analysis using sections with under 10,000 ADT as a single group.

2. Analysis of covariance with combined before and after data: The three initial analyses of covariance, as described above, were repeated using the combined before and after data. The results of these analyses are presented in Tables 49, 50, and 51 of Appendix F. The increased sample size obtained by combining the before and after data made a substantial improvement in the ability of the analyses to detect significant effects; for the combined before and after data, all three factors (highway type, area type and ADT) are significant and so are all of their two-way interactions. Each area type-highway type-ADT combination has an effect upon the mean wet-pavement accident rate. The covariate, SN40, was significant in all three runs. The correlation coefficients for the three runs were nearly the same as before, ranging from 0.28 to 0.43.

In all three analyses, the slopes of the AR-SN40 relationships in individual cells are not significantly different. The three estimated common slopes are virtually identical (-0.048, -0.047, and -0.043), so that it is sufficient to assign a slope of -0.046 accidents/MVM/SN40 to all of the AR-SN40 regression lines. However, the relationship in each cell will have a different intercept.

The magnitude of the common slope indicates that skid number does have a substantial effect on accident rate. For example, if the skid number of a highway was increased by 10 units, the wet-pavement accident rate would, on the average, be reduced by 0.46 accidents/MVM, which is about 15% of the mean wet-pavement accident rate.

The results of the three analyses of covariance calculations were combined to obtain AR-SN40 predictive relationships for the 12 cells defined by two levels of area type, three levels of highway type, and two levels of ADT. The twelve predictive relationships are presented in Table 14 and are of the form:

$$AR - \overline{AR} = -0.046\ (SN40 - \overline{SN40}).$$

These relationships can also be written in the more conventional slope-intercept form as:

$$AR = AR_o - 0.046\ SN40$$

where AR_o = zero-intercept accident rate (accidents/MVM)

The relationships for rural and urban highways are illustrated in Figures 5 and 6, respectively. These predictive relationships constitute a basic input to Phase II of the project where a benefit-cost model for skid reduction countermeasures was constructed.

The predictive value of these relationships is limited by the relatively low correlation coefficients identified earlier. Substantial improvement in the predictive abilities of the relationships can be obtained by the use of multi-year accident samples. This subject is addressed in Section V-J.

Table 14 also shows the adjusted mean wet-pavement accident rate for each cell. This adjusted mean is the best estimate of what the observed cell mean would be if all cells had the same mean skid number. This adjustment is extremely small in comparison to the size of the factor effects. The difference between the adjusted mean wet-pavement accident rate ($\overline{AR'}$) and the overall mean (in this case, 3.0417 - 2.9356 accidents/MVM) is the best measure of the true effect of each area type-highway type-ADT combination.

3. <u>Summary</u>: A series of analyses of covariance identified a significant relationship between wet-pavement accident rate and skid number. Area type, highway type, and ADT and each of their two-way interactions have a significant effect on wet-pavement accident rate. A set of AR-SN40 prediction relationships was developed with a different relationship for each combination of area type, highway type and ADT. The slopes of these relationships are not significantly different, so one common slope was used for all 12 combinations.

TABLE 14

RAW AND ADJUSTED (FOR SN40) EFFECTS OF AREA TYPE, HIGHWAY TYPE AND ADT ON WET PAVEMENT ACCIDENT RATE

Area Type	Highway Type	ADT	$\overline{AR}$ (Mean AR) (Accidents/MVM)	$\overline{SN40}$ (Mean SN40)	$\overline{AR}'$ (Adjusted Mean AR) (Accidents/MVM)
1	1	1	2.95	48.36	3.04
1	1	2	4.08	40.13	3.80
1	2	1	1.82	49.51	1.97
1	2	2	3.99	40.66	3.73
1	3	1	0.70	50.29	0.89
1	3	2	0.65	41.51	0.43
2	1	1	3.45	42.49	3.28
2	1	2	4.72	40.15	4.43
2	2	1	7.01	40.27	6.73
2	2	2	9.57	38.05	9.19
2	3	1	1.63	40.65	1.37
2	3	2	2.23	38.41	1.87
All Data			2.94	46.30	

LEVEL OF FACTORS

Area Type	Highway Type	ADT
Level 1 = Rural	Level 1 = Two-Lane, Uncontrolled Access	Level 1 = Under 10,000
Level 2 = Urban	Level 2 = Multilane, Uncontrolled Access	Level 2 = Over 10,000
	Level 3 = Multilane, Controlled Access	

FORM OF AR-SN40 PREDICTIVE RELATIONSHIPS FOR EACH CELL

$$AR - \overline{AR} = -0.046\ (SN40 - \overline{SN40})$$

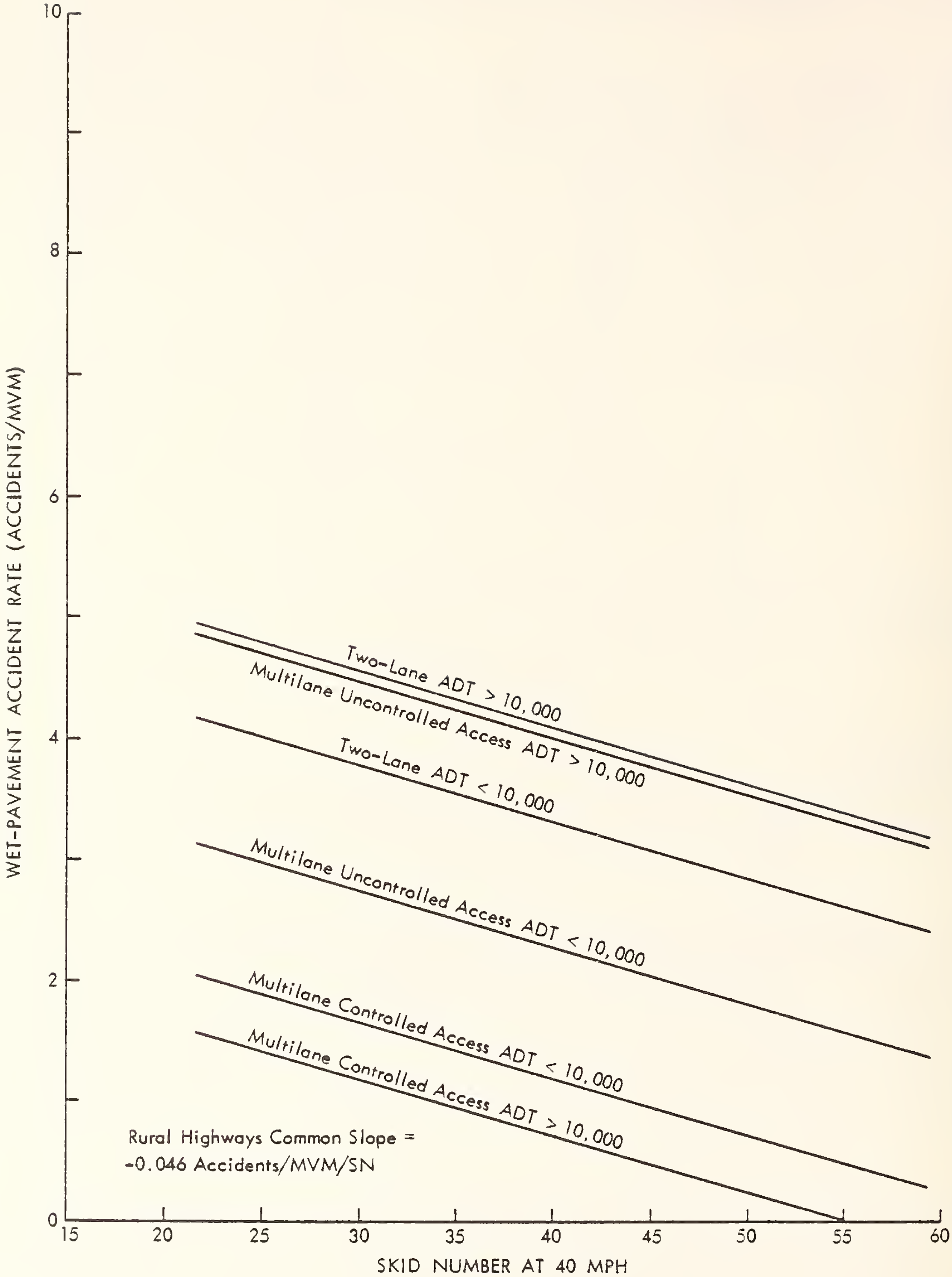

Figure 5 - Relationship Between Wet-Pavement Accident Rate and Skid Number at 40 mph for Rural Highways

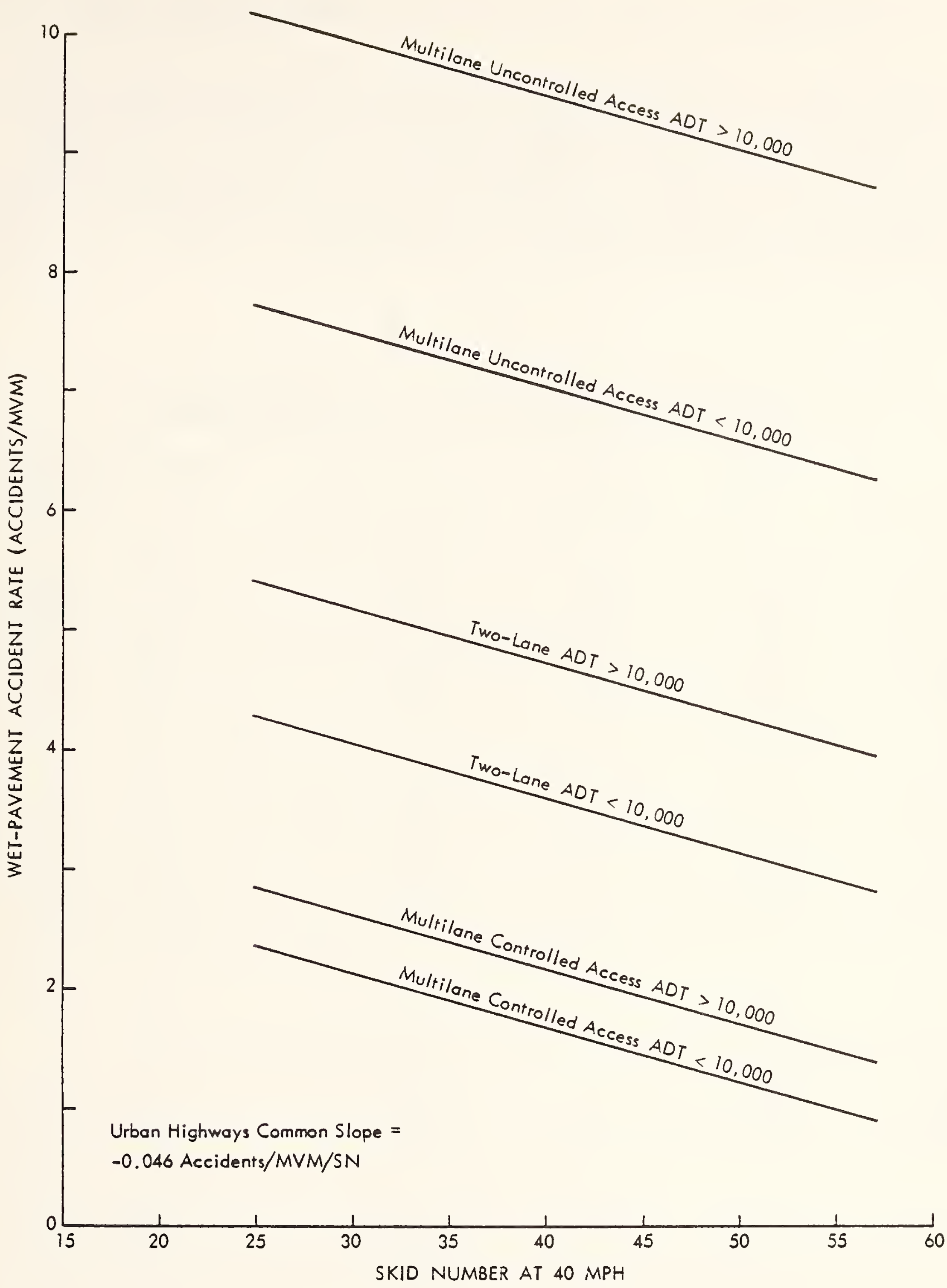

Figure 6 - Relationships Between Wet-Pavement Accident Rate and Skid Number at 40 mph for Urban Highways

F. Relationship Between Wet- and Dry-Pavement Accident Rates

The relationship between wet- and dry-pavement accident rates was examined in detail because of the importance of this relationship to the Phase II benefit-cost model. The correlation coefficients for the two accident rates were computed separately for each of the six area type-highway type combinations for the before period, the after period, and the combined before and after periods. The correlations and their associated 95% confidence intervals are shown in Table 15.

TABLE 15

WET ACCIDENT RATE-DRY ACCIDENT RATE CORRELATIONS

Treatment	Time Period	Sample Size (n)	Correlation Coefficient (r)	Confidence Interval (α = .05) for r
R2LUA	Before	275	0.5193	0.43 - 0.60
U2LUA	Before	18	0.5209	0.07 - 0.79
RMLUA	Before	50	0.5848	0.37 - 0.74
UMLUA	Before	18	0.7640	0.46 - 0.91
RMLCA	Before	53	0.4666	0.22 - 0.65
UMLCA	Before	14	0.6560	0.19 - 0.88
R2LUA	After	243	0.5290	0.43 - 0.61
U2LUA	After	14	0.6129	0.12 - 0.86
RMLUA	After	47	0.8251	0.70 - 0.90
UMLUA	After	16	0.8759	0.67 - 0.96
RMLCA	After	44	0.0513	-0.17 - 0.34
UMLCA	After	14	0.5711	0.06 - 0.85
R2LUA	Both	518	0.5191	0.45 - 0.58
U2LUA	Both	32	0.5987	0.32 - 0.78
RMLUA	Both	97	0.6885	0.57 - 0.78
UMLUA	Both	34	0.8313	0.69 - 0.91
RMLCA	Both	97	0.3805	0.20 - 0.54
UMLCA	Both	28	0.6095	0.31 - 0.80
All	Before	428	0.6299	0.57 - 0.68
All	After	378	0.7089	0.65 - 0.76
All	Both	806	0.6689	0.63 - 0.71

Key to Treatment Codes:

1st Character: R = Rural U = Urban
2nd and 3rd Characters: 2L = two-lane highway ML = multilane highway
4th and 5th Characters: UA = uncontrolled access CA = controlled access

These correlation coefficients (r's) were examined by analysis of variance* of the before data, after data, and combined before and after data to describe: (1) time effects on correlation, (2) treatment (area type-highway type) effects on correlation, and (3) treatment-time interaction effects.

All of the r-values in Table 15 are significantly greater than zero except that for rural, multilane, controlled access (RMLCA) highways in the after period. Nine of the 44 RMLCA highway sections experienced no wet-pavement accidents in the after period, and this probably contributed to the low correlation coefficient for these sections. Except for these sections there is no evidence of time changes in the treatment (area type-highway type) correlations, i.e., the treatment differences are preserved in both time periods.

The slope, intercept and correlation coefficients are shown in Table 16 for each regression relationship between wet-pavement accident rate and dry-pavement accident rate for the combined before and after data set. The data are given for the six combinations of area and highway type considered.

Statistical tests established that the differences between the intercepts for these six regression relationships are not statistically significant. Therefore, each relationship is assigned the common intercept--0.807 wet-pavement accidents/MVM. The slopes for these regressions were examined and found to fall into two statistically distinct groups. One group includes all the urban, multilane, highways (both the UMLUA and UMLCA sections) and has a common slope of 1.487; the other group includes all the rural and urban, two-lane highways (the R2LUA, RMLUA, RMLCA and UZLUA sections) and has a common slope of 0.828. The linear relationships for these two sets of sections is graphically shown in Figure 7. No correlation coefficient can be directly determined for each of these linear relationships because each relationship was developed from a common slope and intercept derived from several regression lines. However, the overall goodness of fit of the two relationships can be judged from the correlation coefficients given in Table 16, which range from 0.38 to 0.69.

The following general conclusions were reached. Correlations between wet-pavement and dry-pavement accident rates are higher for urban than for rural sections, and higher in the after period than in the before period. The correlation for urban, multilane, uncontrolled access (UMLUA) sections is significantly higher than for the other sections and the correlation for RMLCA sections is significantly lower.

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* Estimated correlation coefficients (r's) are not themselves normally distributed and thus not subject to analysis of variance. The Fisher normalizing transformation $Z = 1/2\ \ell n \frac{1+r}{1-r} \approx N(1/2\ \ell n \frac{1+p}{1-p}, \frac{1}{n-3})$ was used, and interpretations drawn from analysis of variance of the Z's. For simplicity, though, the test discussion refers to the correlation coefficients themselves.

TABLE 16

WET ACCIDENT RATE-DRY ACCIDENT RATE REGRESSION RELATIONSHIPS FOR COMBINED BEFORE-AFTER DATA

Treatment	Observed Regression Relationship			Common	Common
	Correlation Coefficient	Slope	Intercept	Slope	Intercept
R2LUA	0.5191	0.884	0.855	0.828	0.807
U2LUA	0.5987	0.748	1.802	0.828	0.807
RMLUA	0.6885	0.771	1.119	0.828	0.807
UMLUA	0.8313	1.479	0.231	1.487	0.807
RMLCA	0.3805	0.614	0.252	0.828	0.807
UMLCA	0.6095	1.497	0.311	1.487	0.807

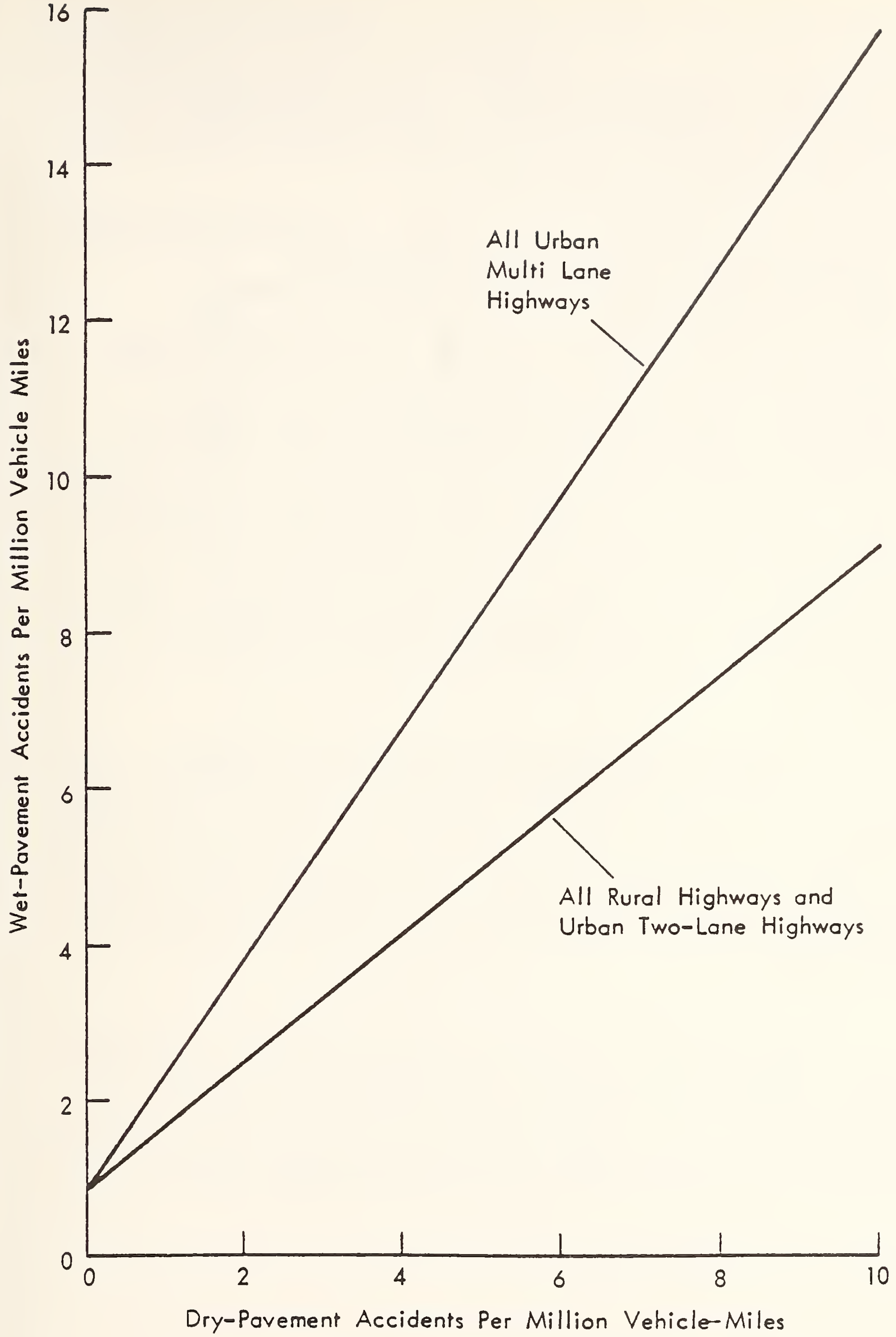

Figure 7 - Relation Between Dry-Pavement and Wet-Pavement Accident Rates

The results show a strong relationship between wet-pavement and dry-pavement accident rates. The correlations are sufficient (on the average) to explain almost one-half of the variation in wet-pavement accident rate. The strength of this relationship was used in the next section in an analysis of covariance to test a postulated relationship between dry-pavement accident rate and the relationship between wet-pavement accident rate and skid number.

G. Influence of Dry-Pavement Accident Rate on the (Wet-Pavement) Accident Rate-Skid Number Relationship

In this section it is postulated that the dry-pavement accident rate has an effect on the slope of the (wet-pavement) accident rate-skid number relationship. The rationale for this postulate is as follows. Dry-pavement accident rate is a measure of whether accident-causing features (other than skid resistance) are present on a section. On a section where high friction demands are present, as evidenced by high dry-pavement accident rate, it is reasonable to expect that wet-pavement accident rate is quite sensitive to skid number. On the other hand, on a section with only small frictional demands, where dry-pavement accident rate is low, wet-pavement accident rate is probably not sensitive to changes in skid number. This postulate, if true, will be very useful in the Phase II benefit-cost model. The postulate was tested using an analysis-of-covariance approach.

a. Relative dry-pavement accident rate investigation: A new variable, relative dry-pavement accident rate (RELDAR), was defined for use as a factor in an analysis of covariance. RELDAR was defined to have three levels. RELDAR has a value of 1 for each section in the lowest third of the dry-pavement accident-rate distribution for its area type-highway type combination. Levels 2 and 3 likewise represent the middle and upper thirds of the dry-pavement accident rate distribution for each area type-highway type combination. Table 17 shows the boundaries of the relative dry-pavement accident-rate levels.

An analysis of covariance was performed with the combined before and after data using area type, highway type and relative dry-pavement accident rate as factors. The results of this analysis are presented in Table 52 in Appendix F. All of these factors and all of their interactions were significant, as was the covariate, SN40. This result implies that each ATYP-HTYP-RELDAR cell imparts a mean effect on wet-pavement accident rate (AR).

TABLE 17

LEVELS OF RELATIVE DRY PAVEMENT ACCIDENT RATE (RELDAR)

Area Type-Highway Type	Dry Pavement Accident Rate (accident/MVM) Corresponding to RELDAR: Level 1	Level 2	Level 3
R2LUA	0 - 1.71	1.72 - 2.62	2.63 - 14.36
RMLUA	0 - 1.17	1.18 - 2.13	2.18 - 14.38
RMLCA	0 - 0.46	0.48 - 0.74	0.75 - 2.18
U2LUA	0 - 2.19	2.20 - 3.56	3.77 - 8.23
UMLUA	1.43 - 4.20	4.21 - 6.51	6.60 - 14.41
UMLCA	0.21 - 0.69	0.74 - 1.30	1.38 - 2.63

In addition, polynomial effects in the relationship between RELDAR and mean wet-pavement accident rate were examined. This analysis showed that this relationship is essentially linear. Thus, not only are mean AR and RELDAR levels correlated, but their relationship is virtually a straight line whose slope is unity.

The analysis of covariance F-test for equal slopes in each ATYP-HTYP-RELDAR cell was not rejected; therefore, the common slope should be used for all cells. This finding appears to contradict the postulate introduced above. However, the F-test considers only the magnitude of the slope dispersion, and cannot detect a systematic pattern in the slopes. An apparent pattern, similar to the relationships postulated above, was observed in the rural sections. The magnitude of the slope of the AR-SN40 relationship appears to increase markedly with RELDAR level, i.e., rural sections with high relative dry-pavement accident rate are much more sensitive to SN40 than rural sections with low relative dry-pavement accident rate. This apparent pattern is not present in the urban sections. However, there are only about 10 urban sections per HTYP-RELDAR cell, a very weak sample size for identifying such a pattern.

The apparent pattern of slopes for rural sections was tested with a two-way analysis of variance with factors highway type and relative dry-pavement accident rate. Both of the factors and their interaction were significant ($F(2,330) = 23.33$ for RELDAR; $F(2,330) = 6.48$ for HTYP; $F(4,330) = 5.20$ for HTYP-RELDAR interaction).

Table 18 displays the very evident change in AR-SN40 slopes with RELDAR discussed above. The table includes both the observed slopes and the theoretical best estimates of slopes obtained from the analysis of variance. Although the correlation coefficients for the regression relationships shown in Table 18 are relatively low, the distinctive pattern of increasing slopes with the level of relative dry-pavement accident rate can be clearly seen. The urban sections are not shown in Table 18, because none of the slopes are significantly different from zero. Any AR-SN40 relationship that exists for urban sections is not well specified by the available data.

Comparison of results from the ATYP-HTYP-RELDAR cells resulted in the following conclusions for rural sections:

1. The magnitude of the AR-SN40 slope does increase as relative dry-pavement accident rate increases, but this increase is more pronounced for two-lane and multilane uncontrolled access sections than for multilane controlled access sections.

TABLE 18

SENSITIVITY OF AR-SN40 RELATIONSHIP TO RELATIVE DRY PAVEMENT ACCIDENT RATE FOR RURAL SECTIONS

Highway Type	Relative Dry-Pavement Accident Rate	No. of Cases	AR (Mean Wet-Pavement Accident Rate) (accidents/MVM)	SN40 (Mean SN40)	Slope of AR-SN40 Relationship (accidents/MVM/SN)		Correlation Coefficient for Observed Regression
R2LUA	1	173	1.6335	48.8474	+0.00901	+0.0080 a/	0.044
R2LUA	2	173	2.6535	48.3942	-0.03810	-0.0406	0.144
R2LUA	3	172	4.7419	46.6506	-0.08657	-0.0856	0.213
RMLUA	1	33	1.1355	48.2636	+0.00243	+0.0080 a/	0.020
RMLUA	2	32	2.2244	46.0969	-0.05416	-0.0406	0.271
RMLUA	3	32	5.1116	42.0437	-0.08026	-0.0856	0.234
RMLCA	1	33	0.4224	45.9273	-0.00763	-0.0052 a/	0.235
RMLCA	2	32	0.6400	42.3156	-0.00656	-0.0129 a/	0.103
RMLCA	3	32	0.9456	45.4750	-0.02254	-0.0194 a/	0.217

a/ Not significantly different from zero.

2. The average slope is greater for two-lane and multilane uncontrolled access sections than for multilane controlled access sections.

Rural sections with high relative dry-pavement accident rate are, in general, more sensitive to SN40 than rural sections with low relative dry-pavement accident rate, but this conclusion may not apply to multilane, controlled access highways. Thus, not only does relative dry-pavement accident rate affect the mean wet-pavement accident rate, but it also affects the AR-SN40 relationship itself.

b. Quantification of dry-pavement accident rate influence: The next step taken was to quantify the effect of dry-pavement accident rate on the AR-SN40 relationship in a form that can be employed in the Phase II benefit-cost model. For this analysis, each of the three levels of relative dry-pavement accident rate for each rural highway type, defined in Table 17, were split into two new levels with an equal number of sections in each. Thus, the entire rural data set was divided into 18 cells defined by six levels of dry-pavement accident rate and three highway types. The slope of the AR-SN40 relationship in each of the 18 cells was determined by simple linear regression. The plotted points in Figure 8 represent the AR-SN40 slope and the mean dry-pavement accident rate for each cell. Statistical tests and engineering judgment were used to develop a relationship between dry-pavement accident rate and the rate of change of wet-pavement accident with skid number from the data plotted in Figure 8. It was determined that the sensivitity of wet-pavement accident rate to skid number does not differ significantly from zero for the points with low dry-pavement accident rate (below about 1 accident/MVM). In the middle range of dry-pavement accident rate, regression analysis was used to estimate the influence of dry-pavement accident rate on the slope of the AR-SN40 relationship. In the model shown in Figure 8, the rate of change of wet-pavement accident rate with skid number increases linearly from zero for dry-pavement accident rates below 1.082 accidents/MVM to -0.0825 accidents/MVM/SN at a dry pavement accident rate of 3.02 accidents/MVM. Above the dry-pavement accident rate of 3.02, there are not adequate data to determine whether the slope of the AR-SN40 relationship levels off or decreases. For predicting the effect of skid number improvements on wet-pavement accident rate, it is recommended that the slope of the AR-SN40 relationship be considered constant at -0.0825 accidents/MVM/SN for highway sections with dry-pavement accident rate above 3.02 accidents/MVM.

The correlation coefficient of the linear regression line for the dry-pavement accident rate range of 1.083 to 3.02 accidents/MVM is 0.78. This relatively high correlation coefficient should not be misinterpreted, however. The slopes used in this regression analysis are themselves the result of regression analyses that range in correlation coefficient from 0.02 to 0.33. Therefore, the reliability of Figure 8 to predict the rate of change of wet-pavement accident rate with skid number for any one particular section is limited.

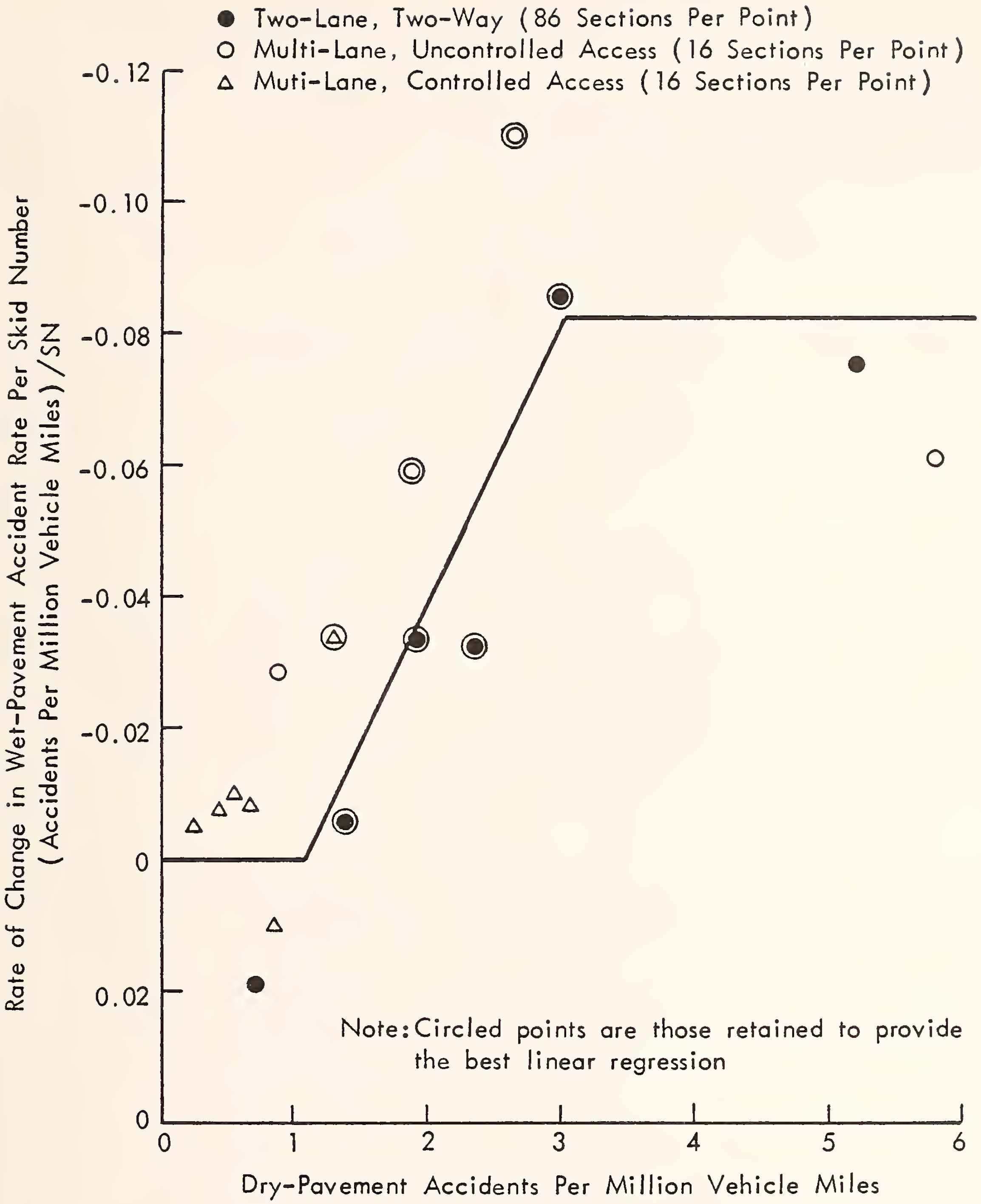

Figure 8 - Rate of Change of Wet-Pavement Accident Rate with Skid Number As a Function of Dry-Pavement Accident Rate for Rural Highways

The AR-SN40 relationship was expressed as:

$$AR = AR_o - 0.046\ SN40$$

in Section V-E. To incorporate the sensitivity to dry-pavement accident rate, the AR-SN40 relationship can be redefined as:

$$AR = AR_o + a_1\ SN40$$

where a_1 is the rate of change of wet-pavement accident rate with skid number defined by the solid line in Figure 8.

Since there is no direct causal relationship between wet- and dry-pavement accidents, the observed sensitivity must represent the indirect influence of factors related to the causation of both wet- and dry-pavement accidents. This finding suggests that factors such as highway geometry (horizontal curves, vertical grades, intersections, etc.), may influence the AR-SN40 relationship.

In summary, the analysis described above indicates that area type, highway type and dry-pavement accident rate have a significant effect on wet-pavement accident rate and, at least for rural sections, dry-pavement accident rate affects the slope of the wet-pavement accident rate-skid number relationship in the manner postulated above. The analysis described in Section V-E found that area type, highway type and ADT also have significant influences on this relationship. It would be natural to conduct an analysis of covariance considering all four factors, but unfortunately an adequate sample size is not available for such an analysis.

H. Influence of Pavement Texture and Exposure to High-Intensity Rainfall on the Accident Rate-Skid Number Relationship

An analysis of covariance approach was used to investigate the influence of both pavement texture and exposure to high-intensity rainfall on the accident rate-skid number relationship. Pavement texture and exposure to high-intensity rainfall are both potentially important elements of the skidding problem. The risk of skidding should be greater when there is an accumulation of water on the pavement during high-intensity rainfall, especially for pavements with limited texture. Pavement texture was represented by mean gradient rating (MGR) with values ranging from 1 to 5 (see Section III-A-5). An hour of exposure to high-intensity rainfall is defined as an hour in which at least 0.5 in. of rainfall was recorded. The total annual number of hours of exposure to high-intensity rainfall was used for this analysis.

Two analyses of covariance were conducted. The first examined pavement texture as a factor. The second examined both pavement texture, exposure to high-intensity rainfall and their interaction.

1. Pavement texture analysis: Pavement texture and highway type were used as factors in the first analysis. Pavement texture was represented by three levels defined by mean gradient rating (MGR). The levels of MGR and the corresponding estimated values of skid number-speed gradient are as follows:

Pavement Texture Level	Mean Gradient Rating (MGR)	Estimated Skid Number-Speed Gradient (SN/mph)
1	under 2.15	over 0.39
2	2.15 - 2.85	0.35 - 0.39
3	over 2.85	under 0.35

Only the after data were used in this analysis, because photographs were available for more sections in the after period than in the before period. Therefore, fewer estimates of skid number-speed gradient had to be made. The sample size of urban sections was not sufficient to include area type as a factor in this analysis, so only the rural sections were used.

The results of this analysis of covariance are shown in Table 53 in Appendix F. Highway type was a significant factor here, as it was throughout the previous analyses. However, neither pavement texture nor the pavement texture-highway type interaction was significant. The residual mean square was not significantly different than if MGR had been excluded from the analysis, and the effect of highway type and the slope of the AR-SN40 relationship were not changed significantly by the inclusion of pavement texture. Thus, the use of pavement texture as a factor in the analysis of covariance does not help to explain either the variation in wet-pavement accident rate or the nature of the AR-SN40 relationship.

The simple correlation coefficient of mean gradient rating, MGR, and wet-pavement accident rate, AR, for two-lane rural highways is 0.087. A statistical technique developed by Box and Cox[20] was used to determine if there exists any transformation of MGR that could improve its correlation with AR to a reasonable level. The technique consists of calculating linear regression relationships between AR and a transformation of the form:

$$Z(MGR) = \frac{MGR^{\lambda} - 1}{\lambda\,(GM(MGR))^{\lambda-1}}$$

where Z(MGR) = Transformed mean gradient rating

MGR = Mean gradient rating

GM(MGR) = Geometric mean of MGR

for successive values of λ . The regression relationship that maximizes the function:

$$L = \frac{-n}{2} \log\ (\text{Res SS}) + \frac{n}{2} \log n$$

where Res SS = Residual sum of squares

n = Sample size

will produce the strongest correlation. This analysis was performed and a maximum value of L was found for $\lambda = -0.25$. The correlation coefficient for the regression between AR and Z(MGR) for $\lambda = -0.25$ is not significantly greater than the correlation coefficient for the regression between AR and MGR. This finding indicates that there is no monotonic transform of MGR that will result in a significant improvement in the correlation between AR and MGR.

A similar regression analysis was performed to express AR as a function of Z(MGR) and SN40 for successive values of λ . As in the previous analysis, no transform of MGR produces a significant improvement in the regression correlation coefficient.

One final data analysis approach was to use the percent skid number gradient (also known as the normalized skid number gradient) as a measure of texture. This quantity is defined as:

$$PSNG = -\frac{dSN}{dV}\,\frac{100}{SN40} = \frac{SNG}{SN40}(100)$$

where PSNG = Percent skid number gradient,

$SNG = \frac{-d(SN)}{dV}$ = Skid number-speed gradient, and

SN = Skid number.

Several researchers including Henry and Hegmon,[5] Veres, et al.,[6] and Gallaway and Rose[7] have found that PSNG is more highly correlated with macrotexture than SNG. The quantity, PSNG, was calculated from the Phase I data using SN40 and the derived relationship between the skid number-speed gradient and the mean gradient rating:

$$PSNG = \frac{SNG}{SN40} \times 100 = \frac{(0.52 - 0.06MGR)}{SN40} \times 100$$

A regression analysis for rural two-lane highway sections found that a regression relationship of AR with SN40 and PSNG does not explain significantly more of the variation in AR than a regression relationship of AR with SN40 alone.

One final technique for relating wet-pavement accident rate to skid number has not been attempted. The analysis reported in Section V-G found that the AR-SN40 relationship is sensitive to the dry-pavement accident rate. This sensitivity, illustrated in Figure 8, is based on the postulate that the dry-pavement accident rate is a measure of the demands for traction to avoid both dry- and wet-pavement accidents. Therefore, highway sections with high traction demands tend to have high dry-pavement accident rates and disproportionately high sensitivity of wet-pavement accident rate to skid number. It is possible that this same postulate may be useful in establishing a relationship between wet-pavement accident rate and skid number, i.e., macrotexture may have a disproportionately high influence on wet-pavement accident rate on highway sections with high traction demands. This postulate could be tested by assigning weight factors to the mean gradient rating (MGR) data. These weight factors should be proportional to the magnitude of the ordinate indicated by the line in Figure 8. (In effect, previous analysis have employed a uniform weight factor of 1.0 for all sections. If the hypothesis presented above is correct, the uniform weight factors have resulted in an unnecessary addition of unassigned variance in the correlation between wet-pavement accident rate and mean gradient rating.) If the use of weight factors produces a significant correlation between wet-pavement accident rate and the mean gradient rating, the relationship could then be incorporated in the benefit-cost model.

Thus, the use of pavement texture as a factor in the analysis of covariance does not help to explain either the variation in wet-pavement accident rate or the nature of the AR-SN40 relationship.

2. Pavement texture and high-intensity rainfall interaction analysis: A second analysis of covariance was used to examine the effect of pavement texture, exposure to high-intensity rainfall, and their interaction on the accident rate-skid number relationship. Highway type, pavement texture (mean gradient rating) and exposure to high-intensity rainfall were used as factors. Exposure to high-intensity rainfall was divided into two levels for analysis of covariance. These were:

Level	Exposure to High-Intensity Rainfall (hours/year)
1	under 12.5
2	over 12.5

Pavement texture was divided into two levels for this analysis:

Pavement Texture Level	Mean Gradient Rating (MGR)	Estimated Skid Number-Speed Gradient (SN/mph)
1	under 2.15	over 0.39
2	over 2.15	under 0.39

The results of the analysis are given in Table 54 in Appendix F. Highway type was again a significant factor. However, exposure to high-intensity rainfall, pavement texture and the exposure-texture interaction were all nonsignificant.

3. Summary: No evidence was found in the data to indicate that either pavement texture or exposure to high-intensity rainfall influences the wet-pavement accident rate or the nature of the accident rate-skid number relationship.

The lack of significance for pavement texture and exposure to high-intensity rainfall was somewhat unexpected, since these are generally regarded in the literature as important variables. However, it must be pointed out that neither of the variables was measured directly in the project, but instead had to be estimated. Pavement texture was estimated from pavement photographs and exposure to high-intensity rainfall was estimated from weather records. Also, other variables, such as pavement cross-slope, that the literature identifies as important to the drainage problem, were not available for this analysis. For these reasons, the results of this analysis of pavement texture and exposure to high-intensity rainfall should be regarded as less than conclusive.

I. Development of an Indirect Relationship Between Wet-Pavement Accident Rate and Pavement Texture

A relationship between wet-pavement accident rate and skid number was developed in Section V-E and refined in Section V-G to include the influence of dry-pavement accident rate. As explained in Section V-H, no direct, explicit relationship could be developed between wet-pavement accident rate and the mean gradient rating (MGR) estimated from pavement surface photographs. Because such a relationship was needed as an option for the Phase II benefit-cost model, a relationship was developed indirectly. This relationship was developed by combining the results of the AR-SN40 relationship developed in this project with the results of recent work on the prediction of skid number from pavement texture parameters conducted at Penn State University. The texture-skid number relationship developed by Penn State is based on the analysis of data from only 20 pavements and the coefficients of the relationship have not been validated. Therefore, the accident rate--texture relationship developed in this section is considered to be less reliable than the accident rate-skid number relationship developed in Section V-E.

The pavement surface properties that influence skid resistance can be divided into two categories: microtexture and macrotexture. Pavement microtexture consists of the microscopic asperities on the surface of individual pieces of aggregate, and to a lesser extent on the surface of the pavement binder (asphalt or portland cement). Microtexture is what makes a piece of aggregate feel smooth or rough to the touch. By contrast, macrotexture consists of the large scale asperities associated with voids in the pavement surface between pieces of aggregate. Thus, in the simplest terms, microtexture is determined by the aggregate surface and macrotexture is determined by the distribution of aggregate sizes and the manner in which the individual pieces of aggregate are assembled to form a pavement surface. Dahir and Henry[21/] have recently developed a model to predict skid number from pavement microtexture and macrotexture. This model is known as the Penn State model and it has the general form:

$$SN_V = C_o e^{C_1 V}$$

where SN_V = Skid number at any speed V,

V = Speed (mph),

C_o = Zero speed intercept (correlated with microtexture), and

C_1 = Function of macrotexture parameters only.

Expressions for C_1 and C_o have been developed empirically by Leu and Henry[22] from data for 20 pavement surfaces.

The term C_o represents the skid resistance at low speeds and is, therefore, a function of microtexture alone. C_o is the zero-speed intercept of skid number, given by Leu and Henry as:

$$C_o = -31.0 + 1.38 \text{ BPN}$$

The macrotexture influence is expressed in terms of the percent skid number gradient defined in Section V-H. By differentiating the general prediction model, it can be shown that:

$$\text{PSNG} = -100\ C_1$$

Leu and Henry have demonstrated that:

$$\text{PSNG} = 4.10(\text{MD})^{-0.47}$$

where MD = Average texture depth (milli-in.) as determined by the sand patch method.

Therefore, it follows that:

$$C_1 = -0.041(\text{MD})^{-0.47}$$

The relationships for C_o and C_1, when substituted in the general model yield:

$$SN_V = (-31.0 + 1.38\text{BPN})e^{-0.041V(\text{MD})^{-0.47}}$$

The Penn State model is extremely useful for predicting skid number, because it separates the influences of microtexture and macrotexture. It can be seen from the previous equation that at very low speeds the skid number is a function of microtexture alone (as measured by BPN), while at higher speeds both macrotexture and microtexture have an influence.

However, there is some concern over whether the previous equation is general enough to be extrapolated to pavement surfaces with high macrotexture, such as open-graded asphalt pavements. This concern arises because the data base used to develop the relationship is limited with respect to both the number of pavements studied (20) and the range of macrotexture (4 to 33 milli-in.). There are no data available to validate the microtexture influence on the Penn State relationship; but there are available two independent sets of skid number and macrotexture data to validate the macrotexture (exponential) portion of the Penn State model for a broader range of macrotexture.

Table 19 shows the coefficients of the macrotexture portion of the Penn State model for the ENSCO data and two independent sets of data. The first independent source was obtained from a recent study in California.[23] These pavements range from 21 to 125 milli-in. in mean texture depth, as determined by the sand patch method, and include dense-graded asphalt surfaces, portland cement concrete surfaces, open-graded asphalt concrete surfaces and chip and seal coats. The second set of independent data was obtained for 31 pavements in Texas.[24] These pavements include dense-graded asphalt concrete, seal coats and sprinkle treatments. They range from 10 to 124 milli-in. in mean texture depth, as determined by the sand patch method.

The results of this attempt to validate the revised coefficients of the Penn State model are somewhat mixed. There is good agreement between the regression coefficients, b_1 and b_2, for the California and the Leu and Henry data, but the agreement between the coefficients for the Texas and Leu and Henry data is not as good. The California and Texas data, which represent several types of pavement surfaces, produce low correlation coefficients in sharp contrast to the Leu and Henry data, which represent only dense-graded asphalt surfaces. The low correlation coefficients for the California and Texas data may be due to seasonal variation of skid number. However, it is also probable that the coefficients of the Penn State model depend, to an extent, on the type of pavement surface. However, until the coefficients have been evaluated completely for a range of pavement surfaces, the Penn State model presented by Leu and Henry appears to be the best available model for predicting skid number from pavement texture.

The relationship between wet-pavement accident rate and skid number developed in the Phase I analysis is:

$$AR = AR_o + a_1 \ SN40$$

The skid number at 40 mph can be predicted from microtexture and macrotexture by the Penn State model as:

$$SN40 = (-31.0 + 1.38 \ BPN)e^{-0.041(40)(MD)^{-0.47}}$$

A relationship between wet-pavement accident rate and pavement microtexture and macrotexture can be obtained by substituting the Penn State expression for SN40 into the AR-SN40 relationship developed in Phase I:

$$AR = AR_o + a_1 \ (-31.0 + 1.38 \ BPN)e^{-0.041(40)(MD)^{-0.47}}$$

The combination of the Penn State and Phase I relationships in this manner assumes implicitly that the entire influence of macrotexture on wet-pavement accident rate can be accounted for by the influence of macrotexture on skid number. There are other ways in which increased macrotexture may influence accident experience, including increases of noise or vibration sensed by the driver and in reduced potential for partial or total hydroplaning (similar to the effect of pavement grooving which is known to decrease accident experience without appreciably changing skid number).

Table 19

MACROTEXTURE TERM OF THE PENN STATE MODEL FOR SEVERAL DATA SETS

$PSNG = b_1 (MD)^{b_2}$

Data Source	Number of Pavements	Range of Macrotexture[a/] (MD) (milli-in.)	Regression Coefficient b_1	Regression Coefficient b_2	Correlation Coefficient
Leu and Henry[22/]	20	4 to 33	4.10	-0.47	0.96
California[23/]	35	21 to 125	4.55	-0.45	0.33
Texas[24/]	31	10 to 124	1.79	-0.25	0.21

a/ Determined by sand patch method.

Figure 9 is an example of this combined relationship for a range of microtexture and macrotexture values. The figure is appropriate for two-lane rural highway sections with ADT less than 10,000. The value of the zero-intercept accident rate, AR_0, corresponding to such sites is taken from the Phase I analysis and is 5.17 accidents/MVM. For purposes of this example, the slope coefficient, a_1, is assigned the value of the "common slope" found in the Phase I analysis: -0.046 accidents/MVM/SN. The solid portion of the curves in Figure 9 is based on the Penn State model with coefficients derived by Leu and Henry; the dashed portion of the curves represents an extrapolation of the model to higher macrotexture values.

Figure 9 spans a range of microtexture and macrotexture typical of common pavement surfaces. The range of texture depth from 5 to 40 milli-in. is typical of dense-graded asphalt pavements and the range from 40 to 120 milli-in. is typical of open-graded asphalt pavements. The figure indicates a strong sensitivity of wet-pavement accident rate to both microtexture and macrotexture. Microtexture appears to be the most important parameter in determining the wet-pavement accident rate, but macrotexture also has a substantial influence, especially in the low macrotexture range. The macrotexture influence increases as the value of microtexture increases. As an example, for a pavement with a British Portable Number of 50, an improvement of macrotexture from 20 to 40 milli-in. (0.5-1.0 mm) will reduce the accident rate by 3.5%. By contrast, for a pavement with a British Portable Number of 80, the same improvement in macrotexture will reduce accident rate by 10.6%.

The indirect relationship between wet-pavement accident rate and pavement texture developed by combining the Penn State model with the Phase I results is incorporated in the Phase II benefit-cost model to provide the option of specifying the skid resistance properties of a pavement surface in terms of microtexture and macrotexture.

J. Influence of Geometric Variables on the Accident Rate-Skid Number Relationship

An analysis was conducted to examine the influence of geometric variables on the accident rate-skid number relationship. The analysis included five variables that were calculated from field inventory data. These variables were used to describe the overall geometrics of each test and control microsection. No attempt was made to investigate the effects of individual geometric features on the relationship. These five variables considered were:

- Number of horizontal curves per mile;
- Percent of microsection length on horizontal curves;
- Number of sag vertical curves per mile;
- Number of intersections per mile; and
- Percent of microsection length on significant grade.

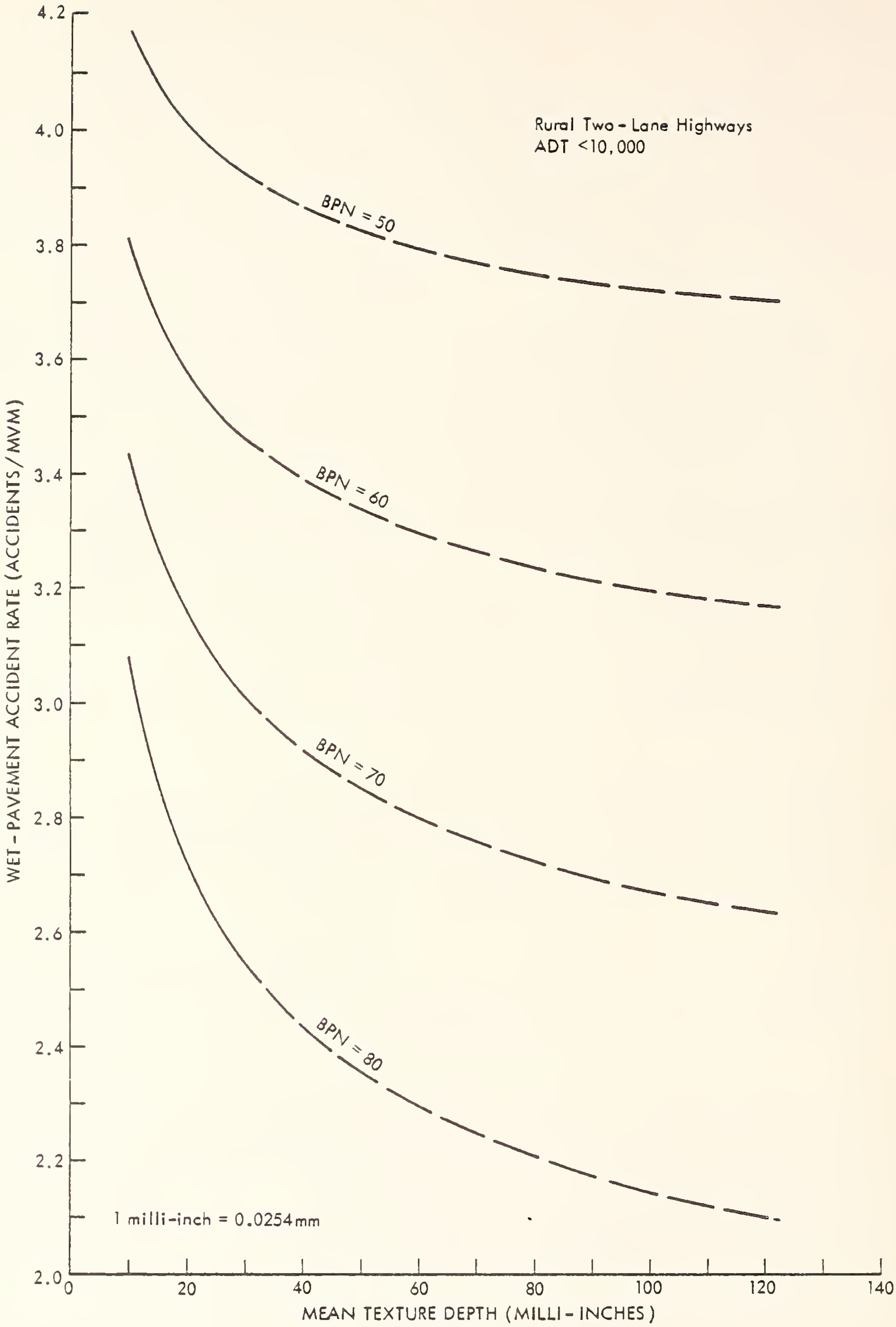

Figure 9 - Wet-Pavement Accident Rate as a Function of British Portable Number (BPN) and Mean Texture Depth for Rural Two-Lane Highways with ADT less than 10,000

Specific definitions of these variables are found in Appendix E. Each of these variables represents a geometric feature potentially related to the causation of wet-pavement accidents. Curves, grades, and intersections increase frictional demands and sag vertical curves can provide an opportunity for water to accumulate on the pavement. Two variables related to horizontal curvature were used because it was not clear a priori which would have the strongest relationship to accident rate.

Table 20 presents the simple correlation coefficients of these five geometric variables with wet-pavement accident rate, skid number, and with each other. Only the rural, two-lane, before data were used for this analysis so that these correlations would not be confounded with the effects of highway type and area type. The correlation between wet-pavement accident rate and each of the geometric variables is much smaller in magnitude than even the weak correlation between wet-pavement accident rate and skid number. Partial correlation coefficients computed for pairs of the seven variables, while controlling for the rest of the variables, were also extremely weak.

The next logical step in the analysis would be to conduct an analysis of covariance incorporating these geometric variables. However, these variables would surely be nonsignificant, because of their minimal correlation with wet-pavement accident rate. Therefore, the investigation of the influence of gross geometric measures on the accident rate-skid number relationship was terminated at this point.

K. Summary of Accident Rate-Skid Number Relationships Used in the Benefit-Cost Model

One important objective of the research in this contract was the development of a benefit cost-model to analyze wet-pavement accident countermeasures. Such a model has been developed and is described in detail in Volume II of this report. The accident rate-skid number relationships presented in this volume form the basis for predicting the effectiveness of resurfacing countermeasures in the benefit-cost model. This section summarizes the relationships that are used in the benefit-cost model.

The general form of the wet-pavement accident rate-skid number relationship presented in Section V-G is:

$$AR = AR_o + a_1 \; SN40$$

where AR = Wet-pavement accident rate (accidents/MVM).

AR_o = Zero-intercept accident rate (accidents/MVM) (a function of area type, highway type and ADT),

Table 20

SIMPLE CORRELATION COEFFICIENTS OF GEOMETRIC VARIABLES WITH ACCIDENT RATE AND SKID NUMBER FOR RURAL TWO-LANE HIGHWAYS

	AR	SN40	CURVSMIL	LENCURVS	SAGCRMIL	ACCPTMIL	GRADE
AR	+1.00000	-0.23075	+0.08397	-0.01900	+0.09719	+0.13712	-0.03743
SN40	-	+1.00000	-0.09844	+0.05251	+0.07924	-0.13496	+0.03523
CURVSMIL	-	-	+1.00000	-	-0.10405	+0.14311	+0.42658
LENCURVS	-	-	-	+1.00000	-0.08232	+0.01740	+0.23986
SAGCRMIL	-	-	-	-	+1.00000	-0.01132	-0.26156
ACCPTMIL	-	-	-	-	-	+1.00000	-0.02771
GRADE	-	-	-	-	-	-	+1.00000

Key:

AR = Wet-pavement accident rate (accidents/MVM)
SN40 = Skid number at 40 mph
CURVSMIL = Number of horizontal curves per mile
LENCURVS = Percent of microsection length on horizontal curves
SAGCRMIL = Number of sag vertical curves per mile
ACCPTMIL = Number of at-grade intersections per mile
GRADE = Percent of microsection length on significant grade

a_1 = Coefficient dependent on dry-pavement accident rate (defined by Figure 7),

and $SN40$ = Skid number at 40 mph.

This relationship is used in the benefit-cost model to predict the decrease (or increase) in accident rate corresponding to an improvement (or decrease) in skid number:

$$\Delta AR = AR_a - AR_b = a_1 \ (SN_a - SN_b)$$

where ΔAR = Change in wet-pavement accident rate (accidents/MVM),

AR_a = Wet-pavement accident rate after improvement (accidents/MVM),

AR_b = Wet-pavement accident rate before improvement (accidents/MVM),

SN_a = Skid number at 40 mph after improvement,

and SN_b = Skid number at 40 mph before improvement.

In the computerized benefit-cost model, the pavement skid number can change both due to resurfacing and due to a year-to-year degradation (or increase) in skid number. The benefit-cost model uses the above relationship to predict the change in accident rate for each year during the service life of each wet-pavement accident rate countermeasure. The benefit-cost model imposes one final constraint on the change in wet-pavement accident experience. The dry-pavement accident rate for a site serves as a lower bound on the wet-pavement accident rate; i.e., no wet-pavement accident countermeasure can reduce the wet-pavement accident rate to less than the dry-pavement accident rate. The changes in accident costs corresponding to the accident reduction estimates discussed above appear in the numerator of the benefit-cost ratio expression.

The computerized model provides the user an option to specify the skid resistance characteristics in terms of two pavement surface parameters: microtexture (represented by the British Portable Number) and macrotexture (represented by the mean texture depth). Under this option, the accident rate expression becomes:

$$AR = AR_o + a_1 \ (-31.0 + 1.38 \ BPN) e^{-0.041(40)(MD)^{-0.47}}$$

where BPN = British Portable Number, and

MD = Mean texture depth (milli-in.) as determined by the sand patch method.

The change in accident rate for a given change in microtexture and macrotexture is determined in a manner entirely analogous to the change in accident rate for a given change in skid number discussed above.

L. Predictive Accuracy of Accident Rate-Skid Number Relationships

The accident experience of a highway section is dependent on many factors, including the factors considered in this study: skid resistance, highway type, area type and ADT. Accident rates are known to be highly variable and difficult to predict even when several important factors are known. The three analyses of covariance calculations used to develop accident rate-skid number relationships in Section V-E have correlation coefficients (multiple r) ranging from 0.28 to 0.43 (see Tables 49, 50, and 51). This means that all of the independent variables included in these analyses explain only 8 to 18% of the variation of wet-pavement accident rates between sections for a 1-year period. The addition of relative dry-pavement accident rate in a subsequent analysis (Table 52) increased the correlation coefficient from 0.43 to 0.59, and the proportion of variation explained from 18 to 35%. Clearly, the usefulness of these relationships to predict the effect of a change of skid number on the wet-pavement accident rate for a given section in a given year is limited.

Two methods are available to reduce the variability of wet-pavement accident rate and, thereby, increase the reliability of the developed prediction relationships. The first method is to use the relationships to examine multi-year rather than 1-year periods for individual highway sections. The second is to examine the effect of a change in skid number for groups of similar highways rather than for individual highway sections.

Because wet-pavement accident rate is a random variable, the discrepancy between observed and predicted values is due to two sources: (1) variation of the AR itself, i.e., "sampling error," and (2) inaccurate and/or incomplete specification of the dependence of AR upon other factors, i.e., "lack of fit." The use of multi-year accident data would decrease the sampling error, but would not affect the lack of fit. The theoretical improvement in predictive accuracy due to decreased sampling error can be derived in the following manner.

Wet-pavement accident rate (AR) is calculated from three random variables: number of wet-pavement accidents (N), hours of exposure to wet-pavement conditions (E), and traffic volume (V). They are related as:

$$AR = k\left(\frac{N}{EV}\right) = k\left(\frac{N}{D}\right)$$

where D = EV, and K is a constant (= 24 x 10^6/section length as accident rate is defined in Section III-D).

The variance of AR (based on 1 year's data) can be expressed in terms of its component variances and covariances. The variance of the denominator is:

$$\sigma_D^2 = \sigma^2_E\mu^2_V + \sigma_V^2\mu_E^2 - 2\mu_E\mu_V\sigma_{EV}$$

where μ_i = mean of variable i ;

σ_i^2 = variance of variable i ; and

σ_{ij} = covariance of variables i and j .

Because it is reasonable to assume that σ_{EV} is zero, i.e., the exposure to wet-pavement conditions and the traffic volume at a site are not interdependent, the above relationship simplifies to:

$$\sigma_D^2 = \sigma_E^2\mu_V^2 + \sigma_V^2\mu_E^2$$

The variance of wet-pavement accident rate based on 1 year's data is:

$$\sigma_{AR}^2 = \left(\frac{\mu_N}{\mu_D}\right)^2\left(\frac{\sigma_n^2}{\mu_N^2} + \frac{\sigma_D^2}{\mu_D^2} - \frac{2\sigma_{ND}}{\mu_N\mu_D}\right)$$

If n years of data are used (rather than one), and E and V are normally distributed, then:

$$\sigma^2_{Dn} = \frac{1}{n}\left(\sigma_E^2\mu^2_V + \sigma_V^2\mu^2_E\right)$$

where the subscript n denotes n years of a data base (instead of 1 year). The 1/n reduction in σ_N^2 and σ_{ND}^2 will occur (assuming that N has a Poisson distribution).

Thus, in general, the variance of the wet-pavement accident rate based on n years of data is 1/n times the variance of the wet-pavement accident rate based on 1 year of data, i.e., $\sigma^2_{ARn} = \frac{1}{n}\sigma_{AR}^2$. This improves the standard deviation for wet-pavement accident rate by $1/\sqrt{n}$. However, this theoretical estimate may be too optimistic, because it regards the repeated years as replicated samples when, of course, fundamental conditions at the site might change in time.

The second method for obtaining more reliable predictions is to apply the relationships to groups of sections rather than to individual sections. A group of sections has a larger expected number of wet-pavement accidents than a single section. This should decrease the variance of wet-pavement accident rate even if only 1-year accident totals are available for each section in the group. Thus, the relationships as developed are more reliable for predicting accident-reduction benefits in a total skid-number improvement program than for use in evaluating individual projects.

M. Comparison of Results with Previous Work

The objective of the sequence of analyses was to establish relationships between wet-pavement accident rate and skid number. These basic relationships are presented in Table 14. As explained in Section V-C, the relationships developed are linear because no other simple function was found to produce a significantly better fit to the data. It was shown that the accident rate-skid number relationships have a common negative slope and that reasonably large changes in accident rate can result from the improvement of skid number. However, as pointed out in Section V-K, because of the high variability of accident rate these relationships are not very reliable for predicting the accident rate of any given section in any given year.

A series of studies on the accident rate-skid number relationship were conducted by the Kentucky Department of Transportation.[11-14] The objective of these studies was to develop an accident rate-skid number relationship for two-lane highways and for multilane controlled-access highways. Figures 10 and 11 illustrate the difference in the form of accident rate-skid number relationships developed herein and in the Kentucky studies. Figure 10 contains two linear accident rate-skid number relationships presented in Section V-E for rural multilane controlled access highways: one for highways with ADTs under 10,000 and one for highways with an ADT over 10,000. Figure 11 illustrates one of the nonlinear relationships developed in the Kentucky study for the same highway type and area type.

There were several differences between the way the data were defined here and in the Kentucky study. First, the Kentucky accident-rate measure used as the dependent variable did not include a factor for exposure to wet-pavement conditions. An estimated wet-pavement exposure for Kentucky was used to make the vertical scale of Figure 11 comparable to Figure 10. Weather data for the Greater Cincinnati Airport located in Boone County, Kentucky, indicate that highway pavements are wet 20% of the time. Second, skid number at 70 mph, rather than skid number at 40 mph, was used as the independent variable in the Kentucky study of multilane, uncontrolled-access highways. This makes direct comparisons between Figures 10 and 11 difficult. However, the skid number distributions from the two studies do have substantial overlap.

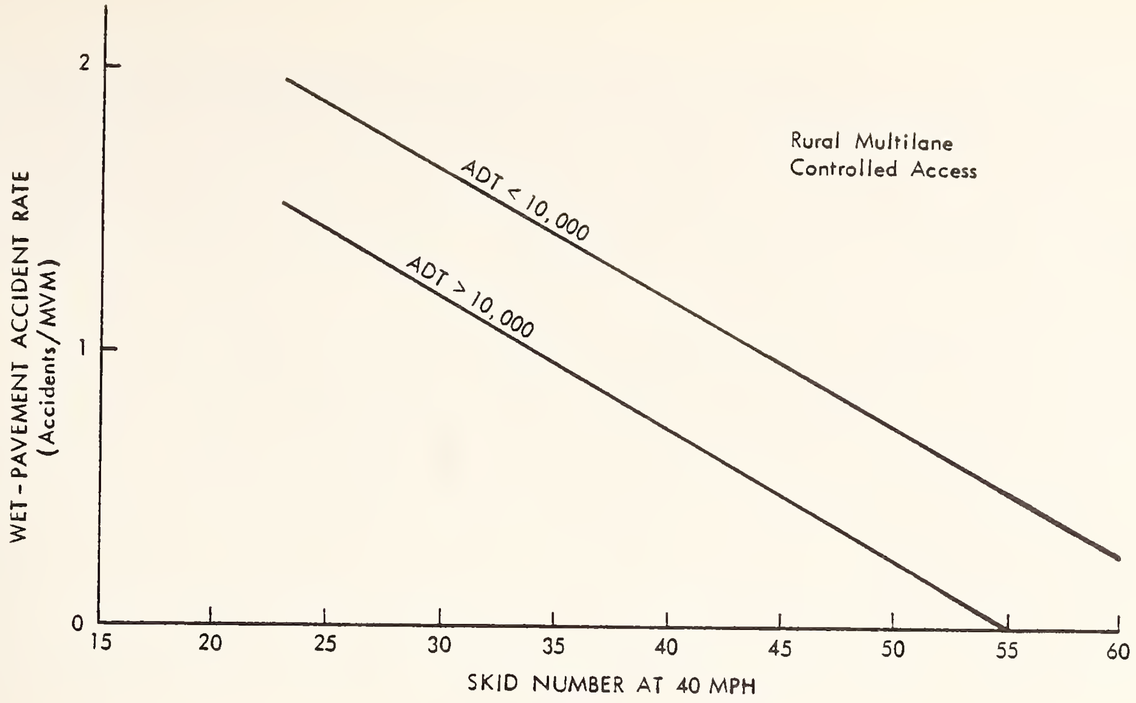

Figure 10 - Accident Rate-Skid Number Relationships Developed in Section V-E

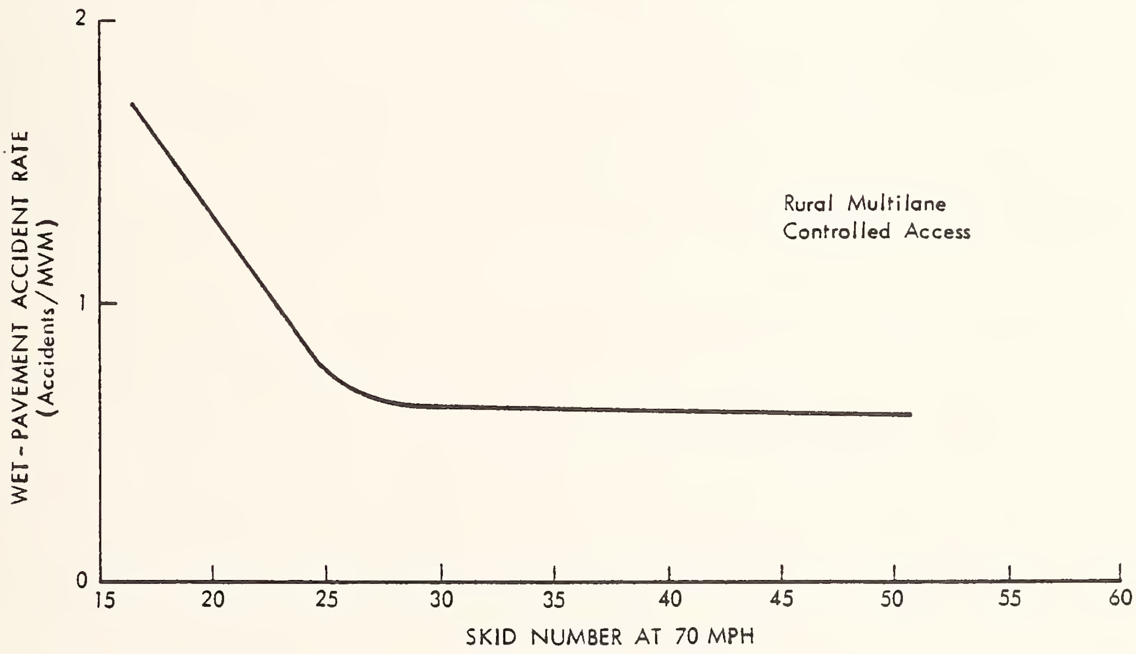

Figure 11 - Accident Rate-Skid Number Relationship from Kentucky Study 11/

The graphs in Figures 10 and 11 both have negative slopes and indicate a roughly comparable range of accident rates. The most obvious difference between the figures is the form of the accident rate-skid number relationship. The Kentucky study found a "critical skid number" in the wet-pavement accident rate-skid number curve. Above this skid number, the Kentucky curve has a very small slope; i.e., further improvement of skid number does not have much effect on accident rate. In contrast, the linear form developed herein has no "break-point" or point of diminishing returns beyond which an improvement of skid number no longer produces a comparable decrease in accident rate. The "critical skid number" found by the Kentucky study is within the range of skid numbers used to develop the linear relationship in Figure 10. The slope of this linear relationship is greater than the slope of the Kentucky curve in the region above the "critical skid number." Thus, these two studies appear to conflict on whether or not a "critical skid number" exists. If a "critical skid number" does exist, it is a logical minimum skid resistance requirement or, at least, a goal toward which pavements should be improved. If this point does not exist, as the results developed herein imply, then the skid number of every pavement should be as high as possible.

These contrasting results are not necessarily in conflict, because entirely different analysis approaches were used in this and the Kentucky study. The current study used a formal statistical analysis to develop an accident rate-skid number relationship. The analysis showed that a linear relationship was the "best" only in the sense that there was no other simple function that fit the data significantly better. The Kentucky study used curve-smoothing techniques, such as the moving-average method, to develop the relationship graphically. Curve-smoothing techniques are also useful for examining such relationships, but they should not be misinterpreted as representing the "best" statistical relationship between the variables.

The best interpretation of these contrasting results is simply that the variability of accident rate is so great and dependent on so many factors other than skid resistance that several interpretations of the accident rate-skid number relationship are possible. The current study and the Kentucky study do not conflict in the basic strategy that a reduction of wet-pavement accidents can be accomplished through improvement of skid number. Those sections with the lowest skid resistance and the highest accident rates should be improved first. Given the low levels of skid resistance in some states, the accident reduction return that is possible seems more likely to be limited by available funds and the characteristics of available aggregate than by a "break-point" in the accident rate-skid number curve, should it actually exist.

No influence on the accident rate-skid number relationship was detected for two factors related to pavement drainage: pavement texture and exposure to high-intensity rainfall. Some effect had been expected because previous research had found these factors to be related to accident experience. For example, a Louisiana study reported by Dart and Mann[15/] found that cross slope, another variable related to drainage, had an important effect on accident rate.

It was also expected that at least some of the geometric variables studied would be significant. Because horizontal curvature reduces the available traction margin, it was expected to affect the accident rate-skid number relationship. However, no correlation was found between accident rate and horizontal curvature variables. One of the Kentucky studies[12/] found that the wet-pavement accident rate-skid number relationship for U.S. numbered routes was sensitive to the density of access points. No similar result was found in the analysis presented in Section V-J for rural two-lane highways, in general. In evaluating the analysis of geometrics it should be kept in mind that this study examined only parameters describing the overall geometrics of highway sections several miles in length. It may be possible to identify a localized effect of geometric variables by examining the accident experience and skid number of individual geometric features.

VI. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn from the Phase I analysis:

1. There is a small, but statistically significant, inverse relationship between skid number and wet-pavement accident rate. However, the large variability of accident rate limits the usefulness of the relationship for predicting the accident rate for a given section for a given year.

2. The linear form for the wet-pavement accident rate-skid number relationship fits the data as well or better than any other simple function. Other research studies suggest the existence of a "critical skid number" or "break-point" in the accident rate-skid number relationship. No direct evidence of such a "break-point" was found in this study. Indirect evidence suggests that the relationship may be non-linear with a smaller slope at higher than at lower skid number.

3. Area type, highway type and ADT are factors with significant effects on the wet-pavement accident rate-skid number relationship. Predictive equations constructed from the analysis of covariance have a common slope, but a different intercept, in each cell defined by these factors.

4. The overall slope of the wet-pavement accident rate-skid number relationship is -0.046 accidents/MVM/SN40.

5. The slope of the wet-pavement accident rate-skid number relationship is greater at high than at low dry-pavement accident rate, at least for rural two-lane and multilane uncontrolled access highway sections. The sensitivity of the slope to dry-pavement accident rate has been quantified in a form suitable for use in the Phase II benefit-cost model. This sensitivity implies that the greatest accident reductions can be attained by increasing the skid number of highways with high accident rates under both wet and dry conditions.

6. The sensitivity of the slope of the wet-pavement accident rate-skid number relationship to dry-pavement accident rate suggests the importance of other factors related to accident causation, such as highway geometrics. However, no correlation was found between wet-pavement accident rate and several factors describing the overall geometrics of highway sections.

7. Resurfacing did not have a significant effect on the mean skid number of the test sections selected for this study. This finding was not unexpected since the test sections were not necessarily resurfaced because of low skid number.

8. No significant influence of pavement texture or exposure to high-intensity rainfall on the accident rate-skid number relationship could be detected. However, this finding is not conclusive because neither pavement texture nor exposure to high-intensity rainfall were measured directly in this study. A relationship between pavement texture and wet-pavement accident rate was developed indirectly by combining the results of this study with the results of recent work conducted at Penn State University. This indirect accident rate-texture relationship is considered to be less reliable than the accident rate-skid number relationship.

9. The predictive ability of the accident rate-skid number relationships developed in this project can be increased through the use of multi-year accident rates and by use of the relationships for groups of sections rather than for individual sections.

These conclusions have inherent recommendations which form the basis for future work. For example, the disappointingly low correlation found between geometric variables and accident rate for overall highway sections suggests a need to examine the effect of geometrics on the accident rate-skid number relationship for localized conditions. Also, further work could be directed towards investigating the form of the accident rate-skid number relationship to improve the amount of variation explained and to resolve the question of the existence of a "critical skid number." An initial step would be to find a suitable analytical form for the relationships developed in the Kentucky Studies[11-14] and to apply that form directly to the data base used for this study.

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APPENDIX A

SUMMARY OF ACCIDENT EXPERIENCE FOR STUDY SECTIONS

This Appendix summarizes the accident experience for the highway sections used in the statistical analyses to establish the accident rate--skid number relationships. The project data base included 428 highway sections with a total centerline length of 2,948 miles. The average section length was 6.9 miles. These sections experienced a total of 17,909 reported accidents in the 1-year before period. A summary of these accidents, classified by area type, highway type and pavement condition, is given in Table 21.

Accident data for the after period were available for only 378 of the 428 study sections. The sections included in the after period data base have a total centerline length of 2,557 miles. These sections experienced a total of 16,062 reported accidents in the 1-year after period. A summary of these accidents is given in Table 22.

Of the 33,971 accidents included in the project data base for both the before and after periods, 8,076 accidents (23.8%) occurred under wet-pavement conditions, 23,385 accidents (68.8%) occurred under dry-pavement conditions and 2,510 accidents (7.4%) occurred under ice and snow-pavement conditions.

TABLE 21

SUMMARY OF ACCIDENT EXPERIENCE IN 1-YEAR BEFORE PERIOD

Area Type	Highway Type	Number of Study Sections	Total Length (miles)	Total Number of Accidents: Wet-Pavement Conditions	Dry-Pavement Conditions	Ice and Snow-Pavement Conditions	All Pavement Conditions
Rural	Two-lane	275	2,058.18	1,618	4,643	471	6,732
Rural	Multilane uncontrolled access	50	275.13	536	1,755	104	2,395
Rural	Multilane controlled access	53	419.81	456	1,355	271	2,082
RURAL TOTALS		378	2,753.12	2,610	7,753	846	11,209
Urban	Two-lane	18	74.90	183	454	31	668
Urban	Multilane uncontrolled access	18	68.60	1,206	3,162	266	4,634
Urban	Multilane controlled access	14	51.40	439	840	119	1,398
URBAN TOTALS		50	194.90	1,828	4,456	416	6,700
COMBINED TOTALS		428	2,948.02	4,438	12,209	1,262	17,909

TABLE 22

SUMMARY OF ACCIDENT EXPERIENCE IN 1-YEAR AFTER PERIOD

Area Type	Highway Type	Number of Study Sections	Total Length (miles)	Total Number of Accidents: Wet-Pavement Conditions	Dry-Pavement Conditions	Ice and Snow-Pavement Conditions	All Pavement Conditions
Rural	Two-lane	243	1,772.46	1,271	4,248	539	6,058
Rural	Multilane uncontrolled access	47	264.42	435	1,588	96	2,119
Rural	Multilane controlled access	44	347.67	195	919	204	1,318
RURAL TOTALS		334	2,384.55	1,901	6,755	839	9,495
Urban	Two-lane	14	54.96	172	492	53	717
Urban	Multilane uncontrolled access	16	65.62	1,153	3,122	269	4,544
Urban	Multilane controlled access	14	51.40	412	807	87	1,306
URBAN TOTALS		44	171.98	1,737	4,421	409	6,567
COMBINED TOTALS		378	2,556.53	3,638	11,176	1,248	16,062

APPENDIX B

FIELD INVENTORY DETAILS

This appendix describes the data elements recorded during the field inventory. These are recorded on special forms, which are shown in Appendix A. The procedures are similar but not identical for two-lane, multilane uncontrolled access, and multilane controlled access highways, but are discussed separately for clarity. First, however, basic information on specifying position and on record keeping is presented.

A. Odometer Mileages

The locations of all observations made in the field inventory are indicated by mileage measured by the fifth-wheel odometer. On all highway sections to be inventoried observations are made while traveling in both directions. The direction in which the first pass over a section is made is arbitrarily designated the forward direction. This direction (north, south, east or west) is recorded on the Cover Sheet. The odometer is started from zero at the beginning of the section. A reference point at which to stop the odometer is selected at the end of the run. This reference point can be the end of the section if this is a point identifiable in both directions of travel. The reference point location and mileage is recorded on the Cover Sheet.

An initial setting is placed on the odometer for the run in the reverse direction. The value of this initial setting is the difference between 1.0 and the decimal portion of the reference point mileage. For example, if the reference point mileage is 4.35, the initial setting would be 1.0 - 0.35 = 0.65. The odometer can then be restarted at the reference point for the run in the reverse direction.

The purpose of the reference point is to establish a correspondence between the odometer mileages in the two directions of travel. If the two roadways of a divided highway have completely independent alignments, which would destroy this correspondence between odometer mileages, this fact is noted in the space provided on the Cover Sheet for comments.

B. Record Keeping

The Cover Sheet is completed for each section. It is titled, "Skid Reduction Field Inventory."

Each additional sheet has a six character identification block which is completed.

STATE		SECTION			DIR
1	2	3	4	5	6

1-2: Two letter code for state name
3: T or C for Test or Control
4-5: Macrosection Number (i.e., 01, 03, 17, etc.)
6: F or R for Forward or Reverse Direction

In addition, the page number of each sheet and the total number of pages of that sheet in a given direction is recorded. It is helpful if the mile number is noted in front of ".00" in the upper left hand corner of each sheet.

C. Two-Lane Highways

On two-lane highways, as well as on multilane highways, either a three- or four-man crew may be used. The positions of the crew members in the van are shown in Figure 12. The tasks of each person (other than the driver) in three- and four-man crews are given below:

3-Man Crew

Direction	Observer No. 1	Observer No. 2
F	Sheet I	Altimeter
R	Sheet I	Sheet II
F	Sheet III	Photos
R		Curves

4-Man Crew

Direction	Observer No. 1	Observer No. 2	Observer No. 3
F	Sheet III	Sheet II	Sheet I
R	Photos	Altimeter	Sheet I
F		Curves	

Item definitions for the sheets used on two-lane highways are described next.

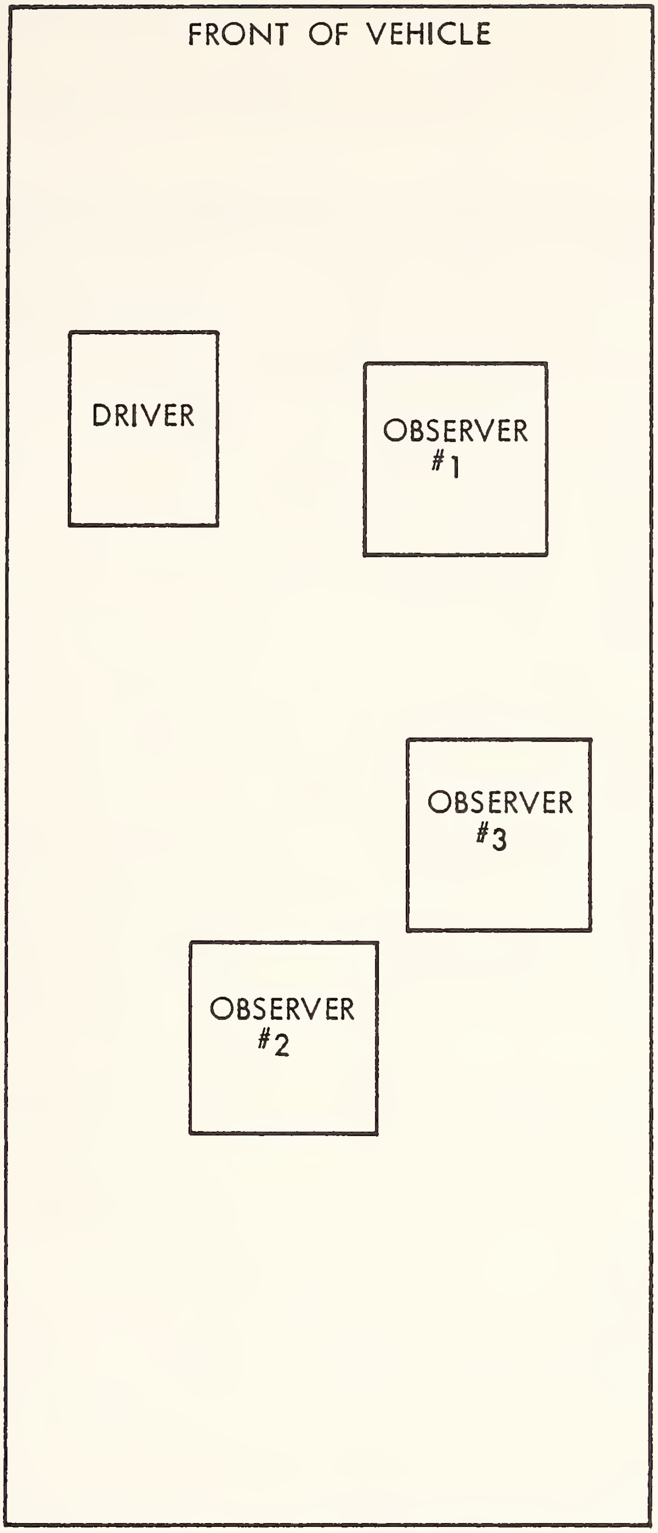


Figure 12 - Positions of Crew Members in the Survey Vehicle

1. Sheet I

Sheet I is recorded in both directions. The entries are:

Item B - Special Lanes. Special lanes which are not associated with intersection channelization (see Column N) are recorded in Column B. Examples of this type of lane are auxiliary lanes, breakdown lanes for disabled vehicles, and climbing lanes on steep grades. This column is for lanes which clearly do not alter the basic number of lanes of the highway. A change in the basic number of lanes is a change in Highway Type and would be recorded in Column S. The codes are:

A - Start of auxiliary lane
B - Start of breakdown lane
C - Start of climbing lane
R - Start of reversible lane
E - End of lane

Item I - Embankment Requiring Guardrail. The longitudinal extent of embankments on the right side of the roadway that might require guardrail but do not have guardrail is recorded. The judged extent of damage of a vehicle that runs off the road is the guiding criteria for recording this item. If, at the most severe point of the embankment, it is possible that a car and driver would suffer greater damage by running onto the embankment than by hitting a guardrail, a "1" is coded at the start of the line showing the extent of the embankment. If the damage would probably be greater, a "2" is coded and if it definitely would be greater, a "3" is coded in the column.

Item W - Shoulder. The type and width of shoulder is recorded at the beginning of each section and at points of change. It is coded as

P - Paved	+ - Over 6 ft
U - Unpaved	- - 6 ft or under

For example, a paved shoulder less than 6 ft wide would be coded P^-.

Item X - Curb. Curb (no median) is coded as follows:

B - Start barrier curb
M - Start mountable curb
E - End of curb

Item D - Drives. The number of driveways in each of the different categories are recorded for a 1/2 mile interval. The code "I" is recorded for each industrial drive, "C" for each commercial drive and a check mark is made for each residential drive.

Item E - Roadside Obstacles. The number of roadside obstacles in each 1/2 mile interval is recorded. For two-lane highways only roadside obstacles within 10 ft of the traveled way are recorded. Structures, supports, etc., made of timber with a side or diameter of 6 in. or more, or made of nonbreakaway steel or concrete with a side or diameter of 3 in. or more, are classified as obstacles. Other features such as trees and rock cuts are also recorded as obstacles. A simple check mark is made for each obstacle noted. Guardrail and bridge rail are not counted as obstacles because the longitudinal extent of these features is recorded separately. Objects behind guardrail are not counted because vehicles are protected from striking them. Signposts which meet the criteria for roadside obstacles are recorded. Culverts with headwalls are recorded as roadside obstacles using the code, C.

2. Sheet II

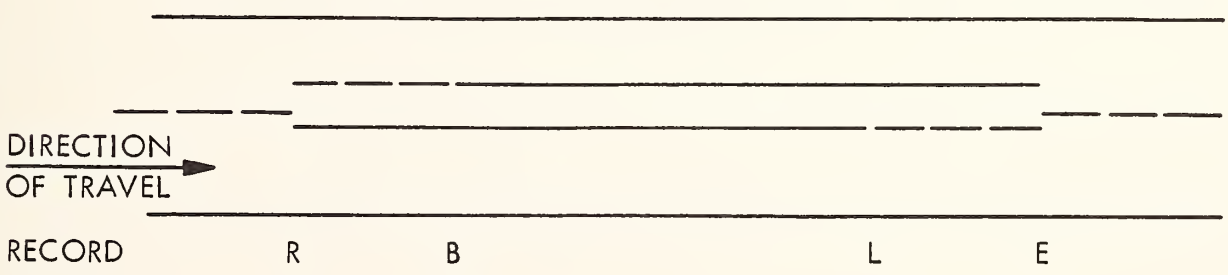
Sheet II is recorded in one direction only. The items are:

Item A - No-Passing Zones. The points of change in no-passing restrictions are recorded as striped on the roadway. If the highway does not have a painted centerline, no entries are made in Column A unless the no-passing restriction is conveyed to the driver by some other means, such as a "Do Not Pass" sign.

The codes used are as follows:

B - Beginning of no passing in both directions
R - Beginning of no passing on right side
L - Beginning of no passing on left side
E - End of no-passing restriction

Because the recorder is concentrating his attention on roadside features, the driver calls off the no-passing codes. An example of the codes is shown below.



Item H - Guardrail. The locations where guardrail begins and ends on each side of the roadway are recorded in a manner similar to that used for no-passing zones. On two-lane highways guardrail is recorded in one direction only. The codes are as follows:

B - Beginning of guardrail on both sides of the roadway
R - Beginning of guardrail on the right side of the roadway
L - Beginning of guardrail on the left side of the roadway
E - End of guardrail section

Item S - Highway Type. Highway type is recorded at the beginning of the section and at each point of change. The number of lanes (both directions) is recorded as well as: D - divided; U - undivided; or CA - controlled access, when each code applies. Examples are 2U, 4U, 4D, and 4DCA.

Item T - Pavement Type. This is recorded at the beginning of the section and at points of change. The codes are:

A - Asphalt concrete
P - Portland cement concrete

Item U - Legal Speed Limit. The legal speed limit is recorded at the beginning of the section and at points of change.

Item V - Advisory Speed Limit. The advisory speed limit is recorded when posted on warning signs at features such as curves.

Item Y - Lane Width. Lane width is recorded at the beginning of the section and at points of change. Codes are:

1 - under 10 ft
2 - 10 ft and 11 ft
3 - 12 ft or over

Item K - Pedestrian Cross Walk. The number of marked pedestrian crosswalks in each half mile is recorded. This information is recorded in one direction only.

3. Sheet III

Sheet III is recorded in one direction only. Thus, items such as location and intersection type apply to both sides of the road.

Location. For future reference in subdividing sections and requesting accident data, the names of streets, county lines and marked mile posts are noted. This information will probably not need to be key-punched. It is important that the locations recorded be legible and spelled properly.

Item L - Intersection Type. A major intersection is one which has control on the inventoried highway which can require vehicles to stop (stop sign, signals). The geometry of major intersections is recorded in Column L.

Minor and intermediate intersections have no control requiring a stop on the inventoried highway. An intermediate intersection is one for which a feature such as a caution flasher, intersection geometry or observed traffic volume indicate that it is an important or high accident intersection. An intermediate intersection is simply coded as such but no record of geometry, channelization or control is made. All intersections not classified as major or intermediate are minor. The codes used in Column L are as follows:

0 - minor intersection
1 - intermediate intersection
2 - right T or Y, major intersection
3 - left T or Y, major intersection
4 - four way, major intersection
5 - offset, major intersection
6 - other, major intersection

Item M - Intersection Control. This item is recorded for major intersections only. The codes are:

1 - two-way stop
2 - four-way stop
3 - signals

Item N - Intersection Channelization. This item is recorded for major intersections only. The codes are:

0 - no channelization
1 - right-turn bay
2 - left-turn bay
3 - right- and left-turn bays
4 - islands and medians
5 - other

Item O - Bridge. A bridge is defined as any structure on the inventory route which has a deck (clear span) and railing, irrespective of the object crossed. Culverts, with or without headwalls, are not classified as bridges. The location of the beginning of a bridge is coded B and the location of the end is coded E. The code BE in a single box indicates a bridge which begins and ends within the 0.05 mile interval.

Item P - Railroad Crossing. At-grade railroad crossings are coded as follows:

1 - sign controlled
2 - signal controlled
3 - gate controlled

4. Pavement Macrotexture Photographic Log

On two-lane highways, macrotexture photographs are taken in one direction only. Mileage where the photograph is taken is recorded to the nearest 0.01 mile. The frame number is recorded from the camera frame counter. Approximately five pictures are taken per mile. The lane will almost always be the right hand lane but is noted if for some reason it is not. The pictures are always assumed to be in the left wheel track of the recorded lane. Type of location is recorded as "T" for tangent section, "C" for curve section and "I" for approaches to major intersections. The last column in each row is reserved for recording the results of the photographic interpretation and is left blank in the field.

5. Altimeter Sheet

On two-lane highways the altimeter is read in one direction only. Vehicle windows should be opened slightly and this fact should be recorded. Other information recorded in the appropriate blanks are the air conditioning and fan status (on or off) and the outside temperature. Elevations are recorded in the appropriate blanks on the sheet. They are recorded every 0.2 mile, to the nearest 5 ft above sea level. If a section is more than 20 miles long, two sheets will be required.

6. Curve Data

Each horizontal line on the curve data form represents one curve. For each curve the direction of curve (R or L) is recorded. On the approach to a curve, the azimuth of the back tangent is recorded. The odometer mileage is recorded at the apparent point of curvature (PC) to the nearest 0.01 mile. At a point near the center of the curve, the accelerometer (a U-tube manometer is in use at present) is read. The observer chooses the point where the reading seems most steady, indicating constant lateral g forces. The speed of the vehicle (at the instant the inclinometer is read) is recorded from the fifth-wheel speedometer. The odometer mileage at the apparent point of tangency (PT) is recorded to the nearest 0.01 mile. The azimuth of the forward tangent is recorded after leaving the curve.

Data are recorded for all curves for which the gyrocompass shows a significant change in heading (i.e., above a 1 degree or 2 degree change which can occur due to steering corrections on a tangent section).

D. Multilane Highway with Uncontrolled Access

The tasks of each person in three- or four-man crews are shown below:

3-Man Crew

Direction	Observer No. 1	Observer No. 2
F	Sheet I	Sheet II
R	Sheet I	Sheet II
F	Sheet III	Altimeter
R	Photos	Curves
F	Photos	Curves*
R*		Altimeter*

4-Man Crew

Direction	Observer No. 1	Observer No. 2	Observer No. 3
F	Sheet III	Sheet I	Sheet II
R	Photos	Sheet I	Sheet II
F	Photos	Curves	Altimeter
R*	Altimeter*	Curves*	

---

* May be required in some cases, if alignments in two directions differ.

1. Sheet I

Sheet I is completed in both directions. Data items are:

Item A - Lane Width. Same as for two-lane highways.

Item B - Legal Speed Limit. Same as for two-lane highways except to record a change in highway type in Column G.

Item C - Advisory Speed Limit. Same as for two-lane highways.

Item D - Special Lanes. Same as for two-lane highways.

Item W - Guardrail. On multilane highways, the presence of guardrail is recorded in both directions. The codes for recording the beginning and end of guardrail sections are as follows:

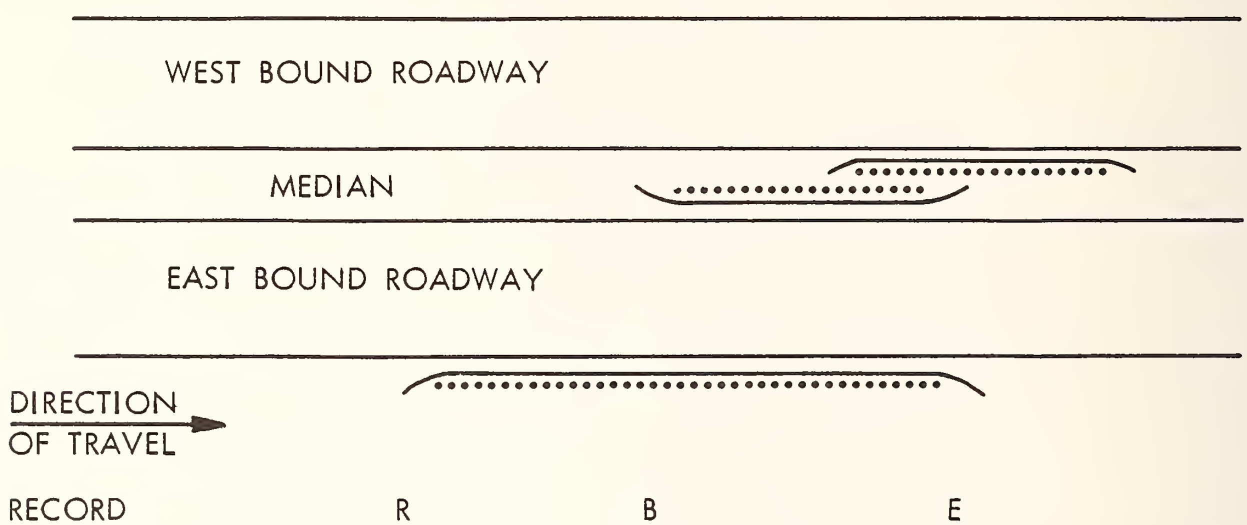
B - Beginning of guardrail on both the right-hand side of the roadway and in the median.

R - Beginning of guardrail on the right-hand side of the roadway only.

L - Beginning of guardrail in the median of the roadway only.

E - End of guardrail section.

If the highway is not divided, only the right-hand side of the roadway is recorded in both directions. The presence of guardrail in medians is recorded only if it is protecting vehicles that are traveling in the same direction as the survey vehicle. Examples of the use of the codes are shown below:



Item X - Embankment Requiring Guardrail. Same as for two-lane roadways.

Item E - Roadside Obstacles. Same as for two-lane roadways.

Item Y - Pedestrian Crosswalks. The number of marked pedestrian crosswalks in each half-mile is recorded. This information can normally be recorded in one direction only.

2. Sheet II

Sheet II is recorded in both directions. The items are:

Item G - Highway Type. Same as for two-lane highways.

Item H - Pavement Type. Same as for two-lane highways.

Item K - Shoulder. Same as for two-lane highways.

Item L - Curb (not median). Same as for two-lane highways.

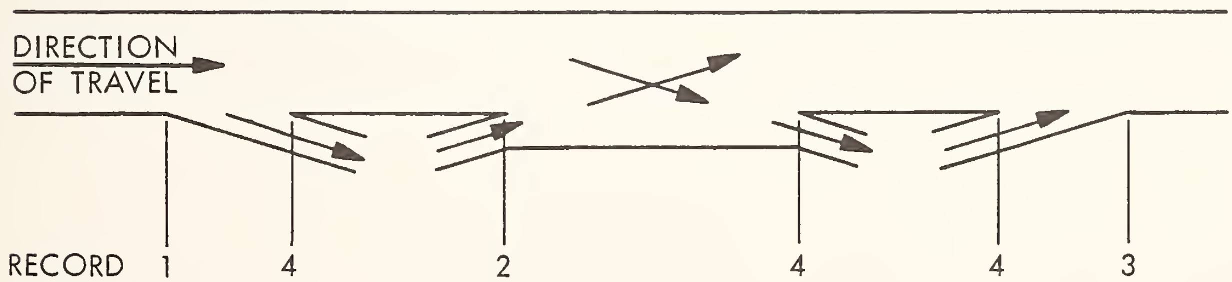
Item O - Interchange Type. The type of interchange can be recorded anywhere between the start of the deceleration lane and the end of the acceleration lane. Interchanges are recorded as one of six basic types. The codes used are as follows:

FC - full cloverleaf
PC - partial cloverleaf
T - T or trumpet
FD - full diamond
HD - half diamond
D - directional
O - other

Item P - Interchange Ramp Length. The locations of ramp features are recorded as follows:

1 - start of deceleration lane
2 - start of acceleration-deceleration lane
3 - end of acceleration lane
4 - gore or merging point

For example, the features of a typical cloverleaf interchange are recorded as shown below.



Item N - Drive. Same as for two-lane highways

3. Sheet III

Sheet III is recorded in one direction only. The items are:

Item Q - Intersection Type. Same as for two-lane highways.

Item R - Intersection Control. Same as for two-lane highways.

Item S - Intersection Channelization. Same as for two-lane highways.

Item T - Railroad Crossing. Same as for two-lane highways.

Item U - Bridge. Same as for two-lane highways.

Location. Same as for two-lane highways.

Item I - Median Type. The types of median, if present, are recorded at the beginning of the section and at points of change. Median types are coded as follows:

P - paved,
U - unpaved
C - curbed
B - barrier

Examples are P, PC, and UCB.

Item J - Median Width. The width of the median is recorded at the beginning of the section and at points where the width changes from one category to another. The categories of median width are recorded as follows:

1 - under 10 ft
2 - 10 ft to 30 ft
3 - over 30 ft

Item Z - Median Openings. The number of median openings in each half mile of roadway is recorded. Major intersections are assumed to have median openings and are therefore not included under this item. Median openings are recorded when they occur at minor or intermediate intersections, drives, or turnarounds.

4. Curve Data Sheet, Photographic Log and Altimeter Sheet

The Curve Data Sheet is completed in the same way as for two-lane highways. However, on divided highways if the roadways do not have similar horizontal curves, the curve data are taken in both directions.

On multilane highways photographs are taken in both directions. In the lane column a notation should be made such as "R" for the right lane, "L" for left lane, "C" for center lane, etc. All pictures are taken in the left wheel track of the designated lane.

The altimeter sheet is filled out in the same manner as for two-lane highways. If the two roadways of a divided highway have significantly different grades, the altimeter data are collected in both directions.

E. Controlled Access Highways

The tasks of each person in three- or four-man crews are shown below.*

3-Man Crew

Direction	Observer No. 1	Observer No. 2
F	Sheet I	Photos
R	Sheet I	Photos
F	Sheet II	Altimeter
R	Sheet II	Curves

4-Man Crew

Direction	Observer No. 1	Observer No. 2	Observer No. 3
F	Sheet II	Photos	Sheet I
R	Sheet II	Photos	Sheet I
F	Altimeter	Curves	

---

* An additional pass may be required to record altimeter or curve data if the roadway alignments in the two directions are dissimilar.

1. Sheet I

Sheet I is recorded in both directions. Items are:

Item E - Curb (not median). Same as for two-lane highways.

Item F - Lane Width. Same as for two-lane highways.

Item B - Guardrail. Same as for multilane highways with uncontrolled access.

Item C - Embankment Requiring Guardrail. Same as for two-lane highways.

Item G - Median Type. Same as for multilane highways with uncontrolled access.

Item H - Median Width. Same as for multilane highways with uncontrolled access.

Item I - Median Opening. This item is completed as for multilane highways with uncontrolled access, and can normally be done in one direction only.

Item K - Roadside Obstacles. The criteria for recording the number of roadside obstacles are the same as that for two-lane highways. However, on controlled access highways all obstacles within 30 ft of the traveled way are recorded.

2. Sheet II

Sheet II is recorded in both directions. Items are:

Item L - Special Lanes. Lanes that are used for special purposes and which do not alter the basic number of lanes in the highway type column are recorded. Codes used are as follows:

A - start of auxiliary lane
B - start of breakdown lane
C - start of climbing lane
R - start of reversible lane
E - end of lane

Item M - Interchange Type. Same as for multilane highways with uncontrolled access.

Item N - Interchange Ramp Length. Same as for multilane highways with uncontrolled access.

Item O - Overpass. The location of overpasses are recorded by placing a check mark in this column.

Item P - Bridge. Same as for two-lane highways.

Item Q - Highway Type. Same as for two-lane highways.

Item R - Pavement Type. Same as for two-lane highways.

Item S - Shoulder. Same as for two-lane highways.

Item T - Legal Speed Limit. Same as for two-lane highways.

Item U - Advisory Speed Limit. Same as for two-lane highways.

Location. Same as for two-lane highways.

3. Other Sheets

On controlled access highways, the Altimeter Sheet, Photographic Log and Curve Data Sheet are completed in the same way as on multilane uncontrolled access highways. There is no Sheet III for this highway type.

APPENDIX C

DEVELOPMENT OF A PHOTOGRAPHIC TECHNIQUE TO ESTIMATE SKID NUMBER-SPEED GRADIENTS OF PAVEMENTS

A. Overview

This Appendix describes the development of a technique to estimate the rate of change of skid number with speed, the skid number-speed gradient, from photographs of a pavement surface taken from a moving vehicle.

The skid number is typically measured at 40 mph. However, skid number at a higher speed, closer to the speeds at which most skidding accidents occur, was postulated to be more closely related to accidents.

The most obvious way to obtain the skid number at a speed higher than 40 mph is to conduct skid tests at the desired speed. However, because of safety considerations and the added expense of skid testing at multiple speeds, most states are reluctant to conduct high-speed skid tests. Another method to obtain the skid number at a speed greater than 40 mph is to measure the skid number at 40 mph and estimate the skid number-speed gradient; i.e., the rate of change of skid number with speed. This rate is negative, because skid number decreases as speed increases. It is conventional to define the gradient as a positive number by taking the negative of the slope of the skid number-speed curve. For this study, the gradient was defined as:

$$SNG = - \frac{SN40 - SN60}{(40 - 60)}$$

where SN40 = skid number at 40 mph,

SN60 = skid number at 60 mph, and

SNG = skid number-speed gradient (SN/mph).

This form of the skid number-speed gradient is most appropriate for adjusting skid numbers measured at 40 mph to a higher speed.

After a review was made of previous work on the estimation of skid number-speed gradient, discussed in Section B of this Appendix, it was decided that the development of a photographic estimation technique had the highest probability of success. The photographic system which was developed is described in Section C. Section D describes the preliminary analysis of the pavement photographs that were obtained. This analysis showed that it was infeasible to estimate the skid-number speed gradient by direct measurement of mean widths of pavement surface voids from the photographs. Instead, a subjective rating system, described in Section E, was developed, validated, and then used to interpret about 32,000 pavement photographs collected from a moving vehicle during the field inventory.

B. Previous Work

Several research projects have been directed toward alternate methods of determining the skid number - speed gradient of selected pavements. The most productive study was done by Schulze and Beckmann.[2] They found that the skid number gradient from 12 to 37 mph (20 to 60 km/hr) was correlated with the mean width of surface voids. The larger void width produces a flatter speed gradient, caused primarily by the better drainage of the water.

The method for obtaining the mean void width was described by Schulze.[3] Stereo photographs were taken of pavement sections and magnified 25 to 1. The outline of each individual void was then traced onto paper and the width of each void measured. Needless to say, this procedure would be overwhelmingly expensive for any major speed gradient inventory.

Gillespie[4] found mean void widths from pavement profile traces obtained with an electromechanical roughness meter. The mean void width was defined as the mean distance between peaks on the trace. When mean void width was compared to the known skid number - speed gradient from 37 to 50 mph (60 to 80 km/hr) for the pavement, the comparision with the extrapolated Schulze and Beckmann curve was excellent.

Goodman[5] developed several techniques for pavement texture measurement from a moving vehicle, although his validation was limited to stationary, laboratory studies. One proposed technique involved photography. A narrow slit of light was projected vertically onto the surface of the pavement and the resulting line was photographed from an angle of 30 degrees to horizontal. In the resulting photograph, the strip of light delineated very well the peaks and valleys along the strip. The number of peaks/inch (inverse of mean void width) from the photographic technique agreed well with the results from an electromechanical roughness meter applied to the same strip of pavement.

Howerter and Rudd[16] have developed a highly sophisticated technique that utilizes stereo photography and computer interpretation to obtain skid resistance parameters. However, the technique in its present form would be quite expensive for large pavement inventory projects.

In summary, Schulze and Beckmann have determined the relationship between mean void width and skid number - speed gradient from 12 to 37 mph (20 to 60 km/hr). Gillespie found that when mean void width is defined as the inverse of peaks/inch, the same relationship exists between mean void width and skid number - speed gradient from 37 to 50 mph (60 to 80 km/hr). Goodman found that a photographic technique can be utilized to determine the number of peaks/inch.

After a thorough review of the literature, we elected to obtain the pavement surface texture data photographically. A photographic approach appeared to offer the highest probability of success because liberal use could be made of "off the shelf" components.

The photographic technique developed for estimating skid number-speed gradient of pavements is described in this Appendix. The technique draws on all of the cited previous work.

C. Photographic Equipment and Testing

Photographs of pavement surfaces were made from a moving Ford Econoline E-200 van at the same time other highway inventory data were being collected. Approximately four photographs/mile were taken of the left wheel track area, where most pavement skid number data are measured. The data were taken while moving at 40 mph because it was impractical to consider stopping the van on the highway.

1. Equipment

A sketch of the photographic equipment configuration is shown in Figure 13. It consists of three parts: a projection system, a camera system and a light shroud and an auxiliary equipment package.*

a. Projection system: The projection system projects a high-intensity, short-duration shadow-bar pattern on the pavement surface. The projected pattern is approximately 6 in. sq and consists of alternate bands of shadow and light approximately 1/4 in. wide. The shadow-bar pattern was projected onto the pavement at a 20 degree angle with the horizontal. This low-incidence light served to delineate the roughness of the pavement. On a smooth surface the interface between a band of light and dark was essentially straight. The rougher the surface, the more crooked the interface line became because of the shadows cast by the peaks in the surface.

(1) Light source: A high-intensity, short-duration light source was needed to "stop" the motion of the pavement relative to the camera. The light source used was an EG and G Model 549 Microflash system composed of a driver unit and a flash unit. The Model 549 has a flash duration of 1/2 to 1 μsec and peak light output of approximately 50 million candlepower. It was selected on the basis of normal photographic considerations.

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* The auxiliary equipment package is not shown in Figure 13.

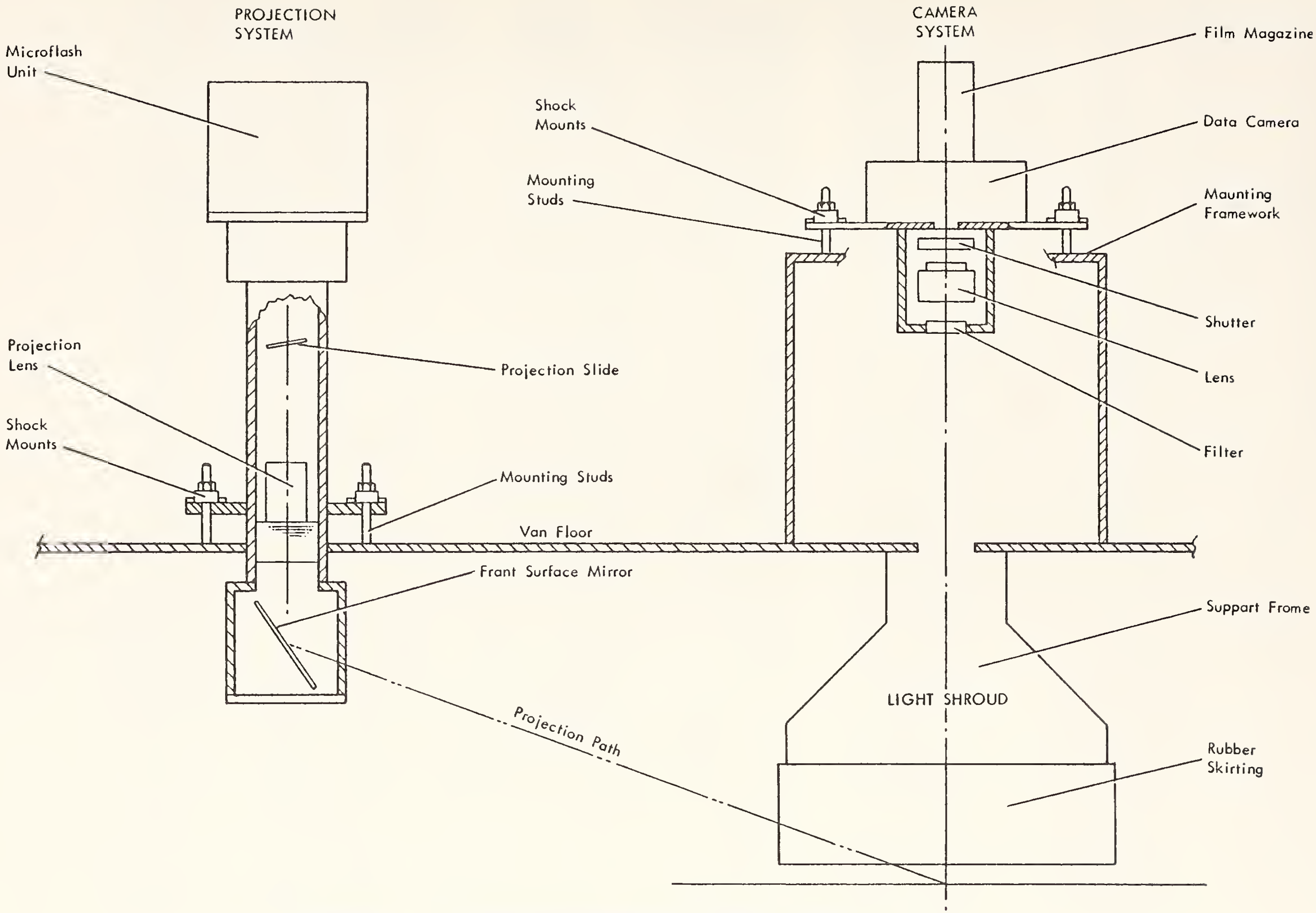

Figure 13 - Principal Components of Photographic System

(2) Projection lens: A 9-in. f/2.5 projection lens was used. Several lenses were tested in laboratory prototypes and the final selection was made on the basis of capability to utilize the light available from the microflash source.

(3) Mirror: A front surface mirror was used to turn the projected light path. It was hoped that a mirror would not be required but the shallow incidence angle, coupled with the height of the van, made a direct path projection impractical. Use of the mirror permits the projector to be installed in the vertical position which is convenient for mounting and alignment adjustment.

(4) Projection slide: The projection slide was a photographic glass plate with sharp-edged opaque bars to generate the shadow pattern. The shadow-bar pattern measures 24 x 36 mm on the slide. The slide was positioned at an angle with the projector axis so that as the van moved up and down in normal roadway driving, the center of the projected pattern remained in focus even though the optical path length changed.

(5) Enclosure and mounting: The projector enclosure was generally tubular for convenience of fabrication. The mirror compartment was rectangular and completely sealed to minimize the possibility of moisture condensation on the reflecting surface. A flange was provided on the projector tube for mounting to the van floor. Mounting was made through a set of four Lordco shock mounts. The shock mounts effectively isolated the projector components from potentially destructive road and engine vibrations. Threaded studs extending through the mounts and fitted with positioning nuts provided convenient attachment and alignment capability. A 6-in. diameter hole cut in the floor of the van allowed the end of the projector (primarily the mirror compartment) to ride in position below floor level.

b. Camera system: A camera system was needed with adequate format to portray salient surface texture features and durability to withstand 60,000 miles of travel in the van. A system was selected composed of a 35-mm data camera and magazine, a 105-mm lens, an electromechanical shutter, appropriate film and a combination housing and mounting structure.

(1) Camera and magazine: The camera used was a 35-mm Fairchild Radarscope camera with 100-ft film magazine, built-in data chamber and electrical pulse operated film advance. This equipment was selected because it is inexpensive, rugged and provided a suitable format including the convenient data chamber.

The camera and magazine were purchased from government surplus and required minimum modification. The internal wiring of the camera was changed slightly to facilitate automatic film advancing and the internal shutter was removed. A microswitch was mounted in the film magazine to sense mechanism movement and was wired to turn on a "film advanced" indicator lamp.

(2) Shutter: An external electromechanical shutter system was fitted to the camera consisting of a Uniblitz Model 155 shutter and remote drive. The camera's internal shutter was not used because the mechanism was complex and delicate and had a short life expectancy. The electromechanical shutter was simple, lightweight and had a rated life in excess of 1/2 million operations.

(3) Camera lens: A Bellows-Nikkar 105-mm, f/4 lens was used. This high-quality lens was well adapted to our application. The 105-mm focal length was selected because it positioned the camera conveniently about 18 in. above the van floor.

(4) Film: The illumination conditions (high intensity but very short duration) necessitated the use of a fast film. Eastman type 2475, 35-mm, black and white, estar base recording film, processed to ASA 5000 was used. Slower films were demonstrated to be inadequate in laboratory tests.

(5) Housing and mounting: A housing was fabricated for the lens, shutter and a photographic filter. The housing was designed to totally enclose the lens and shutter to keep them clean and in good operating condition and to minimize the likelihood of accidental damage.

A flat aluminum plate with appropriate cutouts was mounted on a framework attached to the van floor. The camera was fastened facedown to the top of the plate and the lens/shutter housing was attached to the underside of the plate. This arrangement was chosen because it provides vibration isolation and also facilitates independent removal of either the camera or the lens/shutter assembly without disturbing the rest of the system. The plate was mounted on threaded studs extending through four Lordco shock mounts, similar to the projector mounting. The camera was focused and aimed using positioning nuts to adjust the plate up and down on the studs.

Photographing was done through a 5-in. diameter hole in the van floor.

c. Light shroud: A light shroud was provided to shield the pavement area illuminated by the projector from ambient light. The shroud was needed because ambient light reflecting from the surface would wash out the image of texture detail formed by the oblique lighting of the projection.

The shroud consisted of a sheet-metal frame securely bolted to the underside of the van floor, and a rubber skirting attached to the frame. The skirting plan form is square, about 20 in. on a side. The skirting could be raised and lowered relative to the pavement surface and easily removed when not in use. A hole was cut in one corner to admit light from the projector.

d. Auxiliary equipment: A 12-V storage battery was connected in series with the van battery to supply 24-V DC power to the relay which drives the film advance mechanism.

One-hundred fifteen volt AC power was supplied to the micro-flash drive unit and a cycle timer motor (see below) by a Tripplite, 250-W power inverter connected to the van battery.

A 5-cam cycle timer with drive motor was used to sequence the camera and flash unit, the data-chamber lamps and the film-advance mechanism. The cycle time was 15 sec. The sequence was initiated by a manual push-button switch. The synchronized camera and flash unit fired during the first 2 to 3 sec; the data chamber lamps were turned on next for about 2 sec; and finally the film advance mechanism was actuated. When the sequence was completed, the timer motor stopped, an indicator light came on if the film was advanced properly, and the system was ready for another cycle.

2. Equipment Testing

The complete photographic system was assembled and bench tested in the laboratory. It was then field installed in the van.

After the equipment was installed, test photos were taken under a variety of conditions. These included different pavement types, vehicle speeds, light shroud position, time of day, direction of travel (relative to the sun as ambient light source), etc.

The test film was developed in the field and examined. It was determined that good, usable pictures were obtained provided the light shroud was lowered to between 1/2 and 1 in. (1 to 3 cm) above the pavement surface when the van was at a standstill. With the shroud raised higher, ambient light effects obscured surface texture features. Vehicle speed and bouncing had no obvious effect. Pavement color change, e.g., portland cement concrete to asphalt, altered the appearance of the photographs but visibility of surface texture was retained.

D. Preliminary Analysis of Photographs

The pavement was photographed from directly above and with oblique lighting. The spot of light contained shadow lines intended to delineate the peaks and valleys along a trace of the surface. The flash duration was sufficiently short to obtain streak-free photographs at 40 mph (64 km/hr), but light leakage under the shroud produced minor streaking in most of the photographs.

The first nonlaboratory test of the photographic procedure was made with the vehicle stationary. A photograph (see Figure 14) was taken of a spot of open-textured asphaltic concrete in a parking lot. An impression of the surface was then made and the surface texture later duplicated with a plaster-of-paris replica.

The negative film photograph of the spot was placed on a standard library 35 mm film reader and magnified 2.2 times. The number of peaks/inch was determined by two methods. First, the shadow line was traced onto a piece of tracing paper and the number of peaks/inch counted by hand. Second, a ruler was placed on the viewer screen and the number of peaks along the ruler edge was determined by changes in shade of gray. Then the number of peaks/inch in the same areas of the plaster-of-paris replica were counted by hand. The number of peaks/inch for the shadow line trace, direct measurement and plaster-of-paris replica were 18, 15 and 11, respectively. It appeared that the oblique lighting in the photograph magnified the size of some of the microtexture and it was mistaken for macrotexture.

Another method for analyzing the tracing paper outline of the shadow edge was also utilized. An attempt was made to measure directly the mean void width. The width, parallel to the shadow bar, of each shadow projecting into a void was measured. This method produced unreasonable results for the same reasons as stated above and because of an accumulation of measurement errors. In addition, the method was quite tedious and time consuming.

The analysis technique was then applied to the photographic data actually gathered from a moving vehicle in the field. As stated above, the field photographs from a moving vehicle were of lower resolution than stationary photographs and contained some streaking.

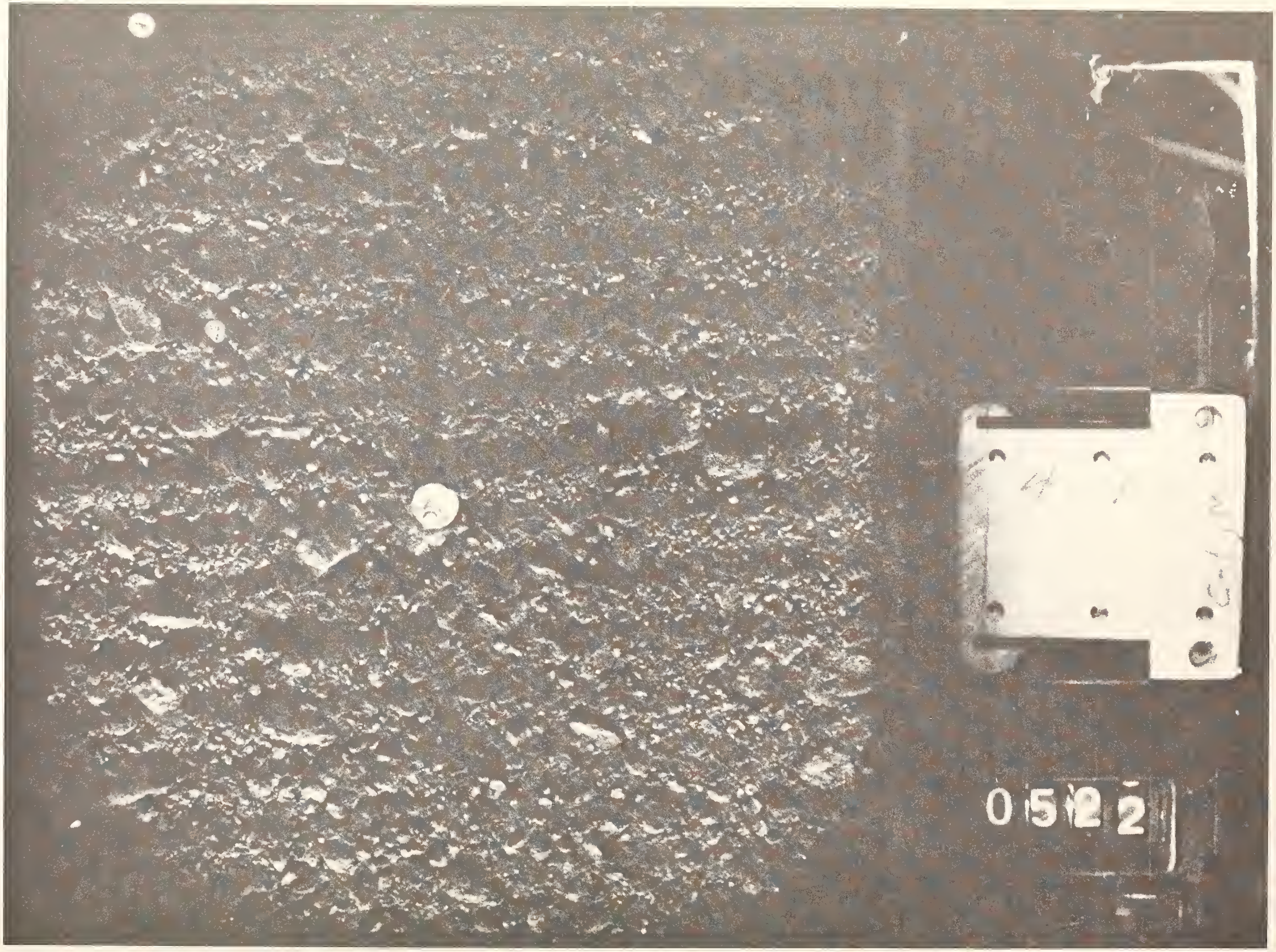

Figure 14 - Photograph of Pavement Macrotexture from Stationary Vehicle

Several of the macrotexture photographs were taken on pavement sections with known speed gradients. The roll of film was first reviewed and rated as to quality of photographs. The term quality is used here as a measure of resolution or clarity of the photograph. It was influenced primarily by motion streaking made visible by ambient light leaking under the light shroud. Quality was determined by comparison to reference photographs. Experience showed that the minor streaking was helpful in interpreting the photograph; too much or too little was undesirable. The average quality photograph is shown in Figure 15. A decision was made to test the film reading procedure only on average quality photographs to avoid any bias that might be introduced by differences in photographic quality. Fortunately, 75 to 80% of all photographs were of the desired quality.

The known gradient photographs were analyzed by two methods. First, the shadow line was traced from the viewer screen onto tracing paper and the number of peaks/inch counted by hand. Second, a ruler was placed in the lighted portion of the photograph and the number of discernible changes in shades of gray along the ruler was counted. From this the number of peaks/inch was determined. A discernible peak on the negative film was defined as a darker area separated from the next darker area along the ruler by a lighter area. The two methods (tracing and direct reading) produced essentially the same results. Because the direct reading method was considerably faster, this method was selected as the primary reading method for subsequent work.

The number of peaks/inch on the known gradients was determined by the direct reading method described above. Only average quality photographs were read to prevent any bias that photographic quality might introduce. An average of six photographs was read for each known gradient and the mean of these readings was utilized. The mean number of peaks/inch was inverted to yield mean void width.

Mean void width may be converted to an index of speed gradient by utilizing the Schulze and Beckmann formula:

$$y = 13.5 - 72.6\,x + 103.6\,x^2$$

where y = mean width of surface voids (hundredths of an inch)

x = coefficient of friction at 30 km/hr - coefficient of friction at 60 km/hr

solving the equation for x yields

$$x = 0.35038 - \sqrt{-0.00754286 + 0.009653\,y}$$

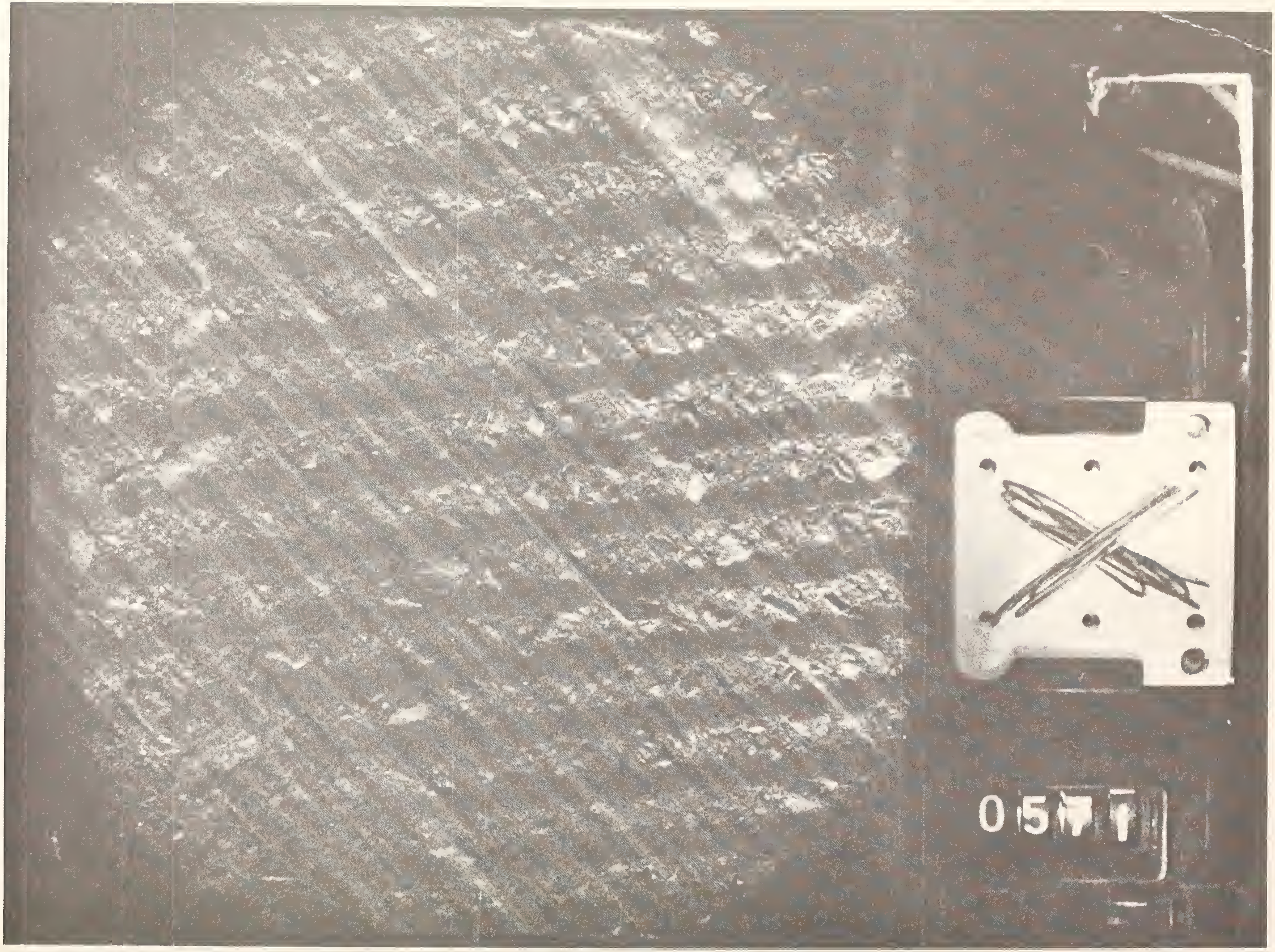

Figure 15 - Average Quality Photograph from Moving Vehicle

This equation yields the change, Δ , in coefficient of friction (CF) between 20 and 60 km/hr. A much more useful term would be Δ SN (Skid Number)/ Δ mph using SN = 100 CF, one mile = 1.609 kilometers and 60 km/hr - 20 km/hr = 40 km/hr; we multiply the right side of the above equation by $\frac{(100)(1.609)}{40}$ = 4.023 to yield:

$$X = SNG = 1.4097 - \sqrt{-.1220776 + .1562293\ y}$$

where y = mean width of surface voids (hundredths of an inch)

and SNG = $\Delta SN/\Delta mph$.

The curve in Kummer and Meyer[9/] is based on this last equation.

The mean void width for each known gradient was converted to skid number - speed gradient, SNG, utilizing the last equation. The results appear in Table 23. Based on this small sample, the method appeared to be accurate enough to be of value to the study. Considering the high variance in the known gradient data, the photoestimated values appeared to be reasonable.

The film reading method adopted for this study appeared to work better on photographs gathered in the field than on laboratory photographs. We believed this difference to be due to the light leakage under the shroud in the field. This light leakage created some streaking on the photograph and reduced the resolution somewhat. This loss in resolution obliterated the shadows cast on the microtexture* by the oblique lighting, and only the macrotexture shadows could be seen. Consequently, the streaked photographs from the field produced better results than the laboratory photographs.

However, this photographic technique had its limitations. We had field photographs of portland cement concrete pavement on which the sand patch test was done. While mean texture depth is not synonymous with mean void width, one would expect them to be positively correlated.

Macrotexture photographic data were available for two pavements. The first one had a mean texture depth of 0.066 in. (0.17 cm) and the second one 0.012 in. (0.030 cm). The latter surface was considered very smooth. The field photographs of these pavements were read and the mean void width on the first pavement was photoestimated to be 1/15 in. (0.17 cm). The film reader reported that photographs of the smoother surface were unreadable. When told that the surface was very smooth and to try again, the mean void width was estimated to be 1/14 in. (0.18 cm). Based on these results, we assumed that our photoestimation technique was not capable of determining the mean void width for very smooth pavements.

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* The term microtexture is used here to describe the small irregularities in the void surfaces which are not meaningful to drainage.

TABLE 23

COMPARISON--KNOWN GRADIENTS VS ESTIMATED GRADIENTS FROM PHOTOGRAPHIC ANALYSIS

Photoestimated SNG $\Delta SN/\Delta MPH$	Skid-Trailer-Measured SNG for Various MPH Ranges			
	30 - 40	40 - 50	50 - 60	30 - 60
0.51	0.63	0.53	0.42	0.53
0.57	0.74	0.44	0.34	0.51
0.48	0.28	0.45	0.18	0.30
0.45	0.31	0.59	0.09	0.33

E. Primary Analysis of Photographs and Reliability of Measurements

For any measurement technique to be valid, it must yield essentially the same results from multiple measurements of the same data. This concept is known as test-retest reliability. Eighty-three moving photographs (photographs from a moving vehicle) were read twice with a 2-month delay between first and second readings. The direct measurement technique (utilizing the ruler as described above) was used both times to determine the number of peaks/inch. The Pearson r for correlation between first and second reading on each photograph was found to be only 0.01. We then grouped the data into three classes as shown in Table 24. The correlation between first and second reading in this case was found to be 0.73. This finding indicated that the rater could rate the pavements into high, medium and low gradients fairly reliably.

TABLE 24

GRADIENT CLASSIFICATIONS - THREE CLASSES

Class	Peaks per Inch	Mean Void Width (in.)	Gradient (ΔSN/ΔMPH)
1	0 - 12	∞ - .08	0 - .35
2	13 - 20	.08 - .05	.36 - .60
3	21 +	.05 - 0	.61 +

When the readings were grouped into five categories as shown in Table 25, the correlation dropped to 0.11, indicating that the rater could not reliably rate the pavement into five classes.

TABLE 25

GRADIENT CLASSIFICATIONS - FIVE CLASSES

Class	Peaks per Inch	Mean Void Width (In.)	Gradient (ΔSN/ΔMPH)
1	0 - 11	∞ - .09	0 - .28
2	12 - 14	.09 - .07	.29 - .42
3	15 - 20	.07 - .05	.43 - .60
4	21 - 32	.05 - .03	.61 - .82
5	33 +	.03 - 0.0	.83 +

1. Subjective Rankings of Pavement Texture

A decision was made at this point to develop a method of ranking the photographs of pavements into several categories without directly counting peaks. Five studies were performed to determine how reliably a number of raters could rate pavement molds and photographs into the several categories. The overall objective of these studies was to develop standards for the individual categories of pavement texture. One macrotexture photograph would be selected as the standard for each category. Then the macrotexture photographs with unknown gradients would be compared to the standards to determine the gradients. The procedure described below traces the development and validation of the technique for subjectively ranking pavement textures in order to estimate skid number - speed gradient.

a. Study (1): The first study utilized 13 molds of pavement texture with known gradients. Molds were positive duplications of the pavement surfaces and were molded from negative silicone impressions. The positive molds were made of Hydro Stone and were, consequently, white in color. Pertinent data about the molds appear in Table 26. Gradients were calculated from multiple speed skid measurements provided by the States and the 40 to 60 mph (64 to 97 km/hr) values were utilized when available.

The raters consisted of six male and six female staff members. The male raters were primarily highway safety engineers and the female raters were stenographers and analysts.

There was some concern that mixing asphalt, portland cement and special pavement molds would cause contamination of the ratings. Consequently, the asphalt pavement molds were rated into smooth, medium and rough categories first, then the portland cement pavement molds were rated and finally the special pavement molds. Since some of the special pavement molds were exceptionally rough or smooth, extra rough and extra smooth categories were added for the final rating.

The relationship between skid number - speed gradient, SNG , and mean texture rating, T , appears in Figure 16. The "goodness" of this relationship is described by the Pearson Correlation Coefficient, r . Except for one outlier, the relationship between the two variables was fairly good ($r = -0.90$). This outlier pavement surface consisted of crushed sand in an epoxy overlay and was extremely smooth. The impression made of the surface contained air bubbles and produced a bad mold. Consequently, that mold was eliminated from later studies. Since all of the surfaces seemed to fit the same general relationship between gradient and mean texture rating, the decision was made to rate the molds from all three surface types as a single group of 12 (excluding the outlier) in the second study.

TABLE 26

PAVEMENT MOLDS UTILIZED IN STUDIES

Mold No.	Type	SNG (ΔSN/ΔMPH)
1	Asphaltic Concrete	0.50
2	Portland Cement	0.40
3	Asphaltic Concrete	0.45
4	Portland Cement	0.50
5	Asphaltic Concrete	0.50
6	Asphaltic Concrete	0.30
7	Asphaltic Concrete	0.35
8	Asphaltic Concrete	0.20
9	Special	0.14
10	Special	0.09
11	Special	0.29
12	Special	0.25
13	Special	0.16

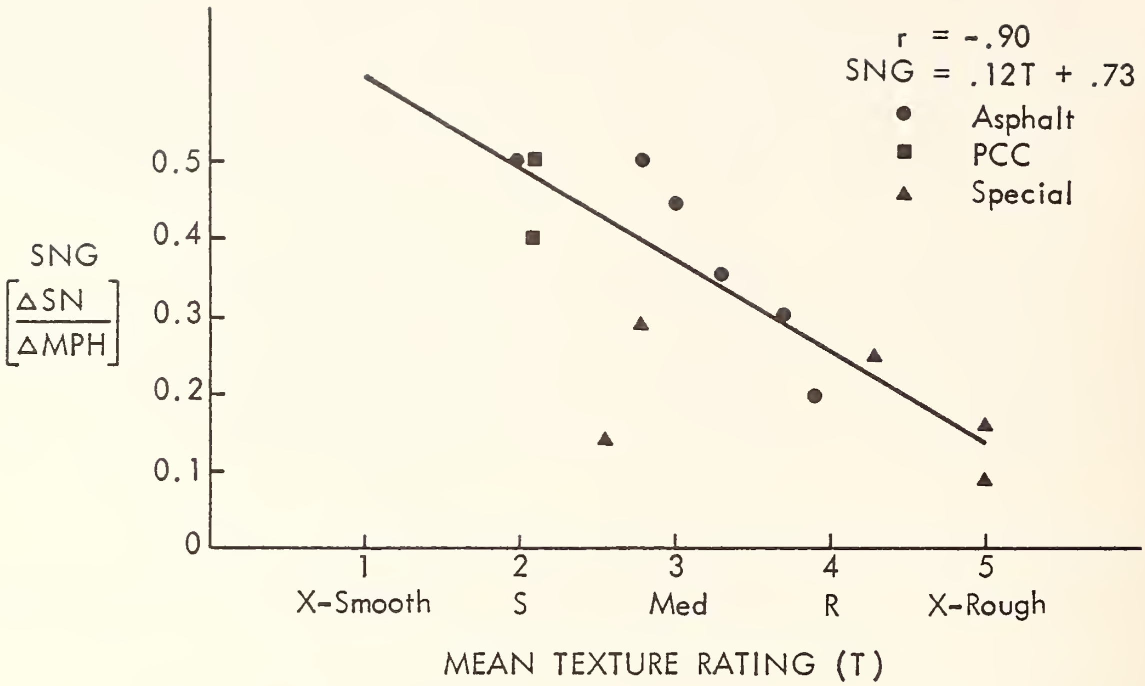


Figure 16 - Mean Texture Rating Versus Known Gradient - Sequential Ratings

b. Study (2): The second study utilized the 12 remaining molds and they were rated into five categories. Two of the original raters were not available for the second study and the ratings were made by the remaining 10.

The relationship between gradient and mean texture rating in the second study appears in Figure 17. Again, the relationship was good (r = -0.92) and the coefficient of concordance (an index of how well the raters agreed on each mold) between raters was 0.90.

c. Study (3): In the third study, the individuals rated photographs of the pavement from which the molds had been made. The photographs had been taken with the inventory van sitting stationary over the exact spot from which the molds had been made. The relationship between gradient and mean texture rating for the still photographs appears in Figure 18. The coefficient of concordance between raters dropped to 0.75 for the still photographs.

d. Study (4): In the fourth study, the individuals rated the macrotexture photographs taken with the van moving at 40 mph (64 km/hr). The location of the pavement photographed was within 10 ft (3 m) of the spot of the impression in all cases. The relationship between gradient and mean texture rating for the moving photographs appears in Figure 19. The coefficient of concordance between raters went back up to 0.92 for the moving photographs.

At first, this was a startling result. However, it must be remembered that when we were counting peaks/inch we got more reasonable results on moving photographs because the streaking washed out the microtexture and made the macrotexture more visible. In this study, the shadow bars in the moving photographs were more visible on the pavement due to the streaking, and the irregularities in the bars made judgment easier than did direct viewing of surface texture.

2. Ranking Agreement and Study (5)

An analysis was done to determine the rank order agreement for pavement texture ratings between molds, still photos and moving photos. The results appear in Table 27.

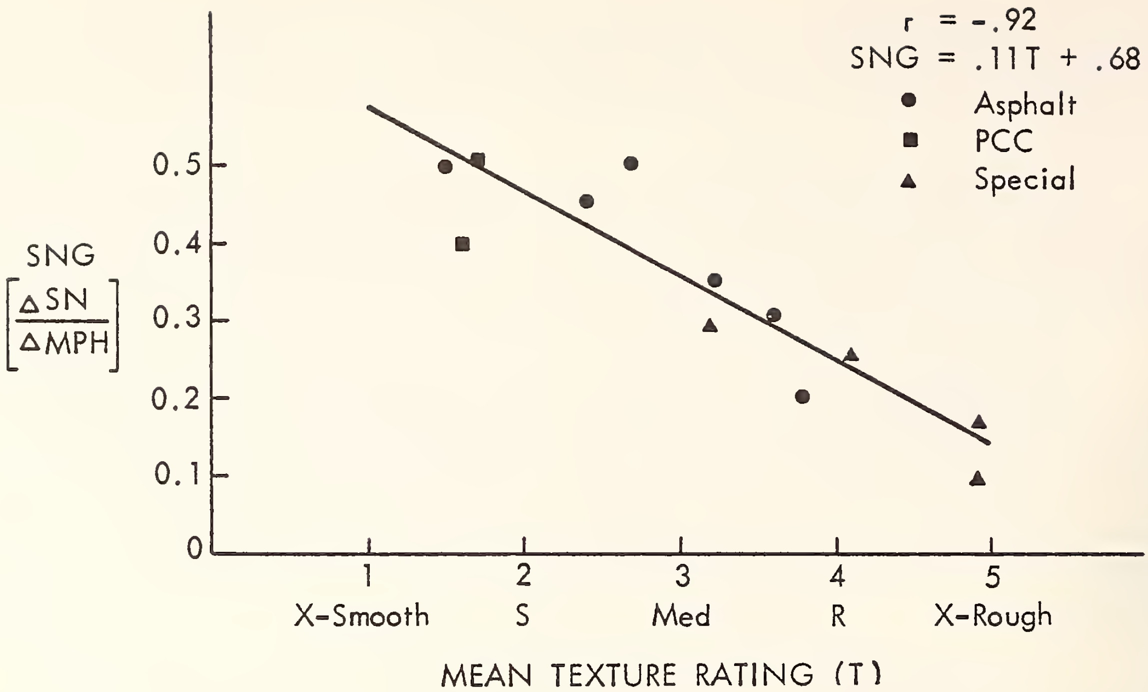


Figure 17 - Mean Texture Rating Versus Known Gradient - 12 Molds Together

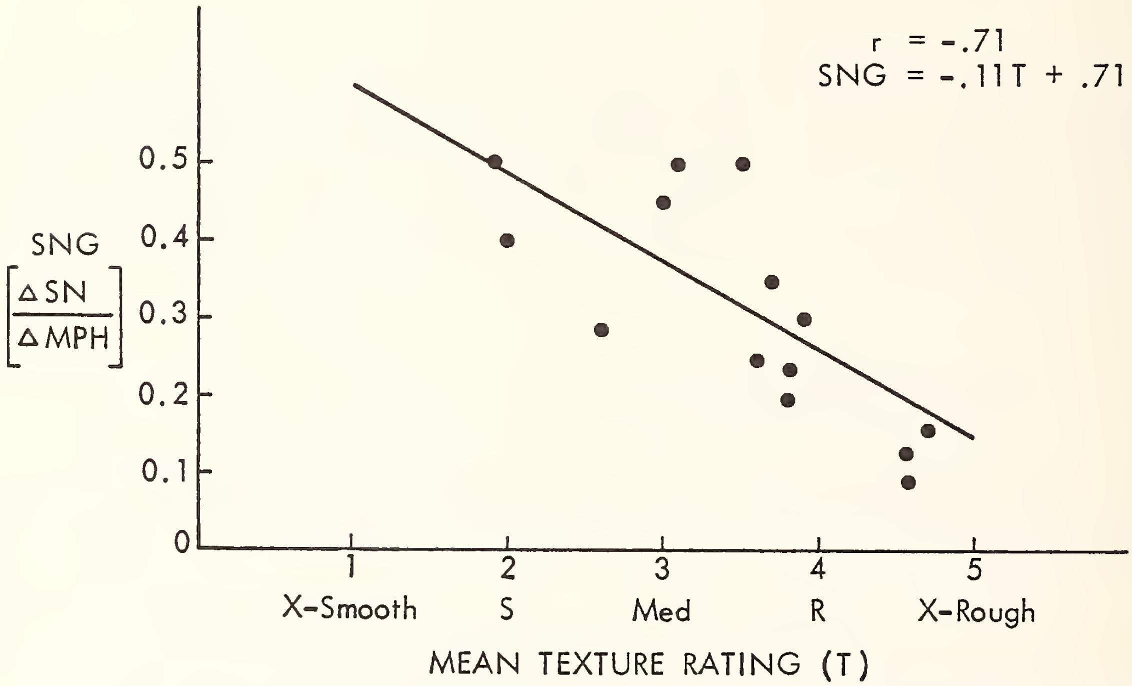


Figure 18 - Mean Texture Rating Versus Known Gradient - Still Photos, First Group

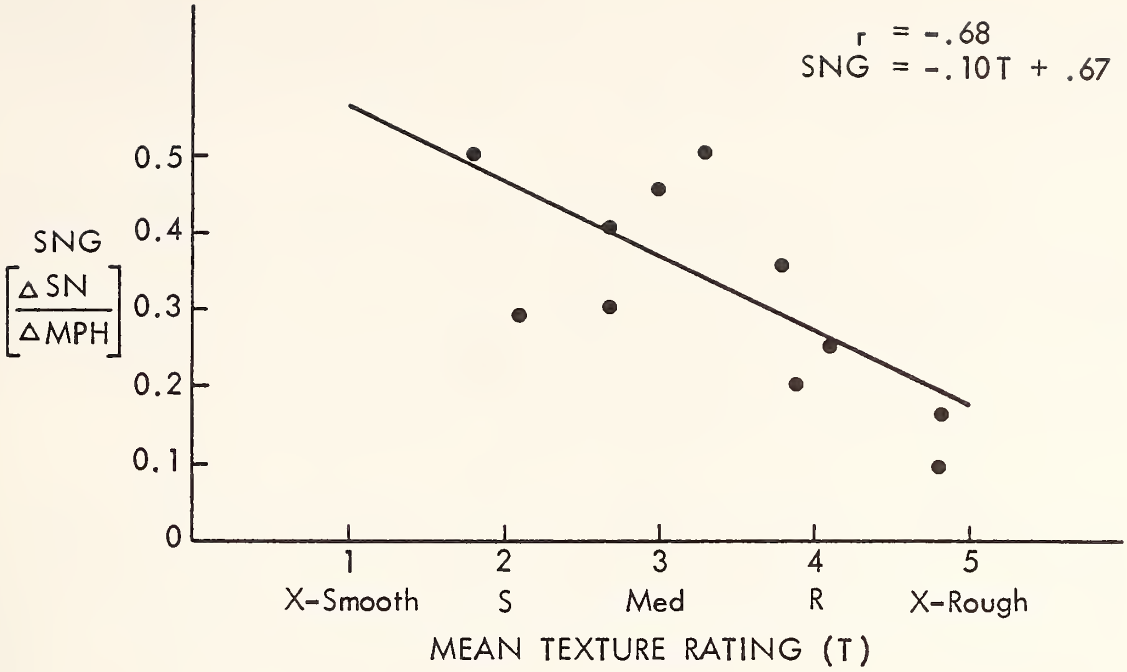


Figure 19 - Mean Texture Rating Versus Known Gradient - Moving Photos, First Group

TABLE 27

RANK ORDER (SPEARMAN RHO) CORRELATIONS

Between Molds and Still Photos	0.83
Between Molds and Moving Photos	0.71
Between Still Photos and Moving Photos	0.80

At the end of the above studies and analyses, it was concluded that raters could rate the moving macrotexutre photographs into surface texture categories with fairly good inter-rater agreement. In addition, the mean ratings for the photographs formed a fairly good relationship with the known gradient.

However, two possibilities could have led to biased results. One possibility was that the raters had used the photographs to remember the molds and were not actually rating texture based strictly on the information in the photographs. The other possibility was that the high agreement between raters on the moving photographs was because they had learned to become better raters through practice on the first three studies. Consequently, the decision was made to conduct a fifth study.

Ten stenographers, none of whom had seen the pavement molds, were asked to rate the 12 still photographs and 12 moving macrotexture photographs. Half of the individuals rated the still photographs first and vice versa. The relationship between mean rank and gradient for still photographs appears in Figure 20 and for moving photographs appears in Figure 21. By comparing the curve in Figure 18 with that in Figure 20 and the curve in Figure 20 with that in Figure 21, one can see that the agreement between the two groups was good. The Spearman rank order correlation between the two groups for mean ranking of textures in moving photographs was found to be 0.90. Consequently, previous knowledge of the molds did not seem to bias the ratings.

The coefficient of concordance was found to be 0.48 for still photographs and 0.69 for moving photographs. Again, the concordance for moving photographs was higher than for still photographs. Since the order effect was controlled in this study, the superiority of moving photographs was apparently real and not a result of learning. This conclusion was reinforced when a Bartlett's Test was made on the variance data and no significant difference was found between the variance for first and second readings.

However, the fact that the first group (who had seen the molds) had a higher coefficient of concordance than the second group, could indicate that the high concordance was due to experience with the molds. Another possiblity is that a basic difference existed between the two groups of raters. Neither of these two possibilities could be ruled out.

Updated skid number data were received from a Skid Test Center at the completion of the five studies. The Test Center data utilized in the studies had been preliminary results obtained shortly after the test surfaces had been laid. The updated data were obtained after the surfaces stabilized. Two of the surfaces (9 and 10 in Table 26) had a higher skid

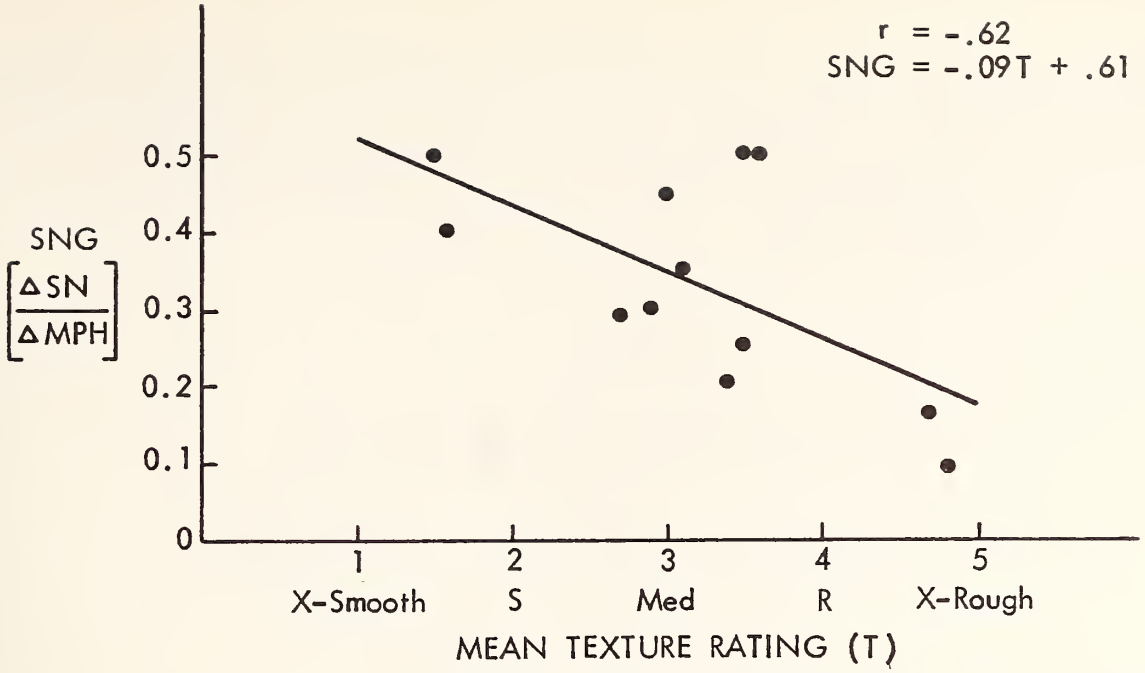


Figure 20 - Mean Texture Rating Versus Known Gradient - Still Photos, Second Group

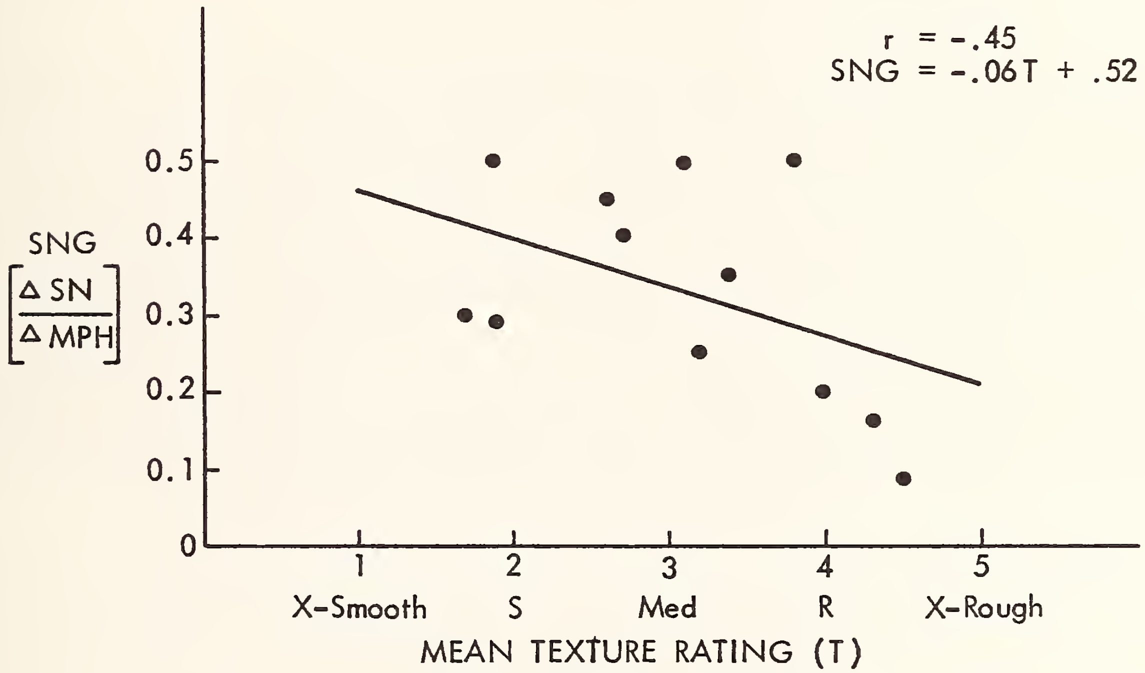


Figure 21 - Mean Texture Rating Versus Known Gradient - Moving Photos, Second Group

number at 60 mph (97 km/hr) than at 40 mph (64 km/hr). Both had an epoxy overlay such that no aggregate directly contacted the tire. Surface No. 9 had previously been eliminated because of a bad mold. Surface No. 10 was then eliminated from further consideration. The updated gradients for the Skid Test Center surfaces 3, 4 and 5 (molds 11, 12 and 13 in Table 23) appear in Table 28.

TABLE 28

UPDATED GRADIENTS FOR TEST CENTER SURFACES

Test Center Surface	Old SNG (ΔSN/ΔMPH)	Updated SNG (ΔSN/ΔMPH)
3	0.29	0.26
4	0.25	0.17
5	0.16	0.05

3. Standards

After the known gradients were updated, it was found that the correlation between mean texture rating and known gradient for the first group of raters (those used in studies 1 through 4) was better than that found for the second group. Consequently, the five standards were chosen in accordance with the ratings of the first group of raters. Figure 22 displays the relationship between mean texture rating and known gradient for the first group of raters utilizing updated gradients. Figure 23 displays the relationship with three outlier points eliminated for ease of selecting the standards. Based on the least squares curve fit of this reduced data set, five standards were chosen that best represented the relationship between mean texture rating and known gradient. The pavements selected as standards appear in Table 29.

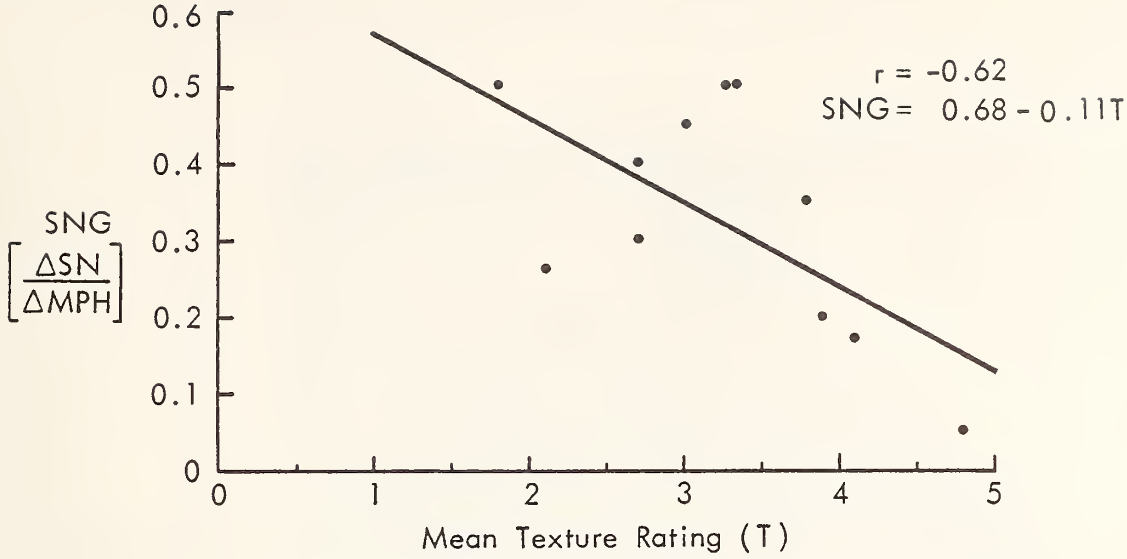


Figure 22 - Mean Texture Rating Versus Known Gradient

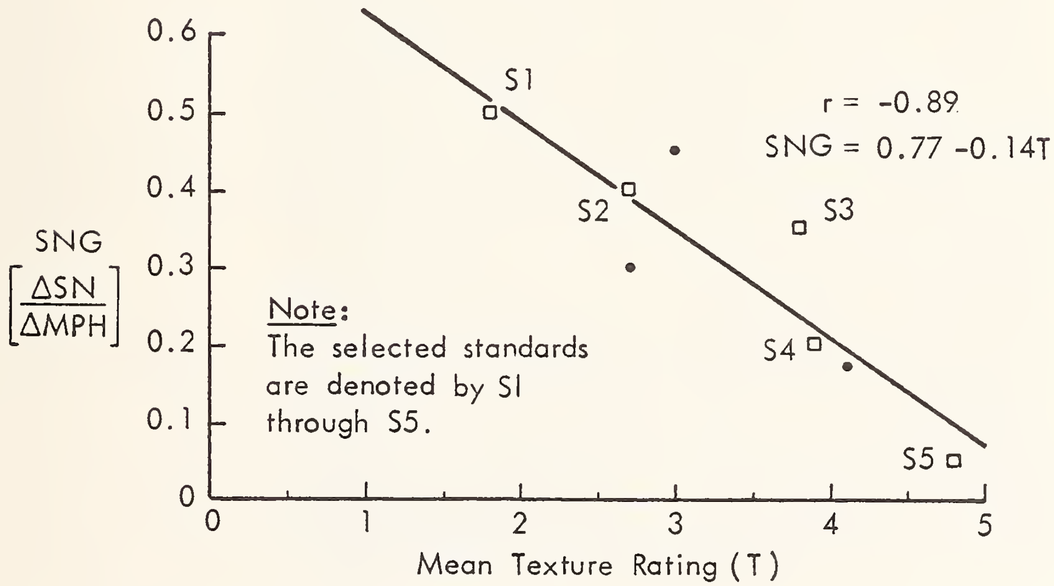


Figure 23 - Mean Texture Rating Versus Known Gradient--
Outliers Eliminated

TABLE 29

STANDARDS CHOSEN FOR PHOTOESTIMATION OF SNG

Standard	Mold Number	Known SNG (ΔSN/ΔMPH)
1	4	0.50
2	2	0.40
3	7	0.35
4	8	0.20
5	13	0.05

At this point, we had five standards for estimating skid number gradient. However, the photoestimation technique had not been tested to determine its accuracy. Fortunately, gradient data were available on nine sections of pavement that had not been utilized in the earlier studies to develop the standards. A total of 208 photographs had been taken in the nine sections.

Negatives of the photographs of the five standards were cut into strips in order to mount all five on one 35-mm slide. This set of standards was projected onto one-half of a rear projection screen. Then the 208 frames of negative film were each projected on the screen next to the standards. A photograph of the actual split projection is given in Figure 24. The rater then judged which standard the frame was most like. The number of that standard (1 to 5) is given in Table 29 which was designated as the gradient rating for that frame.

The gradient ratings were converted into estimated gradient by the following procedure. The mean rating for each section of pavement was found. If the mean rating was an integer number, the known gradient of that standard was assigned to the pavement section as the estimated gradient. For example, if the mean rating was found to be 3.0, the known gradient (.35) of standard 3 in Table 29 was assigned to the pavement section. If the mean rating was a fractional number, the estimated gradient was found by linearly interpolating between the two bordering known gradients. For example, if the mean rating was 1.5, the estimated gradient of 0.45 was assigned to the pavement section.

Standard

Pavement Photograph

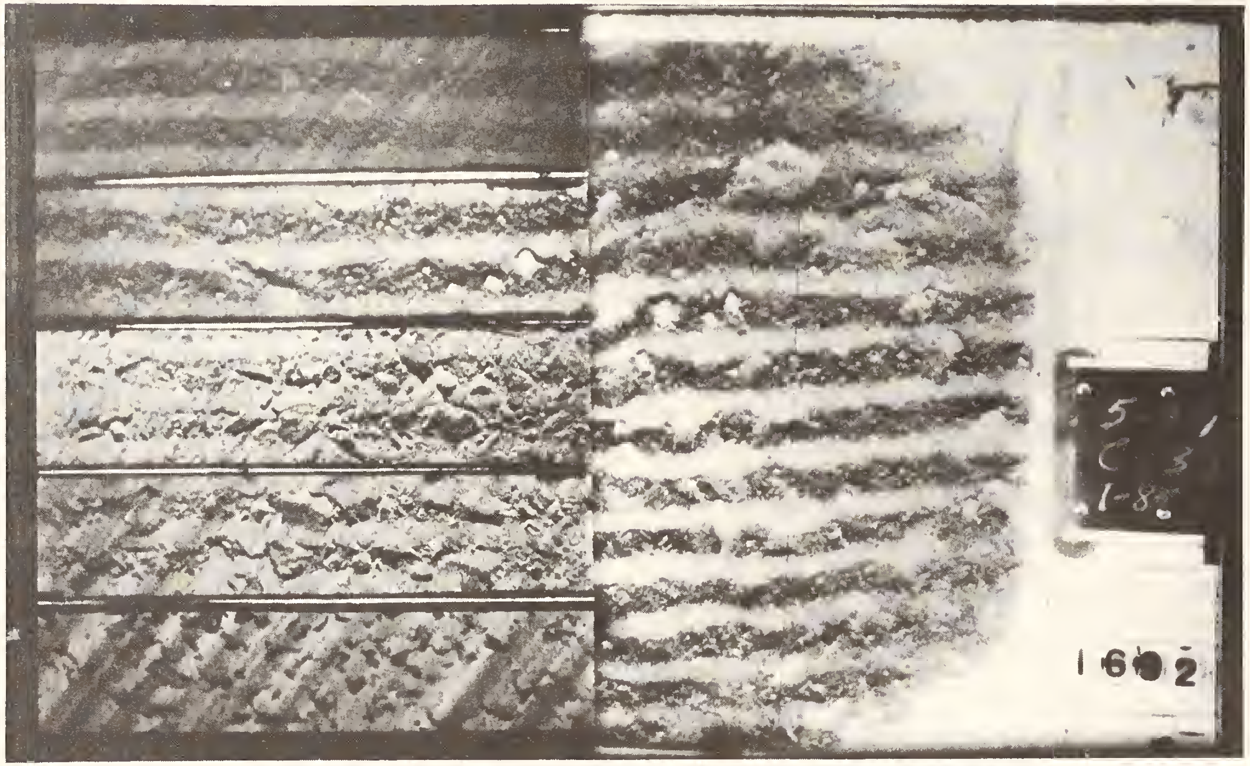


Figure 24 - Negative Photograph of Pavement Projected Beside Five Standards

The relationship between estimated and known gradients using the above procedure appears in Figure 25. The line represents where the points would fall if perfect correlation existed between estimated and known gradient. Note that the points fall fairly close to the line and the Pearson correlation coefficient between estimated and known gradient is 0.81.

4. Rating Conversion Equation

Once the technique was shown to be valid, a decision was made to improve the linear interpolation technique of converting gradient ratings into estimated gradient. The relationship between mean gradient rating ($\overline{R}$) in the validation study and known gradient for each of the nine highway sections appears in Figure 26. The best fit least squares linear regression line for the points had the equation $SNG = 0.52 - 0.06\ \overline{R}$. The correlation coefficient was -0.79 with a standard error of the estimate (SE) of 0.0578. The 95% and 67% confidence intervals are shown in dashed lines. The equation $G = 0.52 - 0.06\ \overline{R}$ then became the equation for converting mean gradient rating to estimated skid number - speed gradient.

5. Reliability

The technique described above was utilized to estimate skid number - speed gradient on 466 sections of highway in 16 states. The gradient ratings for each of about 32,000 frames of film were placed on punched cards for later conversion to estimated gradient by the above equation.

The film reading process took approximately 2 months of half-time work for two technician level readers. At the end of the 2-month period the 208 photographs utilized in the validation study were re-read. The mean gradient rating for each of the nine sections of highway was found and the (Pearson) correlation coefficient between first and second reading was found to be + 0.94, indicating high reliability of the technique.

As a further check, 168 frames of film for a section of highway (with unknown gradient) were re-read. The gradient ratings for each frame were compared to ratings given the frames when they were read along with the other 32,000 frames. The correlation between the first and second reading was found to be + 0.69 which is fairly reliable. Mean rating on first reading was 1.82 and on second reading was 2.37. These ratings convert to estimated gradients of 0.38 and 0.41, respectively. An error of this magnitude was deemed acceptable when considering the variance of the skid number data with which we were working.

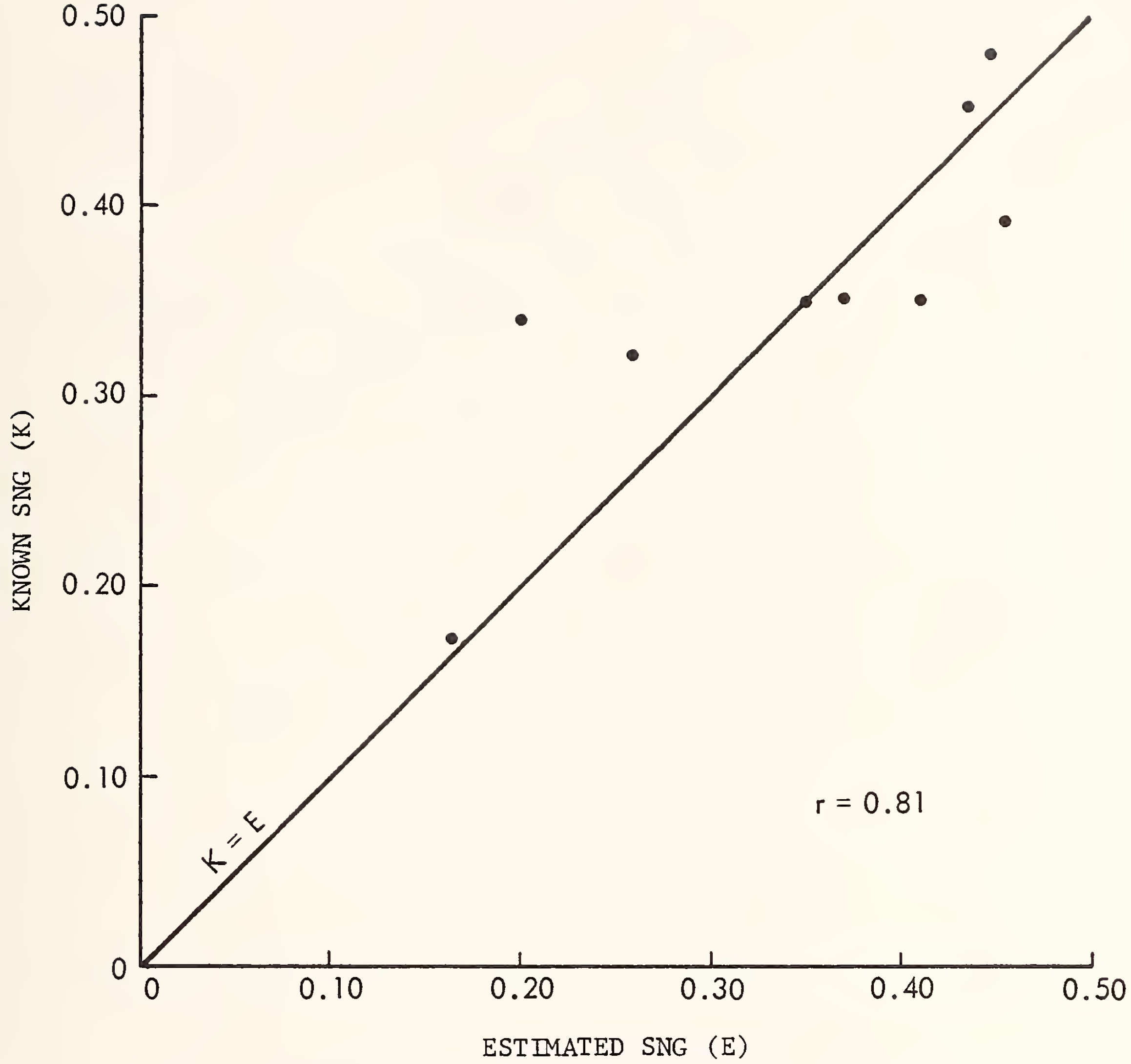


Figure 25 - Relationship Between Photoestimated and Known Gradient

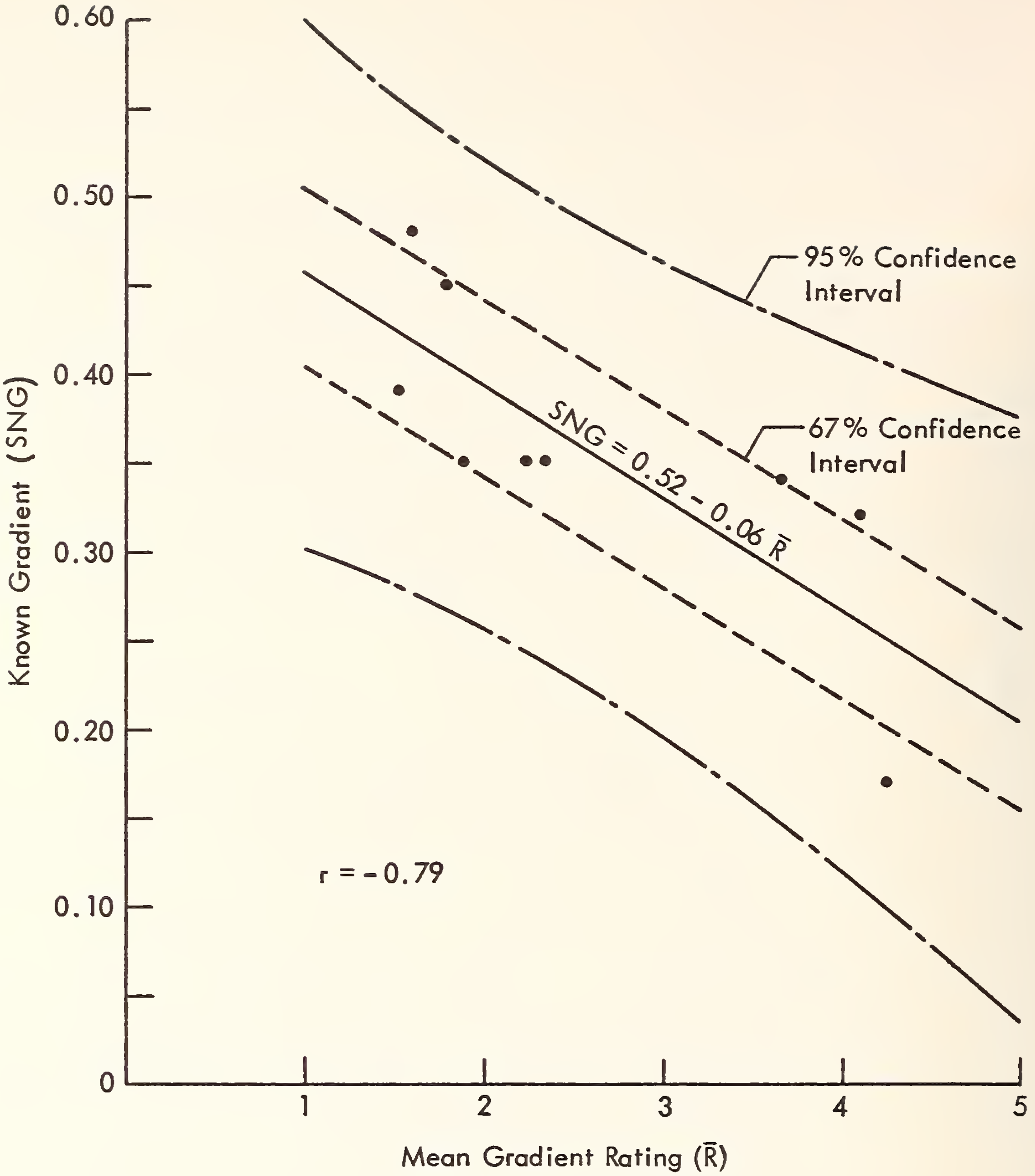


Figure 26 - Relationship Between Mean Gradient Rating and Known Gradient

In conclusion, a valid technique for estimating skid number - speed gradient of pavement surfaces has been developed. The technique and equipment have been field tested and found to be both economical and reliable.

APPENDIX D

COLLECTION AND ANALYSIS OF WET AND DRY PAVEMENT SPEED DATA

A. Summary

The objective of the speed data analysis was to estimate the 85th percentile speed of traffic under wet-pavement conditions for each test and control section. General speed data were collected from each cooperating state that routinely conducts such measurements. However, speed data collected under wet-pavement conditions are generally unavailable. Therefore, the cooperating states conducted comparative speed studies under both wet and dry pavement conditions. These data were used to develop a correction factor to relate wet and dry pavement speeds.

B. Collection of General Speed Data

Speed measurement data were collected from several sources to estimate the 85th percentile wet-pavement speed for each study section. Primary sources of speed measurement data were the cooperating state highway departments. Each of the 16 cooperating states were contacted in order to: (1) obtain copies of available speed measurements on both wet and dry pavements; and (2) determine their willingness to conduct wet-dry comparison speed measurements at six locations in the state.

Three types of general speed data were requested from the state's files:

1. Dry-pavement speed data collected before the energy crisis;

2. Wet-pavement speed data collected before the energy crisis; and

3. Dry-pavement speed data collected after the energy crisis.

The "before" dry-pavement speed data were received from 11 of the cooperating states. Five of the states did not have such information available.

The effort to collect "before" wet-pavement data from the cooperating states was basically unsuccessful. Only Ohio had conducted some speed measurements on wet pavement before July 1973, the date chosen to represent the beginning of the energy crisis. Several of the states indicated that their speed checks were designed to determine the normal operating speed of traffic on their highways and therefore checks were not made under conditions such as wet pavement when speeds could be adversely affected.

"After" dry-pavement speed data were obtained from 12 of the 16 states. Four of the cooperating states did not have such data available. The general speed data were used to estimate the speed of traffic under dry-pavement conditions for each test and control section.

C. Comparison of Wet and Dry Pavement Speeds

The 16 cooperating states were also asked to conduct wet-dry comparison speed measurements at six locations in their state. The six locations represented a sample of three highway types in both rural and urban areas. The highway types specified were two-lane, multilane controlled access and multilane uncontrolled access. Where possible the locations of the measurements were at regular speed check stations. Because the collection of speed data was not initially specified as part of the state's role in cooperating with the project, funds were budgeted to reimburse the states for their labor costs in making the wet-pavement measurements. If the dry-pavement measurements were not available from a state's regular speed check program, the state was also reimbursed for these measurements.

Between February and June of 1975, spot-speed measurements were made by nine of the 16 cooperating highway departments at a total of 48 sites (some of the states were not able to make measurements at all of the six specified locations). At each site, measurements were made under both wet and dry pavement conditions. States that conducted the measurements were Connecticut, Rhode Island, Pennsylvania, West Virginia, Maryland, Michigan, Ohio, Mississippi and Washington. The specific location of each study site was chosen by state personnel.

The requirements of each study were:

1. The speed of at least 200 vehicles should be recorded in each study.

2. Only speeds of free-flowing vehicles should be recorded.

3. Only one direction of traffic should be sampled.

4. Vehicles should be classified as passenger (includes vans and pickups) or truck; and

5. Speed limits at the location should be 55 for all rural locations and at least 45, preferably 55, at urban locations.

The speed measurements were recorded on the field tally sheets that each state normally uses in making speed studies. States were not asked to manipulate the data after it was recorded in the field, and generally the data received from the states were the completed field tally sheets. Although some states did run the data through their regular data handling procedures and submit computer printouts, none of the original distribution data were lost due to summarizing procedures.

Additional wet-pavement speed data were collected in the cooperating states by MRI field inventory personnel when the inventory was suspended because of wet weather. Eight studies of this kind were conducted in five states. Two of these studies also included dry-pavement speed measurements at the same location.

Some speed data were also collected from reviewing available literature. These data were from two sources: speed check publications of states other than the cooperating states and some limited speed data collected as part of previous research. No usable "before" wet-pavement speed data were obtained from the literature.

The original objective of the analysis of the speed data was to develop correction factors for both the before and after periods that would account for the difference between dry and wet pavement speeds. Then the best available data on the operating speed (taken as the 85th percentile speed) on dry pavement for each study section would be converted to an equivalent 85th percentile speed on wet pavement. The analysis inability to obtain "before" wet-pavement speed data restricted the analysis to an investigation of the after period wet-dry comparison speed measurements made by the nine states. (The data collected by MRI field inventory personnel were not used in this analysis because of the limited and restrictive nature of the data.)

The "after" period speed measurement data from the nine states were analyzed by comparing the 85th percentile speeds under wet and dry pavement conditions at each site to determine:

1. If there was a significant difference between the wet and dry pavement speeds; and

2. The "correction factor" or the value of the difference between the 85th percentile wet and dry speeds.

A two-sample t-test was used to determine if the difference between the 85th percentile wet and dry speeds was significant at the 95% confidence level.

The 85th percentile speeds were calculated from the mean speeds with the following equation[17]:

$$V_{85} = \bar{x} + 1.04s,$$

where V_{85} = 85th percentile speed

$\bar{x}$ = mean speed

s = standard deviation of speed

This equation was used because, in a normal population of speeds, 85% of the speeds would be included between zero and $\bar{x} + 1.04s$. The standard deviation of the 85th percentile (s_{85}) was determined from the equation:

$$s_{85}^2 = \frac{pq}{nf_1^2}$$

where $p = 0.85$

$q = 0.15 = 1-p$

n = sample size

$$f^2 = \frac{0.13932^2}{\sigma 2}$$

and σ^2/n = variance of the mean speeds.

Solving for s_{85} yields

$$s_{85} = 2.5574\sigma$$

The derived 85th percentile speed and 85th percentile standard deviation for wet and dry speeds at each site were used in the "t" statistic to determine if there was a significant difference in wet and dry speeds at a site.

The results of this analysis for all 48 locations are shown in Table 30. In considering speeds of passenger vehicles alone, 18 of the 48 sites showed a significant difference between the 85th percentile wet and dry speeds. At two of the sites with a significant difference, the 85th percentile wet speed was higher than the 85th percentile dry speed. When considering the speeds of all vehicles, 16 of 46 sites (not 48 because only passenger vehicle speeds were recorded at two sites) showed a significant difference at the 95% confidence level. Again, at two of the sites the wet 85th percentile speeds were significantly higher than the dry 85th percentile speeds.

TABLE 30

TWO-SAMPLE T-TEST RESULTS

State	Highway Type[a/]	Area Type	Speed Limit	Pavement Surface	85th Speed Passenger Vehicles	85th Speed All Vehicles	Significant Differences Passenger	Significant Differences All Vehicles	Wet-Dry Differences in mph and 95% Confidence Interval Passenger	Wet-Dry Differences in mph and 95% Confidence Interval All Vehicles
Conn.	2L	R	45	Wet	43.36	43.55	No	No	-1.77	-1.60
				Dry	45.44	45.15			±2(1.01)	±2(0.94)
Conn.	2L	U	45	Wet	48.51	48.31	No	No	-1.26	-1.36
				Dry	49.78	49.67			±2(0.88)	±2(0.82)
Conn.	MUA	U	40	Wet	43.43	42.98	Yes	Yes	-3.14	-3.64
				Dry	46.56	46.02			±2(1.32)	±2(1.20)
Conn.	MUA	U	45	Wet	52.41	52.22	Yes	Yes	2.77	2.14
				Dry	50.0	50.08	Wet Above Dry	Wet Above Dry	±2(0.87)	±2(0.81)
Conn.	MCA	U	55	Wet	57.81	57.62	Yes	Yes	-2.77	-2.76
				Dry	60.57	60.39			±2(1.00)	±2(0.93)
Conn.	MCA	R	55	Wet	63.71	63.54	Yes	Yes	2.40	2.28
				Dry	61.30	61.27	Wet Above Dry	Wet Above Dry	±2(1.11)	±2(1.09)
R.I.	2L	U	45	Wet	44.76	44.47	Yes	Yes	-5.09	-5.15
				Dry	49.86	49.62			±2(1.13)	±2(1.03)
R.I.	MUA	U	45	Wet	42.65	42.52	Yes	Yes	-10.31	-9.90
				Dry	52.36	52.41			±2(1.24)	±2(1.24)
R.I.	MCA	U	55	Wet	58.31	57.81	No	No	-0.64	-0.67
				Dry	58.95	58.48			±2(0.95)	±2(0.83)
R.I.	MCA	R	55	Wet	63.58	63.16	No	No	-1.74	-1.34
				Dry	65.32	64.50			±2(1.42)	±2(1.11)
Pa.	MCA	U	55	Wet	60.43	60.13	No	No	1.0930	1.30
				Dry	59.33	58.84			±2(1.42)	±2(1.31)
Pa.	MCA	R	55	Wet	57.67	57.20	Yes	Yes	-5.66	-5.59
				Dry	63.33	62.79			±2(1.35)	±2(1.14)
Pa.	2L	R	50	Wet	51.71	51.59	No	No	-0.43	-0.29
				Dry	52.14	51.89			±2(1.37)	±2(1.29)
Pa.	2L	U	50	Wet	49.76	49.42	No	No	-1.08	-1.16
				Dry	50.85	50.58			±2(1.31)	±2(1.20)
Pa.	MUA	R	50	Wet	55.40	55.15	No	No	-1.08	-1.28
				Dry	56.49	56.43			±2(1.47)	±2(1.40)
Pa.	MUA	U	50	Wet	53.84	53.49	Yes	Yes	-2.65	-2.74
				Dry	56.49	56.23			±2(1.31)	±2(1.24)

TABLE 30 (Continued)

State	Highway Type[a]	Area Type	Speed Limit	Pavement Surface	85th Speed Passenger Vehicles	85th Speed All Vehicles	Significant Differences Passenger	Significant Differences All Vehicles	Wet-Dry Differences in mph and 95% Confidence Interval Passenger	Wet-Dry Differences in mph and 95% Confidence Interval All Vehicles
W.V.	2L	R	55	Wet	53.51	53.46	Yes	Yes	-2.98	-2.97
				Dry	56.49	56.43			±2(0.96)	±2(0.92)
W.V.	2L	U	40	Wet	38.05	38.11	Yes	No	-2.22	-2.01
				Dry	40.27	40.12			±2(1.12)	±2(1.09)
W.V.	MUA	R	55	Wet	57.21	57.18	No	No	-1.30	-1.24
				Dry	58.51	58.42			±2(0.98)	±2(0.94)
W.V.	MUA	U	40	Wet	42.38	42.14	Yes	Yes	-4.66	-3.41
				Dry	47.04	46.90			±2(1.48)	±2(1.40)
W.V.	MCA	R	55	Wet	59.96	59.75	Yes	Yes	-3.73	-3.59
				Dry	63.69	63.34			±2(1.84)	±2(1.75)
W.V.	MCA	U	50	Wet	55.42	55.31	No	No	1.29	1.20
				Dry	54.13	54.11			±2(1.51)	±2(1.28)
Md.	2L	R	50	Wet	45.87	45.57	Yes	Yes	-10.17	-10.22
				Dry	56.04	55.79			±2(1.42)	±2(1.30)
Md.	MUA	R	55	Wet	49.73	48.89	No	No	-0.31	-0.38
				Dry	50.04	49.26			±2(1.42)	±2(1.36)
Mi.	MUA	R	55	Wet	57.61	57.44	No	No	-2.17	-2.13
				Dry	59.78	59.57			±2(1.57)	±2(1.52)
Mi.	2L	U	35	Wet	39.51	39.51	No	No	-0.02	-0.04
				Dry	39.53	39.47			±2(1.13)	±2(1.12)
Mi.	MUA	U	40	Wet	46.82	46.65	No	No	0.45	0.35
				Dry	46.37	46.30			±2(1.27)	±2(1.23)
Mi.	MCA	U	55	Wet	56.49	56.35	Yes	Yes	-3.12	-2.92
				Dry	59.61	59.27			±2(1.30)	±2(1.25)
Mi.	2L	R	55	Wet	60.43	60.03	No	No	3.13	2.96
				Dry	57.30	57.07			±2(1.78)	±2(1.73)
Mi.	MCA	R	55	Wet	64.57	64.28	No	No	1.09	1.17
				Dry	63.48	63.11			±2(1.33)	±2(1.38)
Oh.	MCA	R	55	Wet	61.47	61.17	Yes	Yes	-3.62	-2.96
				Dry	65.09	64.13			±2(1.16)	±2(0.96)
Oh.	2L	R	55	Wet	60.29	59.81	No	No	-1.85	-1.93
				Dry	62.14	61.73			±2(1.44)	±2(1.29)
Oh.	MCA	U	50	Wet	58.85	58.75	No	No	-2.01	-1.89
				Dry	60.86	60.64			±2(1.17)	±2(1.15)
Oh.	MUA	R	55	Wet	58.71	58.20	Yes	Yes	-4.24	-4.19
			Truck 50	Dry	62.95	62.39			±2(1.15)	±2(1.05)

TABLE 30 (Concluded)

State	Highway Type[a]	Area Type	Speed Limit	Pavement Surface	85th Speed Passenger Vehicles	85th Speed All Vehicles	Significant Differences Passenger	Significant Differences All Vehicles	Wet-Dry Differences in mph and 95% Confidence Interval Passenger	Wet-Dry Differences in mph and 95% Confidence Interval All Vehicles
Oh.	MUA	U	45	Wet	50.65	49.90	No	No	-0.94	-0.99
				Dry	51.58	50.89			±2(1.29)	±2(1.16)
Oh.	2L	U	50	Wet	49.29	49.32	No	No	-1.45	-1.40
				Dry	50.74	50.72			±2(1.48)	±2(1.42)
Ms.	MCA	U	50	Wet	51.88	52.13	Yes	Yes	-5.96	-5.81
				Dry	57.84	57.94			±2(1.01)	±2(1.00)
Ms.	MCA	R	55	Wet	63.36	63.60	No	No	0.85	1.02
				Dry	62.51	62.58			±2(1.22)	±2(1.15)
Ms.	MUA	U	45	Wet	45.10	45.11	No	No	-1.07	-1.09
				Dry	46.17	46.20			±2(1.01)	±2(1.03)
Ms.	MUA	R	55	Wet	63.37	63.58	No	No	0.66	0.71
				Dry	62.71	62.87			±2(1.30)	±2(1.21)
Ms.	2L	U	45	Wet	43.12	43.35	No	No	-2.00	-1.88
				Dry	45.12	45.23			±2(1.24)	±2(1.25)
Ms.	2L	R	55	Wet	58.05	57.97	No	No	0.12	-0.29
				Dry	57.93	58.26			±2(1.49)	±2(1.38)
Wa.	MCA	U	55	Wet	59.64	59.58	No	No	-1.10	-0.95
				Dry	60.74	60.53			±2(0.87)	±2(0.78)
Wa.	MCA	R	55	Wet	59.83	59.16	No	No	-0.04	-0.48
				Dry	59.87	59.63			±2(1.09)	±2(0.80)
Wa.	MUA	U	50	Wet	50.01	Same*	No	--	-1.49	--
				Dry	51.50	51.46			±2(1.14)	--
Wa.	MUA	R	50	Wet	49.90	50.17	Yes	No	-2.30	-2.00
				Dry	52.20	52.17			±2(1.08)	±2(1.05)
Wa.	2L	U	40	Wet	45.00	Same*	No	--	-1.03	--
				Dry	46.02	Same*			±2(1.27)	--
Wa.	2L	R	50	Wet	55.52	55.51	No	No	0.04	0.09
				Dry	55.46	55.38			±2(1.32)	±2(1.27)

a/ Highway type legend.

2L - Two-lane
MCA - Multilane controlled access
MUA - Multilane uncontrolled access

* Passenger vehicles only in sample.

The difference between the wet and dry 85th percentile speeds and the 95% confidence interval for this difference are also shown in Table 29 (negative differences indicate wet speeds are lower than dry speeds). The difference in passenger vehicle speeds ranged from -10.31 ± 2.48 mph to + 3.13 ± 3.56 mph. The value of the difference for all vehicle speeds ranged from -10.22 ± 2.60 mph to + 2.96 ± 3.46 mph. In both of the above cases the negative differences are significantly different from zero, while the positive differences are not.

The analysis of each site separately did not give a clear picture of whether wet and dry pavement speeds were actually different. While some sites showed that 85th percentile speeds were as much as 10 mph lower on wet pavements than on dry, at almost two-thirds of the sites there was no significant difference between the wet and dry speeds. Including the speed measurements for trucks did not seem to alter results, either.

In order to obtain a clearer picture of the wet-dry pavement speeds, the data were grouped by highway-area type and speed limit, and then the grouped data were again analyzed by the two-sample t-test.

The results of this analysis are shown in Table 31. For passenger vehicles only, the rural two-lane, urban two-lane, and urban multilane controlled-access sites showed significant differences at the 95% confidence level. For all of these three types of sites, the dry pavement 85th percentile speeds were higher than the wet speeds by 1.5 to 2 mph.

For all vehicles, the differences were significant for all highway area types except rural two-lane roadways. Dry-pavement 85th percentile speeds were generally 1 to 2 mph higher than wet-pavement speeds. The analysis of the data grouped in this way did not seem to have a clear-cut result, and passenger speeds only and speeds of all vehicles varied more than before.

The results of the analysis of the data grouped by speed limit are shown in Table 32. Sites with speed limits of 40 mph did not show a significant difference between wet and dry 85th percentile speeds for passenger vehicles or all vehicles. However, the groups of sites with speed limits of 45, 50 and 55 mph did indicate that dry 85th percentile speeds were significantly higher than wet 85th percentile speeds. The value of the difference was about 1 to 2 mph. This analysis indicated that a significant difference was more likely at higher speed limits.

Finally, the data were analyzed by grouping all measurements together and again testing the differences between wet and dry 85th percentile speeds by the two-sample t-test. For passenger vehicles, dry 85th percentile speeds were significantly higher than wet 85th percentile speeds. This difference was -1.45 ± 0.64 mph at the 95% confidence level. For all vehicles, the dry 85th percentile speeds were also significantly higher and this difference was -1.19 ± 0.58 mph at the 95% confidence level.

TABLE 31

SPEED DATA GROUPED BY AREA-HIGHWAY TYPE

Area-Highway Type	Significant Difference		Wet-Dry Correction Factor and 95% Confidence Interval	
	Passenger	All Vehicles	Passenger	All Vehicles
Rural two-lane	Yes	No	-1.98 ±2(0.75)	- .93 ±2(0.63)
Urban two-lane	Yes	Yes	-2.09 ±2(0.57)	-2.12 ±2(0.54)
Rural MCA	No	Yes	-0.83 ±2(0.51)	-0.89 ±2(0.44)
Urban MCA	Yes	Yes	-1.59 ±2(0.46)	-1.48 ±2(0.42)
Rural MUA	No	Yes	-1.45 ±2(0.81)	-1.61 ±2(0.75)
Urban MUA	No	Yes	-1.09 ±2(0.56)	-1.10 ±2(0.54)

TABLE 32

DATA GROUPED BY SPEED LIMIT

Speed Limit	Significant Differences: Passenger Vehicles	Significant Differences: All Vehicles	Correction Factor: Passenger Vehicles	Correction Factor: All Vehicles
40	No	No	-1.25 ±2(0.92)	-1.12 ±2(0.89)
45	Yes	Yes	-1.97 ±2(0.51)	-1.98 ±2(0.48)
50	Yes	Yes	-2.01 ±2(0.45)	-2.13 ±2(0.48)
55	Yes	Yes	-0.90 ±2(0.38)	-0.95 ±2(0.34)

Although the analysis of the group of all speed measurements did indicate a small (but statistically significant) difference in wet and dry pavement speeds, the relationship of this difference to characteristics of the site was still not clear. Before "correction factors" or average differences could be applied to regular dry-pavement spot speeds, these relationships had to be determined so correction factors would be appropriate for the site that the dry-speed data were taken from.

In order to determine how the correction factor should be stratified, the variability in 85th percentile speed was examined. Variables that were included in this analysis were pavement condition (wet or dry), area type, highway type, and state. Components of variance for the four variables and their interactions were estimated. To facilitate the analysis of variance, only data from states where speed measurements were made at all six area-highway types were analyzed--Pennsylvania, West Virginia, Michigan, Ohio, Mississippi and Washington.

The estimates of the variability are shown in Table 33. All non-zero components of variance are shown in the table. There were significant interactions between area type and state and area type and highway type. The significance of these interactions indicates that these characteristics must be considered when determining 85th percentile dry speeds.

Pavement condition (wet or dry) accounted for a significant (although small) part of the variance, which agrees with the results of the two-sample t-test analysis. However, since there were no significant interactions between pavement condition and the other variables, the data indicate that a uniform correction factor for wet-pavement conditions could be applied to all 85th percentile dry speeds.

The correction for wet-pavement conditions of -1.19 ± 0.58 mph, which was obtained when all speed measurements were grouped, was applied to the "after" period 85th percentile dry-pavement speeds to obtain the 85th percentile wet-pavement speeds which were, in turn, used to adjust the "after" period skid number of the pavement sections to SN_{85}. This same wet-pavement correction factor was also applied to the general speed data collected from before the energy crisis.

TABLE 33

COMPONENTS OF VARIANCE

Characteristic	Variance	Percentage of Total Variance
Area Type	33.89	38.7
Highway Type	21.47	24.5
Area Type-State Interaction	11.31	12.9
Area Type-Highway Type Interaction	7.15	8.2
State	2.11	2.4
Pavement Condition	0.66	0.8
Residual	11.07	12.6

APPENDIX E

DEFINITIONS OF MICROSECTION FILE PARAMETERS

This Appendix provides definitions of the parameters contained in the Microsection File. Most of these parameters were used directly or indirectly in the data analysis. The ten general categories of parameters included in the File are: (A) General, (B) Accidents, (C) Exposure, (D) Skid Resistance, (E) Pavement and Cross Section, (F) Access Points, (G) Traffic Control, (H) Obstacles, (I) Curves and (J) Grades.

A. General

This section of the Microsection File contains nine general parameters that are not otherwise classified.

1. State: The state in which each section is located is represented by one of the following codes:

Code	State	Code	State
01	California	09	Mississippi
02	Connecticut	10	North Carolina
03	Florida	11	Ohio
04	Louisiana	12	Pennsylvania
05	Maine	13	Rhode Island
06	Maryland	14	South Carolina
07	Massachusetts	15	Washington
08	Michigan	16	West Virginia

2. Type of microsection: 1 = Test, 0 = Control.

3. Microsection number: Each microsection is identified by a three-digit number between 001 and 999. Matching test and control microsections have identical microsection numbers between 001 and 700. Unmatched control microsections have microsection numbers between 701 and 999.

4. Microsection length: A microsection may be composed of several highway segments. The total length of a microsection is calculated as:

$$L = \sum_{\substack{\text{All} \\ \text{Segments}}} \left(\begin{matrix}\text{Final Coordinate} \\ \text{of Segment}\end{matrix} - \begin{matrix}\text{Initial Coordinate} \\ \text{of Segment}\end{matrix} \right)$$

where L = microsection length (miles).

The quantity L is uniquely used throughout this Appendix and is not defined again.

5. Highway type: The highway type of a microsection is given by a 4-character code. The first character is the number of lanes. The second character is divided (D) or undivided (U). The final two characters represent controlled access (CA) or uncontrolled access (blank). Examples: 4DCA = 4-lane, divided, controlled access; 2U = 2-lane, undivided, uncontrolled access.

6. Area type: 1 = Rural, 2 = Urban.

7. One-way or two-way: 1 = Microsection consists of a one-way roadway, 2 = microsection consists of a two-way roadway.

8. Weighted average ADT: A microsection may have several zones with different ADT. The weighted average ADT for the microsection is defined as:

$$ADT = \frac{\sum_{i=1}^{z} ADT_i(L_i)}{L}$$

where ADT = Weighted average ADT (vehicles),

ADT_i = Average daily traffic for i^{th} zone (vehicles),

L_i = Length of i^{th} zone (miles), and

z = Number of zones in the microsection.

9. Microsection segment code: The following codes are used to classify microsections:

1 = Microsection is continuous;

2 = Microsection is discontinuous because of the removal of a non-homogeneous highway-type segment; and

3 = Microsection is discontinuous for some other reason.

B. Accidents

The Microsection File contains a summary of accident experience compiled by month for a 1-year period. Accidents are classified as occurring under one of three pavement conditions: (1) wet conditions, (2) ice and snow conditions, and (3) dry or other conditions.

1. First month of period: This 3-digit code identifies the first month of the 1-year study period for this microsection. The first two digits represent the month (01 = January, . . ., 12 = December) and the last digit represents the year (0 = 1970, . . ., 5 = 1975).

2. Last month of period: This 3-digit code identifies the last month of the 1-year study period and is defined in the same manner as the first month above.

3. Number of wet accidents by month: This portion of the File contains the number of accidents occurring on the microsection under wet-pavement conditions during each of the 12 months of the study period.

4. Total number of wet accidents in period: This parameter is the total number of accidents occurring on the microsection under wet pavement conditions during the entire 12-month period, i.e., the sum of the 12 values in Section 3 above.

5. Number of ice and snow accidents by month: This portion of the File contains the number of accidents occurring on the microsection under ice and snow conditions during each of the 12 months of the study period.

6. Total number of ice and snow accidents in period: This parameter is the total number of accidents occurring on the microsection under ice and snow conditions during the entire 12-month period, i.e., the sum of the 12 values in Section 5 above.

7. Number of dry and other accidents by month: This portion of the File contains the number of accidents occurring on the microsection under dry and other pavement conditions during each of the 12 months of the study period.

8. Total number of dry and other accidents by month: This parameter is the total number of accidents occurring on the microsection under dry and other pavement conditions during the entire 12-month period, i.e., the sum of the 12 values in Section 7 above.

9. Wet pavement accident rate: This rate is calculated as:

$$AR = \frac{(24)(10^6)(N_W)}{(L)(E_W)(ADT)}$$

where AR = Wet-pavement accident rate (accidents/MVM),

N_w = Total number of wet-pavement accidents in period (discussed in Section 4 above),

L = Microsection length,

E_w = Exposure to wet-pavement conditions (hours), and

ADT = Weighted-average ADT.

C. Exposure

The Microsection File contains estimates of monthly exposure to various pavement conditions corresponding to the accident categories described above.

1. Number of hours of wet-pavement exposure by month: This portion of the File contains the estimated number of hours of exposure to wet-pavement conditions during each of the 12 months of the study period.

2. Total hours of wet exposure in period: This parameter is the estimated total number of hours of exposure to wet-pavement conditions for the entire 12-month period, i.e., the sum of the 12 values in Section 1 above.

3. Number of hours of ice and snow exposure by month: This portion of the File contains the estimated number of hours of exposure to ice and snow conditions during each of the 12 months of the study period.

4. Total hours of ice and snow exposure in period: This parameter is the estimated total exposure to ice and snow conditions for the entire 12-month period, i.e., the sum of the 12 values in Section 3 above.

5. Number of hours of dry exposure by month: This portion of the File contains the estimated number of hours of exposure to dry-pavement conditions during each of the 12 months of the study period.

6. Total hours of dry exposure in period: This parameter is the estimated total exposure to dry-pavement conditions for the entire 12-month period, i.e., the sum of the 12 values in Section 5 above.

7. Number of hours of exposure to high-intensity rainfall by month: This portion of the file contains the estimated number of hours in which rainfall in excess of 1/2 in. occurred during each of the 12 months of the study period.

8. Total hours of exposure to high-intensity rainfall in period: This parameter is the estimated total number of hours of exposure to rainfall in excess of 1/2 in. during the 12-month period, i.e., the sum of the 12 values in Section 7 above.

9. Mean annual number of days with thunderstorms: This parameter, the mean annual number of days with thunderstorms, is another variable indicating exposure to high-intensity rainfall. It was compiled from a map published by the U.S. Environmental Data Service.

D. Skid Resistance

The following skid resistance parameters were included in the Microsection File.

1. Mean gradient rating: This parameter is the mean of the gradient ratings on the microsection (1-5 scale) determined from the pavement photographs taken during the field inventory. Where photographs are not available, the mean gradient rating is estimated as 1.9 for old portland cement concrete pavements, 2.1 for old asphalt concrete pavements and 1.5 for new asphalt concrete pavements.

2. Mean skid number at 40 mph: This parameter is the mean of the results of all skid tests in the travel lane on a microsection. (The travel lane on a multilane highway is the outside lane.) Where skid tests were conducted at 40 mph (the majority of cases), the test results were averaged directly. Where skid tests were conducted at speeds other than 40 mph, they were first converted to 40 mph as follows:

$$SN40 = SN_T - (40 - V_T)(0.52 - 0.06\bar{R})$$

where $SN40$ = Skid number at 40 mph,

SN_T = Skid number at test speed,

V_T = Test speed (mph), and

$\bar{R}$ = Mean gradient rating.

Prior to averaging the skid data, the raw skid numbers were adjusted whenever possible using the skid trailer calibration results.

3. <u>Standard deviation of skid number at 40 mph</u>: This parameter is the standard deviation of the skid numbers that were averaged in Section 2 above.

4. <u>Date of skid test</u>: This is a 3-digit parameter identifying the month and year when skid tests were conducted on each section. The first two digits represent the month (01 = January, . . ., 12 = December) and the last digit represents the year (0 = 1970, . . ., 6 = 1976).

5. <u>85th percentile speed</u>: The 85th percentile speed of traffic on the microsection in miles per hour is contained in the File.

6. <u>Mean skid number at 85th percentile speed</u>: The mean skid number at the 85th percentile speed is determined as follows:

$$\overline{SN(85)} = \overline{SN40} - (V_{85} - 40)(0.52 - 0.06\bar{R})$$

where $\overline{SN(85)}$ = Mean skid number at 85th percentile speed,

$\overline{SN40}$ = Mean skid number at 40 mph,

V_{85} = 85th percentile speed (mph), and

$\bar{R}$ = Mean gradient rating.

E. <u>Pavement and Cross Section</u>

This section of the File contains nine parameters describing the pavement and cross section of each microsection.

1. <u>Percent of length with paved shoulder</u>: The first pavement and cross section parameter is the percent of the microsection length with paved shoulder. Shoulder paving was recorded in both directions for all microsections. This parameter is calculated as:

$$\%\ PS = \frac{PS_F + PS_R}{2L} \times 100$$

where % PS = Percent of length with paved shoulder,

PS_F = Length of paved shoulder in forward direction (miles), and

PS_R = Length of paved shoulder in reverse direction (miles).

2. Percent of length with shoulder over 6 ft wide: Shoulder width is handled in a manner analogous to shoulder paving:

$$\% \, WS = \frac{WS_F + WS_R}{2L} \times 100$$

where $\% \, WS$ = Percent of length with shoulder over 6 ft wide,

WS_F = Length of shoulder over 6 ft wide in forward direction (miles), and

WS_R = Length of shoulder over 6 ft wide in reverse direction (miles).

3. Percent of length with asphalt pavement: The percent of the microsection length with asphalt concrete pavement was determined directly from field inventory data for all control microsections. Most microsections were entirely asphalt concrete pavement (% AP = 100) or entirely portland cement concrete pavement (% AP = 0). However, some sections had minor inclusions of a contrasting pavement type. For test microsections inventoried before resurfacing, the field data were also used directly to determine the percent of asphalt pavement for the before period. The percent of asphalt pavement after resurfacing was 100% for these test sections. Test sections inventoried after resurfacing were assigned a value of 0% or 100% for the before period based on information provided by the cooperating states.

4. Percent of length with lane width under 10 ft: Lane width was recorded in only one direction for two-lane highways. The percent of length with lane width under 10 ft (% NLW) was defined as:

$$\% \, NLW = \frac{NCW}{L} \times 100$$

where $\% \, NLW$ = Percent of length with lane width under 10 ft, and

NLW = Length with lane width under 10 ft (miles).

Lane width was recorded in both the forward and reverse directions for all multilane highways. In these cases, this parameter was defined as:

$$\% \, NLW = \frac{NLW_F + NLW_R}{2L} \times 100$$

where $\% \, NLW$ = Percent of length with lane width under 10 ft,

NLW_F = Length with lane width under 10 ft in forward direction (miles), and

NLW_R = Length with lane width under 10 ft in reverse direction (miles).

5. Percent of length with lane width 12 ft or over: The percent of length with lane width 12 ft or over (% WLW) is computed in a manner exactly analogous to the percent of length with lane width under 10 ft. The percent of length with lane width between 10 and 12 ft (% MLW) can be computed as:

$$\% \text{ MLW} = 100 - \% \text{ NLW} - \% \text{ WLW}.$$

6. Percent of length with paved median: The percent of length with paved median is computed as:

$$\% \text{ PM} = \frac{\text{PM}}{\text{L}} \times 100$$

where % PM = Percent of length with paved median, and

PM = Length of paved median (miles).

7. Percent of length with curbed median: The percent of length with curbed median is determined in a manner entirely analogous to percent of length with paved median.

8. Percent of length with median width under 10 ft: The percent of length with median width under 10 ft is determined as:

$$\% \text{ NMW} = \frac{\text{NMW}}{\text{L}} \times 100$$

where % NMW = Percent of length with median width under 10 ft, and

NMW = Length with median width under 10 ft (miles).

9. Percent of length with median width over 30 ft: The percent of length with median width over 30 ft is determined as:

$$\% \text{ WMW} = \frac{\text{WMW}}{\text{L}} \times 100$$

where % WMW = Percent of length with median width over 30 ft, and

WMW = Length with median width over 30 ft (miles).

The percent of length with median width between 10 and 30 ft (% MMW) is:

$$\% \text{ MMW} = 100 - \% \text{ NMW} - \% \text{ WMW}.$$

F. Access Points

Intersections, interchange ramps, driveways and median openings were recorded in the field inventory. The following counts of these features are included in the File. Definitions of each access point category are found in Appendix B.

1. Number of residential drives

2. Number of commercial drives

3. Number of industrial drives

4. Number of minor intersections

5. Number of intermediate intersections

6. Number of major intersections

7. Number of interchange ramps

8. Number of median openings

9. Density of access points: This parameter is the total number of major, intermediate and minor intersections divided by the length of the section.

G. Traffic Control

The File contains two kinds of traffic control information: legal speed limit and percent of length in no-passing zones for each direction.

1. Legal speed limit: The program tabulated the length of each microsection where each value of speed limit was in effect at the time of the field inventory (after the imposition of the nationwide 55-mph speed limit). The parameter placed in the File is the speed limit that was in effect for the greatest portion of the microsection.

2. Percent no-passing zones--forward direction: This parameter was the percent of the microsection length for which passing was prohibited for vehicle traveling in the forward direction.

3. Percent no-passing zones--reverse direction: This parameter was the percent of the microsection length for which passing was prohibited for a vehicle traveling in the reverse direction.

H. Obstacles

This section of the File contains six parameters related to fixed obstacles outside the traveled way. Definitions of the various categories of obstacles are found in Appendix B.

1. Number of roadside obstacles--forward direction: This parameter is the number of roadside obstacles on the right side of the road when traveling in the forward direction.

2. Number of roadside obstacles--reverse direction: This parameter is the number of roadside obstacles on the right side of the road when traveling in the reverse direction.

3. Percent of length with guardrail or bridge rail--forward direction: For an undivided road, this parameter is the percent of the microsection length with either guardrail or bridge rail on the right shoulder when traveling in the forward direction. For a divided road, it is the average percent of the microsection length with guardrail or bridge rail on the right shoulder and in the median when traveling in the forward direction.

4. Percent of length with guardrail or bridge rail--reverse direction: This parameter is entirely analogous to the previous parameter, but is determined for the reverse direction.

5. Percent of length with barrier curb: The percent of length with barrier curb is:

$$\% \text{ BC} = \frac{BC_{FS} + BC_{FM} + BC_{RM} + BC_{RS}}{nL} \times 100$$

where $\%$ BC = Percent of length with barrier curb,

BC_{FS} = Length of barrier curb on right shoulder in forward direction (miles),

BC_{FM} = Length of barrier curb in median in forward direction (miles). (If section is not divided, this quantity is zero.),

BC_{RM} = Length of barrier curb in median in reverse direction (miles). (If section is not divided, this quantity is zero.),

BC_{RS} = Length of barrier curb on right shoulder in reverse direction (miles),

$n = 4$ for a divided section, and

$n = 2$ for an undivided section.

6. Percent of length with mountable curb: The definition of this parameter is entirely analogous to the percent of length with barrier curb.

I. Curves

The Microsection File contains nine parameters relating to curves: the number of curves on the microsection, the percent of section length on curves, the mean and standard deviation of demand skid number, the maximum demand skid number, the mean traction margin for curves, the minimum traction margin for curves and the mean and standard deviation of traction margin for both curves and tangents.

The following quantities are used in the calculation of the curve parameters:

PC = Coordinate of the point of curvature for the curve (miles),

PT = Coordinate of the point of tangency for the curve (miles),

Y_B = Azimuth of back tangent of the curve (degrees),

Y_F = Azimuth of forward tangent of the curve (degrees),

A = Accelerometer reading, ratio of lateral acceleration to acceleration of gravity (dimensionless),

V_A = Speed of survey vehicle at time of accelerometer reading (mph),

V_{85} = 85th percentile speed of traffic on the microsection (mph), and

$\overline{SN(85)}$ = Microsection mean skid number at 85th percentile speed.

For some curves, values for one or more of these variables are missing. No analysis of such curves could be made.

The File parameters are:

1. Number of curves on microsection: The total number of curves which lie wholly or partly within the final section boundaries is defined as n .

2. Percent of section length on curves: The length of the i^{th} curve in the section is:

$$L_{c_i} = PT_i - PC_i$$

where L_{c_i} = length of the i^{th} curve (miles).

The percent of the microsection length on curves, P_c , is:

$$P_c = \frac{100}{L} \sum_{i=1}^{n} L_{c_i}$$

3. Mean and standard deviation of demand skid number: The change in heading (ΔY) in degrees for a curve is the smaller of the two quantities $|Y_F - Y_B|$ and $360 - |Y_F - Y_B|$.

The radius of curvature for a curve is:

$$R_i = \frac{5280(57.296)L_{c_i}}{\Delta Y}$$

where R = radius of curvature of the i^{th} curve (ft).

The superelevation of a curve is:

$$e_i = \frac{0.0668(V_A)^2}{R} - A \text{ for a left curve, and}$$

$$e_i = \frac{0.0668(V_A)^2}{R} + A \text{ for a right curve}$$

where e_i = superelevation of the i^{th} curve (ft/ft).

Superelevation, as measured in the field, is an extremely variable quantity. To avoid the use of absurdly large or small values, e_i was restricted to the range $0 \leq e_i \leq 0.1$. A value of 0 was assumed for e_i values calculated to be less than 0; a value of 0.1 was assumed for e_i values calculated to be greater than 0.1.

The demand skid number of the i^{th} curve at the 85th percentile speed, DSN_i , is:

$$DSN_i = \left| \frac{6.68 \left(V_{85_i}\right)^2}{R_i} - 100e_i \right| .$$

The mean demand skid number for all curves on the microsection is calculated by weighing the DSN of each curve by its length:

$$\overline{DSN} = \frac{\sum_{i=1}^{n} DSN_i\left(L_{c_i}\right)}{CL}$$

where $\overline{DSN}$ = Mean demand skid number at 85th percentile speed, and

$$CL = \sum_{i=1}^{n} L_{c_i} = \text{Total length of all curves on the microsection (miles).}$$

The weighted standard deviation of demand skid number for all curves on the microsection was defined as:

$$S_{DSN} = \left[\frac{100}{99\ CL} \sum_{i=1}^{n} L_{c_i} (DSN_i - \overline{DSN})^2 \right]^{1/2}$$

Unlike the mean, there is no unique definition for the standard deviation of a weighted distribution. In this case, the weights used were percentages of the total length on curves, which sum to 100%; therefore, a total sample size of 100 was used in the calculation of standard deviation. The denominator of the expression for standard deviation contains the sum of the weights minus 1 degree of freedom, in this case, 99.

4. Maximum demand skid number: The largest demand skid number for any curve on each macrosection (DSN_{max}) is also placed in the File.

5. Mean traction margin for curves: The mean traction margin for all the curves on a microsection is defined as:

$$\overline{TM}_c = \frac{1}{CL} \sum_{i=1}^{n} \left(TM_{c_i}\right)\left(L_{c_i}\right) = \overline{SN(85)} - \overline{DSN}$$

where $\overline{TM}_c$ = mean traction margin for the curves, and

$TM_{c_i} = \overline{SN(85)} - DSN_i$ = traction margin for the i th curve.

6. Minimum traction margin for curves: The minimum traction margin for all the curves on a microsection is defined as:

$$TM_{min} = \overline{SN(85)} - DSN_{max}.$$

7. Mean and standard deviation of traction margin for both curves and tangents: The weighted mean traction margin for both curves and tangents, $\overline{TM}$, is:

$$\overline{TM} = \frac{(L - CL)\ \overline{SN(85)} + CL\ (\overline{TM}_c)}{L}.$$

The weighted standard deviation of traction margin for both curves and tangents is:

$$S_{TM} = \left[\frac{\frac{100\ (L - CL)}{L}\ (\overline{SN(85)})^2 + \frac{100}{L} \sum_{i=1}^{n} L_{c_i}\left(TM_{c_i} - \overline{TM}_c\right)^2}{99}\right]^{1/2}$$

The minimum traction margin for both curves and tangents is not calculated because it is equal to the minimum traction margin for curves alone.

J. Grade

The final two parameters in the File are related to grade and vertical profile. Both parameters were determined from the altimeter data collected at 0.2-mile intervals in the field inventory.

1. Percent of length on significant grade: This parameter is the percent of the microsection length on significant grade. A grade is significant if it is greater than or equal to 4% and at least 0.4 miles in length.

2. Number of sag vertical curves: This parameter is the total number of sag vertical curves on each microsection. One sag vertical curve was counted at each point where the profile grade changed sign from negative to positive.

APPENDIX F

ANALYSIS OF COVARIANCE RESULTS

This Appendix presents the results of 20 analyses of covariance that were used in Section V to develop the relationship between wet-pavement accident rate and skid number. Table 34 identifies the variable names used throughout this Appendix. Tables 35 through 54 present the analyses of covariance. The following information is presented for each analysis:

- Dependent variable;
- Factors used to define the covariance framework;
- Covariate;
- Input data used for each analysis of covariance;
- Total number of cases in the input data (total sample size);
- Figure illustrating the factor levels used in the covariance framework;
- Common slope determined by the analysis;
- Multiple r for the analysis;
- Multiple r^2 for the analysis;
- Analysis of variance tabulation;
- Slope, intercept, sample size and means for the regression in each cell of the covariance framework;
- Total residual sum of squares and its four components used in the calculation of the following F-ratios; and
- Four F-ratios used to interpret analysis of covariance results at the 95% confidence level.

TABLE 34

VARIABLE NAMES USED IN THE ANALYSES OF COVARIANCE

Variable Name	Variable
ADT	Average daily traffic volume (vehicles)
AR	Wet-pavement accident rate (accidents/MVM)
ARDIF	Difference between wet-pavement accident rate for after period and wet-pavement accident rate for before period (AR (after) - AR (before)).
ATYP	Area type (levels: rural, urban)
DAR	Dry-pavement accident rate (accidents/MVM)
HTYP	Highway type Levels: 2LUA = Two-lane, uncontrolled access MLUA = Multilane, uncontrolled access MLCA = Multilane, controlled access
MGR	Mean gradient rating (1 to 5 scale)
RAIN	Exposure to high-intensity rainfall (hours/year)
RELDAR	Relative dry-pavement accident rate level as defined in Table 16
SN40	Skid number at 40 mph
SN40DIF	Difference between skid number at 40 mph for after period and skid number at 40 mph for before period (SN40 (after) - SN40 (before)).
SN(85)	Skid number at 85th percentile speed
TIME	Study period Levels: before, after

TABLE 35

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, HTYP, TIME
COVARIATE	SN40
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

			HTYP		
			2LUA	MLUA	MLCA
BEFORE	ATYP	RURAL			
		URBAN			
AFTER	ATYP	RURAL			
		URBAN			

COMMON SLOPE = -0.049

MULTIPLE r = 0.433 MULTIPLE r^2 = 0.187

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1281.385	4	320.346	43.865	0.001
ATYP	541.364	1	541.364	74.129	0.001
HTYP	799.245	2	399.622	54.721	0.001
TIME	9.462	1	9.462	1.296	0.254
Covariates	133.339	1	133.339	18.258	0.001
SN40	133.339	1	133.339	18.258	0.001
2-Way Interactions	341.317	5	68.263	9.347	0.001
ATYP HTYP	324.162	2	162.081	22.194	0.001
ATYP TIME	13.442	1	13.442	1.841	0.172
HTYP TIME	3.454	2	1.727	0.236	0.999
3-Way Interactions	12.387	2	6.194	0.848	0.999
ATYP HTYP TIME	12.387	2	6.194	0.848	0.999
Explained	1768.430	12	147.369	20.179	0.001
Residual	5791.250	793	7.303		
TOTAL	7559.680	805	9.391		

TABLE 36

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, HTYP, TIME
COVARIATE	SN(85)
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

			HTYP		
			2LUA	MLUA	MLCA
BEFORE	ATYP	RURAL			
		URBAN			
AFTER	ATYP	RURAL			
		URBAN			

COMMON SLOPE = -0.031

MULTIPLE r = 0.421 MULTIPLE r^2 = 0.177

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1281.385	4	320.346	43.329	0.001
ATYP	541.364	1	541.364	73.224	0.001
HTYP	799.245	2	399.622	54.052	0.001
TIME	9.462	1	9.462	1.280	0.257
Covariates	60.023	1	60.023	8.119	0.005
SN(85)	60.023	1	60.023	8.119	0.005
2-Way Interactions	344.680	5	68.936	9.324	0.001
ATYP HTYP	327.486	2	163.743	22.148	0.001
ATYP TIME	13.996	1	13.996	1.893	0.165
HTYP TIME	2.826	2	1.413	0.191	0.999
3-Way Interactions	10.729	2	5.364	0.726	0.999
ATYP HTYP TIME	10.728	2	5.364	0.726	0.999
Explained	1696.820	12	141.402	19.126	0.001
Residual	5862.859	793	7.393		
TOTAL	7559.680	805	9.391		

TABLE 37

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, HTYP, TIME
COVARIATE	SN40
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

	ATYP	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
BEFORE	RURAL			
	URBAN			
AFTER	RURAL			
	URBAN			

COMMON SLOPE = -0.049

MULTIPLE r = 0.433 MULTIPLE r^2 = 0.187

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1281.385	4	320.346	43.865	0.001
ATYP	541.364	1	541.364	74.129	0.001
HTYP	799.245	2	399.622	54.721	0.001
TIME	9.462	1	9.462	1.296	0.254
Covariates	133.339	1	133.339	18.258	0.001
SN40	133.339	1	133.339	18.258	0.001
2-Way Interactions	341.317	5	68.263	9.347	0.001
ATYP HTYP	324.162	2	162.081	22.194	0.001
ATYP TIME	13.442	1	13.442	1.841	0.172
HTYP TIME	3.454	2	1.727	0.236	0.999
3-Way Interactions	12.387	2	6.194	0.848	0.999
ATYP HTYP TIME	12.387	2	6.194	0.848	0.999
Explained	1768.430	12	147.369	20.179	0.001
Residual	5791.250	793	7.303		
TOTAL	7559.680	805	9.391		

TABLE 37 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

	ATYP		HTYP: 2LUA	MLUA	MLCA
BEFORE	RURAL	b	-0.08449	-0.06440	-0.01406
		a	+7.20139	+6.02587	+1.45747
		$\overline{AR}$	3.1205	3.0890	0.8396
		$\overline{SN40}$	48.3029	45.6060	43.9302
		N	275	50	53
	URBAN	b	+0.01622	+0.21289	-0.04546
		a	+2.93154	-0.24968	+4.11545
		$\overline{AR}$	3.6156	8.0850	2.1379
		$\overline{SN40}$	42.1722	39.1500	43.5000
		N	18	18	14
AFTER	RURAL	b	-0.03400	-0.09902	-0.00468
		a	+4.48548	+6.99956	+0.67117
		$\overline{AR}$	2.8674	2.5057	0.4586
		$\overline{SN40}$	47.5860	45.3808	45.3773
		N	243	47	44
	URBAN	b	+0.20283	-0.11673	-0.11252
		a	-3.18972	+13.31473	+5.73278
		$\overline{AR}$	4.8407	8.8069	1.7907
		$\overline{SN40}$	39.5928	38.6187	35.0357
		N	14	16	14

RESIDUALS FROM OVERALL REGRESSION

Sum of Squares	df
SS_t = 7348.31076	793
SS_1 = 5630.68746	782
SS_2 = 161.33109	11
SS_3 = 1510.83386	10
SS_4 = 45.45835	1

F_1 = 19.37054 > F(11,793) OVERALL REGRESSION IS SIGNIFICANT

F_2 = 10.84303 > F(22,782) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

F_3 = 2.03690 < F(11,782) ACCEPT COMMON SLOPE FOR ALL CELLS

F_4 = 20.68521 > F(10,793) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 38

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, ADT, TIME
COVARIATE	SN40
INPUT DATA	RURAL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	712

			HTYP		
			2LUA	MLUA	MLCA
BEFORE	ADT	0-9,999			
		Over 10,000			
AFTER	ADT	0-9,999			
		Over 10,000			

COMMON SLOPE = -0.047

MULTIPLE r = 0.350 MULTIPLE r^2 = 0.123

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	552.621	4	138.155	20.824	0.001
HTYP	527.269	2	263.634	39.738	0.001
ADT	87.070	1	87.070	13.124	0.001
TIME	17.914	1	17.914	2.700	0.097
Covariates	103.288	1	103.288	15.569	0.001
SN40	103.288	1	103.288	15.569	0.001
2-Way Interactions	57.947	5	11.589	1.747	0.121
HTYP ADT	56.104	2	28.052	4.228	0.015
HTYP TIME	1.281	2	0.641	0.097	0.999
ADT TIME	0.199	1	0.199	0.030	0.999
3-Way Interactions	0.357	2	0.179	0.027	0.999
HTYP ADT TIME	0.357	2	0.179	0.027	0.999
Explained	714.215	12	59.518	8.971	0.001
Residual	4637.434	699	6.634		
TOTAL	5351.648	711	7.527		

TABLE 38 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

			HTYP		
	ADT		2LUA	MLUA	MLCA
BEFORE	0-9,999	b	-0.07320	+0.05626	-0.07669
		a	+6.62783	-0.78482	+4.70157
		$\overline{AR}$	3.0650	2.0241	0.8847
		$\overline{SN40}$	48.6725	49.9259	49.7684
		N	262	27	19
	Over 10,000	b	-0.27528	-0.05665	-0.01668
		a	+15.48617	+6.63540	+1.49285
		$\overline{AR}$	4.2400	4.3391	0.8144
		$\overline{SN40}$	40.8538	40.5348	40.6676
		N	13	23	34
AFTER	0-9,999	b	-0.02581	-0.04184	-0.00889
		a	+4.05200	+3.66978	+0.92461
		$\overline{AR}$	2.8130	1.6162	0.4720
		$\overline{SN40}$	48.0138	49.0846	50.9400
		N	231	26	15
	Over 10,000	b	-0.11372	-0.10832	-0.00580
		a	+8.38984	+8.02591	+0.69843
		$\overline{AR}$	3.9150	3.6071	0.4517
		$\overline{SN40}$	39.3500	40.7952	42.5000
		N	12	21	29

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 5258.41620	699
SS_1 = 4550.12568	688
SS_2 = 87.69484	11
SS_3 = 613.90146	10
SS_4 = 6.69422	1

$F_1 = 8.50314 > F(11,699)$ OVERALL REGRESSION IS SIGNIFICANT

$F_2 = 4.86804 > F(22,688)$ CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

$F_3 = 1.20544 < F(11,688)$ ACCEPT COMMON SLOPE FOR ALL CELLS

$F_4 = 9.25256 > F(10,699)$ NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 39

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, ADT, TIME
COVARIATE	SN40
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

		ADT		
		0-9,999	10,000-19,999	Over 20,000
BEFORE (ATYP)	RURAL			
	URBAN			
AFTER (ATYP)	RURAL			
	URBAN			

COMMON SLOPE = -0.044

MULTIPLE r = 0.286 MULTIPLE r^2 = 0.082

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	521.334	4	130.334	15.355	0.001
ATYP	441.799	1	441.799	52.051	0.001
ADT	39.194	2	19.597	2.309	0.098
TIME	7.929	1	7.929	0.934	0.999
Covariates	98.364	1	98.364	11.589	0.001
SN40	98.364	1	98.364	11.589	0.001
2-Way Interactions	133.116	5	26.623	3.137	0.008
ATYP ADT	115.221	2	57.611	6.787	0.001
ATYP TIME	16.221	1	16.221	1.911	0.163
ADT TIME	8.586	2	4.293	0.506	0.999
3-Way Interactions	76.077	2	38.039	4.482	0.012
ATYP ADT TIME	76.077	2	38.039	4.482	0.012
Explained	828.895	12	69.075	8.138	0.001
Residual	6730.785	793	8.488		
TOTAL	7559.680	805	9.391		

TABLE 39 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$AR = (b)(SN40) + a$

			ADT		
			0-9,999	10,000-19,999	Over 20,000
BEFORE	ATYP	RURAL	b -0.06528 a = +6.02817 $\overline{AR}$ = 2.8392 $\overline{SN40}$ = 48.8500 N = 308	b = -0.17816 a = +10.74310 $\overline{AR}$ = 3.3291 $\overline{SN40}$ = 41.6152 N = 46	b = +0.01333 a = +0.71057 $\overline{AR}$ = 1.2279 $\overline{SN40}$ = 38.8250 N = 24
		URBAN	b = +0.06182 a = +0.61345 $\overline{AR}$ = 3.3277 $\overline{SN40}$ = 43.9077 N = 13	b = -0.03 a = +5.34 $\overline{AR}$ = 4.2450 $\overline{SN40}$ = 38.4800 N = 10	b = -0.04348 a = +7.53359 $\overline{AR}$ = 5.7344 $\overline{SN40}$ = 41.3778 N = 27
AFTER	ATYP	RURAL	b = -0.03322 a = +4.17315 $\overline{AR}$ = 2.5695 $\overline{SN40}$ = 48.2776 N = 272	b = -0.06707 a = +5.39951 $\overline{AR}$ = 2.5663 $\overline{SN40}$ = 42.2390 N = 41	b = -0.11816 a = +6.12551 $\overline{AR}$ = 1.4576 $\overline{SN40}$ = 39.5048 N = 21
		URBAN	b = +0.18381 a = -2.43641 $\overline{AR}$ = 4.6800 $\overline{SN40}$ = 38.7167 N = 12	b = -0.25848 a = +17.84997 $\overline{AR}$ = 8.2950 $\overline{SN40}$ = 36.9667 N = 6	b = +0.14327 a = -0.46355 $\overline{AR}$ = 4.9162 $\overline{SN40}$ = 37.5500 N = 26

RESIDUALS FROM OVERALL REGRESSION

Sum of Squares	df
SS_t = 7348.31076	793
SS_1 = 6569.99934	782
SS_2 = 162.16877	11
SS_3 = 597.10245	10
SS_4 = 19.04020	1

$F_1 = 6.59792 > F(11,793)$ OVERALL REGRESSION IS SIGNIFICANT
$F_2 = 4.21087 > F(22,782)$ CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
$F_3 = 1.75475 < F(11,782)$ ACCEPT COMMON SLOPE FOR ALL CELLS
$F_4 = 7.03343 > F(10,793)$ NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 40

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	ARDIF
FACTORS	ATYP, HTYP
COVARIATE	SN40DIF
INPUT DATA	AFTER - BEFORE DIFFERENCES--ALL SECTIONS
TOTAL NO. OF CASES	378

ATYP	HTYP: 2LUA	MLUA	MLCA
RURAL			
URBAN			

COMMON SLOPE = 0.028

MULTIPLE r = 0.111 MULTIPLE r^2 = 0.012

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	19.342	3	6.447	0.829	0.999
ATYP	13.511	1	13.511	1.737	0.185
HTYP	10.852	2	5.426	0.697	0.999
Covariates	16.775	1	16.775	2.156	0.139
SN40DIF	16.775	1	16.775	2.156	0.139
2-Way Interactions	6.199	2	3.099	0.398	0.999
ATYP HTYP	6.199	2	3.099	0.398	0.999
Explained	42.316	6	7.053	0.906	0.999
Residual	2886.631	371	7.781		
TOTAL	2928.947	377	7.769		

TABLE 40 (Concluded)

INDIVIDUAL CELL REGRESSIONS

ARDIF = (b)(SN40DIF) + a

ATYP	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
RURAL	b = +0.02588 a = -0.21477 $\overline{\text{ARDIF}}$ = -0.2544 $\overline{\text{SN40DIF}}$ = -1.5317 N = 243	b = -0.01091 a = -0.69093 $\overline{\text{ARDIF}}$ = -0.6823 $\overline{\text{SN40DIF}}$ = -0.7872 N = 47	b = -0.01282 a = -0.30917 $\overline{\text{ARDIF}}$ = -0.3127 $\overline{\text{SN40DIF}}$ = 0.2773 N = 44
URBAN	b = 0.04713 a = 1.09180 $\overline{\text{ARDIF}}$ = 0.8807 $\overline{\text{SN40DIF}}$ = -4.4786 N = 14	b = 0.29970 a = 0.23720 $\overline{\text{ARDIF}}$ = -0.0681 $\overline{\text{SN40DIF}}$ = -1.0188 N = 16	b = -0.02543 a = -0.56237 $\overline{\text{ARDIF}}$ = -0.3471 $\overline{\text{SN40DIF}}$ = -8.4643 N = 14

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 2917.43664	371
SS_1 = 2821.22765	366
SS_2 = 65.48863	5
SS_3 = 12.31671	4
SS_4 = 18.40365	1

$F_1 = 0.78963 > F(5,371)$ OVERALL REGRESSION IS SIGNIFICANT

$F_2 = 1.24813 > F(10,366)$ CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

$F_3 = 1.69918 < F(5,366)$ ACCEPT COMMON SLOPE FOR ALL CELLS

$F_4 = 0.39573 > F(4,371)$ NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 41

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	ARDIF
FACTORS	HTYP, ADT
COVARIATE	SN40DIF
INPUT DATA	AFTER - BEFORE DIFFERENCES--RURAL SECTIONS
TOTAL NO. OF CASES	334

		HTYP		
		2LUA	MLUA	MLCA
ADT	0-9,999			
	Over 10,000			

COMMON SLOPE = 0.017

MULTIPLE r = 0.072 MULTIPLE r^2 = 0.005

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	7.218	3	2.406	0.328	0.999
HTYP	6.078	2	3.039	0.415	0.999
BADTLVL	0.002	1	0.002	0.000	0.999
Covariates	5.149	1	5.149	0.703	0.999
SN40DIF	5.149	1	5.149	0.703	0.999
2-Way Interactions	5.068	2	2.534	0.346	0.999
HTYP BADTLVL	5.068	2	2.534	0.346	0.999
Explained	17.436	6	2.906	0.397	0.999
Residual	2395.669	327	7.326		
TOTAL	2413.104	333	7.247		

TABLE 41 (Concluded)

INDIVIDUAL CELL REGRESSIONS

ARDIF = (b)(SN40DIF) + a

ADT		HTYP 2LUA	MLUA	MLCA
	0-9,999	b = +0.03034 a = -0.18406 $\overline{\text{ARDIF}}$ = -0.2309 $\overline{\text{SN40DIF}}$ = -1.5440 N = 234	b = -0.03172 a = -0.89008 $\overline{\text{ARDIF}}$ = -0.8472 $\overline{\text{SN40DIF}}$ = -1.3520 N = 25	b = -0.02035 a = -0.34209 $\overline{\text{ARDIF}}$ = -0.3737 $\overline{\text{SN40DIF}}$ = 1.5526 N = 19
	Over 10,000	b = -0.03387 a = -0.90658 $\overline{\text{ARDIF}}$ = -0.8656 $\overline{\text{SN40DIF}}$ = -1.2111 N = 9	b = 0.03521 a = -0.48988 $\overline{\text{ARDIF}}$ = -0.4950 $\overline{\text{SN40DIF}}$ = -0.1455 N = 22	b = -0.00226 a = -0.26797 $\overline{\text{ARDIF}}$ = -0.2664 $\overline{\text{SN40DIF}}$ = -0.6920 N = 25

RESIDUALS FROM OVERALL REGRESSION

Sum of Squares	df
SS_t = 2408.41100	327
SS_1 = 2384.48579	322
SS_2 = 11.22439	5
SS_3 = 1.56589	4
SS_4 = 11.13493	1

F_1 = 0.34572 > F(5,327) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 0.32309 > F(10,322) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 0.30315 < F(5,322) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 0.05343 > F(4,327) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 42

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	ARDIF
FACTORS	ATYP, ADT
COVARIATE	SN40DIF
INPUT DATA	AFTER-BEFORE DIFFERENCES--ALL SECTIONS
TOTAL NO. OF CASES	378

		ADT	
ATYP	0-9,999	10,000-19,999	Over 20,000
RURAL			
URBAN			

COMMON SLOPE = 0.026

MULTIPLE r = 0.101 MULTIPLE r^2 = 0.010

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	15.220	3	5.073	0.653	0.999
ATYP	13.428	1	13.428	1.727	0.186
BADTLVL	6.730	2	3.365	0.433	0.999
Covariates	14.600	1	14.600	1.878	0.168
SN40DIF	14.600	1	14.600	1.878	0.168
2-Way Interactions	14.688	2	7.344	0.945	0.999
ATYP BADTLVL	14.688	2	7.344	0.945	0.999
Explained	44.508	6	7.418	0.954	0.999
Residual	2884.439	371	7.775		
TOTAL	2928.947	377	7.769		

TABLE 42 (Concluded)

INDIVIDUAL CELL REGRESSIONS

ARDIF = (b)(SN40DIF) + a

ATYP		ADT: 0-9,999	ADT: 10,000-19,999	ADT: Over 20,000
	RURAL	b = +0.01918 a = -0.27086 $\overline{\text{ARDIF}}$ = -0.2961 $\overline{\text{SN40DIF}}$ = -1.3151 N = 278	b = -0.01779 a = -0.45321 $\overline{\text{ARDIF}}$ = -0.4442 $\overline{\text{SN40DIF}}$ = -0.5083 N = 36	b = +0.03719 a = -0.44314 $\overline{\text{ARDIF}}$ = -0.4675 $\overline{\text{SN40DIF}}$ = -0.6550 N = 20
	URBAN	b = -0.23110 a = -1.46338 $\overline{\text{ARDIF}}$ = 0.1018 $\overline{\text{SN40DIF}}$ = -6.7727 N = 11	b = 0.17246 a = 1.75557 $\overline{\text{ARDIF}}$ = 1.7457 $\overline{\text{SN40DIF}}$ = -0.0571 N = 7	b = +0.12259 a = +0.31038 $\overline{\text{ARDIF}}$ = -0.2677 $\overline{\text{SN40DIF}}$ = -4.7154 N = 26

RESIDUALS FROM OVERALL REGRESSION

Sum of Squares	df
SS_t = 2917.43664	371
SS_1 = 2822.79768	366
SS_2 = 61.76077	5
SS_3 = 27.84032	4
SS_4 = 5.03786	1

$F_1 = 0.84573 > F(5,371)$ OVERALL REGRESSION IS SIGNIFICANT

$F_2 = 1.22708 > F(10,366)$ CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

$F_3 = 1.60156 < F(5,366)$ ACCEPT COMMON SLOPE FOR ALL CELLS

$F_4 = 0.89518 > F(4,371)$ NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 43

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	ARDIF
FACTORS	HTYP, ATYP
COVARIATE	SN40DIF
INPUT DATA	AFTER-BEFORE DIFFERENCES-TEST SECTIONS
TOTAL NO. OF CASES	130

		HTYP		
		2LUA	MLUA	MLCA
ATYP	RURAL			
	URBAN			

COMMON SLOPE = 0.021

MULTIPLE r = 0.138 MULTIPLE r^2 = 0.019

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	17.438	3	5.813	0.701	0.999
HTYP	8.878	2	4.439	0.535	0.999
ATYP	4.503	1	4.503	0.543	0.999
Covariates	3.608	1	3.608	0.435	0.999
SN40DIF	3.608	1	3.608	0.435	0.999
2-Way Interactions	56.939	2	28.469	3.433	0.035
HTYP ATYP	56.939	2	28.469	3.433	0.035
Explained	77.985	6	12.998	1.567	0.161
Residual	1020.031	123	8.293		
TOTAL	1098.016	129	8.512		

TABLE 43 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$ARDIF = (b)(SN40DIF) + a$$

ATYP	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
RURAL	b = N/A a = N/A $\overline{ARDIF}$ = -0.2235 $\overline{SN40DIF}$ = -0.8227 N = 88	b = +0.02182 a = -0.04757 $\overline{ARDIF}$ = -0.0321 $\overline{SN40DIF}$ = 0.7071 N = 14	b = -0.03494 a = -0.29899 $\overline{ARDIF}$ = -0.4918 $\overline{SN40DIF}$ = 5.5182 N = 11
URBAN	b = +0.12931 a = +1.22436 $\overline{ARDIF}$ = 0.9183 $\overline{SN40DIF}$ = -2.3667 N = 6	b = +0.30199 a = -3.09105 $\overline{ARDIF}$ = -3.8400 $\overline{SN40DIF}$ = -2.4800 N = 5	b = 0.05216 a = -0.00473 $\overline{ARDIF}$ = -0.5150 $\overline{SN40DIF}$ = -9.7833 N = 6

TABLE 44

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	ARDIF
FACTORS	HTYP, ADT
COVARIATE	SN40DIF
INPUT DATA	AFTER-BEFORE DIFFERENCES--RURAL TEST SECTIONS
TOTAL NO. OF CASES	113

	HTYP		
ADT	2LUA	MLUA	MLCA
0-9,999			
Over 10,000			

COMMON SLOPE = -0.002

MULTIPLE r = 0.108   MULTIPLE r^2 = 0.012

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	10.402	3	3.467	0.422	0.999
HTYP	3.767	2	1.883	0.229	0.999
BADTLVL	9.098	1	9.098	1.106	0.296
Covariates	0.017	1	0.017	0.002	0.999
SN40DIF	0.017	1	0.017	0.002	0.999
2-Way Interactions	8.266	2	4.133	0.503	0.999
HTYP BADTLVL	8.266	2	4.133	0.503	0.999
Explained	18.685	6	3.114	0.379	0.999
Residual	871.798	106	8.225		
TOTAL	890.483	112	7.951		

TABLE 44 (Concluded)

INDIVIDUAL CELL REGRESSIONS

ARDIF = (b)(SN40DIF) + a

ADT	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
0-9,999	b = -0.00782 a = -0.14848 $\overline{\text{ARDIF}}$ = -0.1425 $\overline{\text{SN40DIF}}$ = -0.7655 N = 84	b = +0.16028 a = +0.75809 $\overline{\text{ARDIF}}$ = 0.5429 $\overline{\text{SN40DIF}}$ = -1.3429 N = 7	b = N/A a = N/A $\overline{\text{ARDIF}}$ = -0.7460 $\overline{\text{SN40DIF}}$ = 9.0800 N = 5
Over 10,000	b = +0.03378 a = -1.85660 $\overline{\text{ARDIF}}$ = -1.9250 $\overline{\text{SN40DIF}}$ = -2.0250 N = 4	b = +0.03145 a = -0.69386 $\overline{\text{ARDIF}}$ = -0.6071 $\overline{\text{SN40DIF}}$ = 2.7571 N = 7	b = -0.02892 a = -0.20625 $\overline{\text{ARDIF}}$ = -0.2800 $\overline{\text{SN40DIF}}$ = 2.5500 N = 6

TABLE 45

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, HTYP
COVARIATE	SN40
INPUT DATA	BEFORE DATA, ALL SECTIONS
TOTAL NO. OF CASES	428

		HTYP		
		2LUA	MLUA	MLCA
ATYP	RURAL			
	URBAN			

COMMON SLOPE = -0.060

MULTIPLE r = 0.420 MULTIPLE r^2 = 0.177

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	572.468	3	190.823	27.054	0.001
ATYP	191.663	1	191.663	27.173	0.001
HTYP	393.288	2	196.644	27.879	0.001
Covariates	97.379	1	97.379	13.806	0.001
SN40	97.379	1	97.379	13.806	0.001
2-Way Interactions	154.635	2	77.317	10.962	0.001
ATYP HTYP	154.635	2	77.317	10.962	0.001
Explained	824.481	6	137.414	19.482	0.001
Residual	2969.525	421	7.054		
TOTAL	3794.006	427	8.885		

TABLE 45 (Concluded)

INDIVIDUAL CELL REGRESSIONS

AR = (b)(SN40) + a

ATYP		HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
RURAL	b	-0.08449	-0.06440	-0.01406
	a	+7.20139	+6.02587	+1.45747
	$\overline{AR}$	3.1205	3.0890	0.8396
	$\overline{SN40}$	48.3029	45.6060	43.9302
	N	275	50	53
URBAN	b	+0.01622	+0.21289	-0.04546
	a	+2.93154	-0.24968	+4.11545
	$\overline{AR}$	3.6156	8.0850	2.1379
	$\overline{SN40}$	42.1722	39.1500	43.5000
	N	18	18	14

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 3672.55878	421
SS_1 = 2880.64888	416
SS_2 = 89.03400	5
SS_3 = 692.16508	4
SS_4 = 10.71083	1

F_1 = 19.92878 > F(5,421) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 11.43612 > F(10,416) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 2.57151 < F(5,416) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 24.53136 > F(4,421) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 46

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, ADT
COVARIATE	SN40
INPUT DATA	BEFORE DATA, RURAL SECTIONS ONLY
TOTAL NO. OF CASES	378

ADT	RURAL	HTYP 2LUA	MLUA	MLCA
	0-9,999			
	Over 10,000			

COMMON SLOPE = -0.063

MULTIPLE r = 0.361 MULTIPLE r^2 = 0.131

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	284.797	3	94.932	14.460	0.001
HTYP	281.769	2	140.884	21.459	0.001
ADT	48.712	1	48.712	7.420	0.007
Covariates	86.300	1	86.300	13.145	0.001
SN40	86.300	1	86.300	13.145	0.001
2-Way Interactions	34.613	2	17.306	2.636	0.071
HTYP ADT	34.613	2	17.306	2.636	0.071
Explained	405.709	6	67.618	10.299	0.001
Residual	2435.749	371	6.565		
TOTAL	2841.458	377	7.537		

TABLE 46 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

RURAL (ADT)	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
0-9,999	b = -0.07320 a = +6.62783 $\overline{AR}$ = 3.0650 $\overline{SN40}$ = 48.6725 N = 222	b = +0.05626 a = -0.78482 $\overline{AR}$ = 2.0241 $\overline{SN40}$ = 49.9259 N = 27	b = -0.07669 a = +4.70157 $\overline{AR}$ = 0.8847 $\overline{SN40}$ = 49.7684 N = 19
Over 10,000	b = -0.27528 a = +15.48617 $\overline{AR}$ = 4.2400 $\overline{SN40}$ = 40.8538 N = 13	b = -0.05665 a = +6.63540 $\overline{AR}$ = 4.3391 $\overline{SN40}$ = 40.5348 N = 23	b = -0.01668 a = +1.49285 $\overline{AR}$ = 0.8144 $\overline{SN40}$ = 40.6676 N = 34

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 2772.54128	371
SS_1 = 2376.07159	366
SS_2 = 59.71391	5
SS_3 = 325.39188	4
SS_4 = 11.36390	1

F_1 = 10.25841 > F(5,371) OVERALL REGRESSION IS SIGNIFICANT

F_2 = 6.10705 > F(10,366) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

F_3 = 1.83962 < F(5,366) ACCEPT COMMON SLOPE FOR ALL CELLS

F_4 = 12.39029 > F(4,371) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 47

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, ADT
COVARIATE	SN40
INPUT DATA	BEFORE DATA, ALL SECTIONS
TOTAL NO. OF CASES	428

		ADT	
ATYP	0-9,999	10,000-19,999	Over 20,000
RURAL			
URBAN			

COMMON SLOPE = -0.055

MULTIPLE r = 0.263 MULTIPLE r^2 = 0.069

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	189.196	3	63.065	7.836	0.001
ATYP	150.434	1	150.434	18.692	0.001
ADT	10.015	2	5.008	0.622	0.999
Covariates	72.982	1	72.982	9.068	0.003
SN40	72.982	1	72.982	9.068	0.003
2-Way Interactions	143.674	2	71.837	8.926	0.001
ATYP ADT	143.674	2	71.837	8.926	0.001
Explained	405.852	6	67.642	8.405	0.001
Residual	3388.155	421	8.048		
TOTAL	3794.006	427	8.885		

TABLE 47 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$AR = (b)(SN40) + a$

ATYP	ADT: 0-9,999	ADT: 10,000-19,999	ADT: Over 20,000
RURAL	b = -0.06528 a = +6.02817 $\overline{AR}$ = 2.8392 $\overline{SN40}$ = 48.8500 N = 308	b = -0.17816 a = +10.74310 $\overline{AR}$ = 3.3291 $\overline{SN40}$ = 41.6152 N = 46	b = +0.01333 a = +0.71057 $\overline{AR}$ = 1.2279 $\overline{SN40}$ = 38.8250 N = 24
URBAN	b = +0.06182 a = +0.61345 $\overline{AR}$ = 3.3277 $\overline{SN40}$ = 43.9077 N = 13	b = -0.03 a = +5.34 $\overline{AR}$ = 4.2450 $\overline{SN40}$ = 38.4800 N = 10	b = -0.04348 a = +7.53359 $\overline{AR}$ = 5.7344 $\overline{SN40}$ = 41.3778 N = 27

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 3672.55878	421
SS_1 = 3334.91328	416
SS_2 = 54.57702	5
SS_3 = 282.88504	4
SS_4 = 0.18344	1

F_1 = 7.03184 > F(5,421) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 4.21182 > F(10,416) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.36160 < F(5,416) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 8.78411 > F(4,421) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 48

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ADT
COVARIATE	SN40
INPUT DATA	BEFORE DATA, RURAL 2-LANE SECTIONS
TOTAL NO. OF CASES	275

	ADT			
	0-2,999	3,000-4,999	5,000-9,999	Over 10,000
RURAL				

COMMON SLOPE = -0.078

MULTIPLE r = 0.245 MULTIPLE r^2 = 0.060

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	41.796	3	13.932	1.743	0.157
ADT	41.796	3	13.932	1.743	0.157
Covariates	95.499	1	95.499	11.947	0.001
SN40	95.499	1	95.499	11.947	0.001
Explained	137.294	4	34.324	4.294	0.002
Residual	2158.243	270	7.993		
TOTAL	2295.538	274	8.378		

TABLE 48 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

	ADT			
	0-2,999	3,000-4,999	5,000-9,999	10,000-19,999
RURAL 2-LANE	b = -0.06032 a = +5.94757 $\overline{AR}$ = 2.9432 $\overline{SN40}$ = 49.8042 N = 120	b = -0.12081 a = +8.73068 $\overline{AR}$ = 2.89260 $\overline{SN40}$ = 48.8762 N = 80	b = -0.02078 a = +4.56908 $\overline{AR}$ = 3.6089 $\overline{SN40}$ = 46.2193 N = 62	b = -0.27528 a = +15.48617 $\overline{AR}$ = 4.2400 $\overline{SN40}$ = 40.8538 N = 13

Sums of Squares	df
SS_t = 2173.32843	270
SS_1 = 2113.47455	267
SS_2 = 44.79576	3
SS_3 = -0.22541	2
SS_4 = 15.28353	1

$F_1 = 0.62792 > F(3,270)$ OVERALL REGRESSION IS SIGNIFICANT
$F_2 = 1.26025 > F(6,267)$ CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
$F_3 = 1.88638 < F(3,267)$ ACCEPT COMMON SLOPE FOR ALL CELLS
$F_4 = -0.01410 > F(2,270)$ NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 49

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, HTYP
COVARIATE	SN40
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

ATYP	HTYP: 2LUA	MLUA	MLCA
RURAL			
URBAN			

COMMON SLOPE = -0.048

MULTIPLE r = 0.431   MULTIPLE r^2 = 0.185

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1271.922	3	423.974	58.101	0.001
ATYP	541.708	1	541.708	74.236	0.001
HTYP	798.148	2	399.074	54.689	0.001
Covariates	130.041	1	130.041	17.821	0.001
SN40	130.041	1	130.041	17.821	0.001
2-Way Interactions	327.292	2	163.646	22.426	0.001
ATYP HTYP	327.292	2	163.646	22.426	0.001
Explained	1729.258	6	288.209	39.496	0.001
Residual	5830.422	799	7.297		
TOTAL	7559.680	805	9.391		

TABLE 49 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

		HTYP		
		2LUA	MLUA	MLCA
ATYP	RURAL	b = -0.05775 a = +5.77196 $\overline{AR}$ = +3.0018 $\overline{SN40}$ = +47.9666 N = 518	b = -0.08326 a = +6.59433 $\overline{AR}$ = +2.8064 $\overline{SN40}$ = +45.4969 N = 97	b = -0.01092 a = +1.15353 $\overline{AR}$ = +0.6668 $\overline{SN40}$ = +44.5866 N = 97
	URBAN	b = +0.07276 a = +1.16532 $\overline{AR}$ = +4.1516 $\overline{SN40}$ = +41.0437 N = 32	b = +0.06259 a = +5.99006 $\overline{AR}$ = +8.4247 $\overline{SN40}$ = +38.9000 N = 34	b = -0.04330 a = +3.66441 $\overline{AR}$ = +1.9643 $\overline{SN40}$ = +39.2679 N = 28

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 7348.31076	799
SS_1 = 5762.63171	794
SS_2 = 68.53310	5
SS_3 = 1450.88003	4
SS_4 = 66.26592	1

F_1 = 41.57659 > F(5,799) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 21.84816 > F(10,794) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.88856 < F(5,794) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 49.70075 > F(4,799) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 50

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, ADT
COVARIATE	SN40
INPUT DATA	RURAL SECTIONS ONLY, BEFORE AND AFTER
TOTAL NO. OF CASES	712

		HTYP	
ADT	2LUA	MLUA	MLCA
0-9,999			
Over 10,000			

COMMON SLOPE = -0.047

MULTIPLE r = 0.345 MULTIPLE r^2 = 0.119

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	534.707	3	178.236	26.972	0.001
HTYP	525.014	2	262.507	39.724	0.001
ADT	86.805	1	86.805	13.136	0.001
Covariates	101.459	1	101.459	15.353	0.001
SN40	101.459	1	101.459	15.353	0.001
2-Way Interactions	56.647	2	28.323	4.286	0.014
HTYP ADT	56.647	2	28.324	4.286	0.014
Explained	692.816	6	115.469	17.473	0.001
Residual	4658.832	705	6.608		
TOTAL	5351.648	711	7.527		

TABLE 50 (Concluded)

INDIVIDUAL CELL REGRESSIONS

$$AR = (b)(SN40) + a$$

ADT		HTYP 2LUA	HTYP MLUA	HTYP MLCA
0-9,999	b =	-0.04815	-0.00027	-0.03858
	a =	+5.27579	+1.83731	+2.64264
	$\overline{AR}$ =	2.9469	1.8240	0.7026
	$\overline{SN40}$ =	48.3639	49.5132	50.2853
	N =	493	53	34
Over 10,000	b =	-0.18824	-0.08832	-0.01278
	a =	+11.63849	+7.58064	+1.17806
	$\overline{AR}$ =	4.0840	3.9898	0.6475
	$\overline{SN40}$ =	50.1320	40.6591	41.5111
	N =	25	44	63

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 5258.41620	705
SS_1 = 4611.79072	700
SS_2 = 47.44555	5
SS_3 = 593.03678	4
SS_4 = 6.14315	1

F_1 = 18.13266 > F(5,705) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 9.81480 > F(10,700) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.44030 < F(5,700) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 22.43345 > F(4,705) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 51

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	ATYP, ADT
COVARIATE	SN40
INPUT DATA	ALL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	806

ATYP	ADT 0-9,999	ADT 10,000-19,999	ADT Over 20,000
RURAL			
URBAN			

COMMON SLOPE = -0.043

MULTIPLE r = 0.284 MULTIPLE r^2 = 0.081

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	513.406	3	171.135	20.002	0.001
ATYP	442.290	1	442.290	51.694	0.001
ADT	39.631	2	19.816	2.316	0.097
Covariates	95.608	1	95.608	11.175	0.001
SN40	95.608	1	95.608	11.175	0.001
2-Way Interactions	114.483	2	57.242	6.690	0.001
ATYP ADT	114.483	2	57.242	6.690	0.001
Explained	723.500	6	120.583	14.094	0.001
Residual	6836.180	799	8.556		
TOTAL	7559.680	805	9.391		

TABLE 51 (Concluded)

INDIVIDUAL CELL REGRESSIONS

AR = (b)(SN40) + a

ATYP		ADT 0-9,999	ADT 10,000-19,999	ADT Over 20,000
ATYP	RURAL	b = -0.04779 a = +5.03467 $\overline{AR}$ = 2.7127 $\overline{SN40}$ = 48.5815 N = 580	b = -0.11306 a = +7.70803 $\overline{AR}$ = 2.9697 $\overline{SN40}$ = 41.9092 N = 87	b = -0.04897 a = +3.25190 $\overline{AR}$ = 1.3351 $\overline{SN40}$ = 39.1422 N = 45
ATYP	URBAN	b = +0.06338 a = +1.35200 $\overline{AR}$ = 3.9768 $\overline{SN40}$ = 41.4160 N = 25	b = -0.13639 a = +10.93461 $\overline{AR}$ = 5.7637 $\overline{SN40}$ = 37.9125 N = 16	b = +0.06798 a = +2.64793 $\overline{AR}$ = 5.3330 $\overline{SN40}$ = 39.5000 N = 53

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 7348.31076	799
SS_1 = 6755.98816	794
SS_2 = 82.42019	5
SS_3 = 487.62793	4
SS_4 = 22.27448	1

F_1 = 11.91541 > F(5,799) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 6.96129 > F(10,794) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.93729 < F(5,794) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 14.24362 > F(4,799) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 52

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, ATYP, RELDAR
COVARIATE	SN40
INPUT DATA	ALL SECTIONS
TOTAL NO. OF CASES	806

		HTYP	
	2LUA	MLUA	MLCA
RELDAR = 1			
ATYP RURAL			
ATYP URBAN			
RELDAR = 2			
ATYP RURAL			
ATYP URBAN			
RELDAR = 3			
ATYP RURAL			
ATYP URBAN			

COMMON SLOPE = -0.035

MULTIPLE r = 0.593 MULTIPLE r^2 = 0.352

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	2594.356	5	518.871	96.256	0.001
HTYP	794.553	2	397.277	73.699	0.001
ATYP	557.402	1	557.402	103.404	0.001
RELDAR	1322.428	2	661.214	122.662	0.001
Covariates	66.735	1	66.735	12.380	0.001
SN40	66.735	1	66.735	12.380	0.001
2-Way Interactions	578.968	8	72.371	13.426	0.001
HTYP ATYP	329.759	2	164.879	30.587	0.001
HTYP RELDAR	187.766	4	46.941	8.708	0.001
ATYP RELDAR	62.169	2	31.084	5.766	0.003
3-Way Interactions	77.475	4	19.369	3.593	0.007
HTYP ATYP RELDAR	77.475	4	19.369	3.593	0.007
Explained	3317.535	18	184.307	34.191	0.001
Residual	4242.344	787	5.391		
TOTAL	7559.879	805	9.391		

TABLE 52 (Continued)

INDIVIDUAL CELL REGRESSIONS

AR = (b)(SN40) + a

RELDAR	ATYP	Statistic	HTYP: 2LUA	HTYP: MLUA	HTYP: MLCA
RELDAR = 1	RURAL	b	+0.00901	+0.00243	-0.00763
		a	+1.17988	+1.01797	+0.77263
		$\overline{AR}$	1.6200	1.1355	0.4224
		$\overline{SN40}$	48.8474	48.2636	45.9273
		N	173	33	33
	URBAN	b	-0.08623	-0.26044	-0.05613
		a	+6.08350	+13.44598	+3.25608
		$\overline{AR}$	2.9755	4.0117	0.9030
		$\overline{SN40}$	36.0454	36.2250	41.9200
		N	11	12	10
RELDAR = 2	RURAL	b	-0.03810	-0.05416	-0.00656
		a	+4.49745	+4.72109	+0.91762
		$\overline{AR}$	2.6535	2.2244	0.6400
		$\overline{SN40}$	48.3942	46.0969	42.3156
		N	173	32	32
	URBAN	b	+0.13020	-0.13622	-0.01297
		a	-1.38614	+14.24968	+2.29514
		$\overline{AR}$	4.2409	8.9682	1.7956
		$\overline{SN40}$	43.2182	38.7727	38.5222
		N	11	11	9
RELDAR = 3	RURAL	b	-0.08657	-0.08026	-0.02254
		a	+8.78023	+8.48597	+1.97084
		$\overline{AR}$	4.7419	5.1116	0.9456
		$\overline{SN40}$	46.6506	42.0437	45.4750
		N	172	32	32
	URBAN	b	+0.01205	-0.09780	+0.03157
		a	+4.81482	+16.79762	+2.14195
		$\overline{AR}$	5.3470	12.6955	3.3122
		$\overline{SN40}$	44.1500	41.9454	37.0667
		N	10	11	9

TABLE 52 (Concluded)

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 7348.31076	787
SS_1 = 4140.79677	770
SS_2 = 102.15793	17
SS_3 = 2990.15555	16
SS_4 = 115.20051	1

F_1 = 33.88198 > F(17,787) OVERALL REGRESSION IS SIGNIFICANT

F_2 = 17.54270 > F(34,770) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT

F_3 = 1.11745 < F(17,770) ACCEPT COMMON SLOPE FOR ALL CELLS

F_4 = 34.66412 > F(16,787) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 53

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, MGR
COVARIATE	SN40
INPUT DATA	AFTER DATA, RURAL SECTIONS
TOTAL NO. OF CASES	334

		HTYP	
MGR	2LUA	MLUA	MLCA
Under 2.15			
2.15-2.85			
Over 2.85			

COMMON SLOPE = -0.038

MULTIPLE r = 0.329   MULTIPLE r^2 = 0.108

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	231.725	4	57.931	8.475	0.001
HTYP	221.207	2	110.603	16.181	0.001
MGR	15.585	2	7.792	1.140	0.321
Covariates	37.628	1	37.628	5.505	0.019
SN40	37.628	1	37.628	5.505	0.019
2-Way Interactions	10.903	4	2.726	0.399	0.999
HTYP MGR	10.903	4	2.726	0.399	0.999
Explained	280.256	9	31.140	4.556	0.001
Residual	2214.598	324	6.835		
TOTAL	2494.854	333	7.492		

TABLE 53 (Concluded)

INDIVIDUAL CELL REGRESSIONS

AR = (b)(SN40) + a

MGR	HTYP 2LUA	HTYP MLUA	HTYP MLCA
Under 2.15	b = -0.05827 a = +5.61448 $\overline{AR}$ = 2.9095 $\overline{SN40}$ = 46.4242 N = 165	b = -0.09323 a = +6.92142 $\overline{AR}$ = 2.8147 $\overline{SN40}$ = 44.0500 N = 36	b = -0.00076 a = +0.54568 $\overline{AR}$ = 0.5121 $\overline{SN40}$ = 44.2606 N = 33
2.15-2.85	b = +0.01942 a = +2.08770 $\overline{AR}$ = 3.0364 $\overline{SN40}$ = 48.8454 N = 44	b = +0.27920 a = -10.72394 $\overline{AR}$ = 2.1567 $\overline{SN40}$ = 46.1333 N = 6	b = -0.01611 a = +1.07652 $\overline{AR}$ = 0.3100 $\overline{SN40}$ = 47.5857 N = 7
Over 2.85	b = +0.06729 a = -1.02697 $\overline{AR}$ = 2.4447 $\overline{SN40}$ = 51.5941 N = 34	b = -0.07227 a = +4.60670 $\overline{AR}$ = 0.7000 $\overline{SN40}$ = 54.0600 N = 5	b = -0.02582 a = +1.58741 $\overline{AR}$ = 0.2775 $\overline{SN40}$ = 50.7250 N = 4

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 2464.24676	324
SS_1 = 2155.33853	316
SS_2 = 59.30111	8
SS_3 = 242.59153	7
SS_4 = 7.01559	1

F_1 = 4.56467 > F(8,324) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 2.83062 > F(16,316) CELL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.08679 < F(8,316) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 5.07014 > F(7,324) NO SIGNIFICANT MEANS REGRESSION EXISTS

TABLE 54

ANALYSIS OF COVARIANCE

DEPENDENT VARIABLE	AR
FACTORS	HTYP, MGR, RAIN
COVARIATE	SN40
INPUT DATA	RURAL SECTIONS, BEFORE AND AFTER
TOTAL NO. OF CASES	712

MGR Under 2.15

RAIN	HTYP: 2LUA	MLUA	MLCA
Under 12.5 hr			
Over 12.5 hr			

MGR Over 2.15

RAIN	HTYP: 2LUA	MLUA	MLCA
Under 12.5 hr			
Over 12.5 hr			

COMMON SLOPE = -0.065

MULTIPLE r = 0.337 MULTIPLE r^2 = 0.114

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	497.463	4	124.366	15.920	0.001
HTYP	490.632	2	245.316	31.402	0.001
MGR	16.291	1	16.291	2.085	0.145
RAIN	13.423	1	13.423	1.718	0.187
Covariates	207.336	1	207.336	26.541	0.001
SN40	207.336	1	207.336	26.540	0.001
2-Way Interactions	18.233	5	3.647	0.467	0.999
HTYP MGR	9.970	2	4.985	0.638	0.999
HTYP RAIN	9.555	2	4.777	0.612	0.999
MGR RAIN	0.036	1	0.036	0.005	0.999
3-Way Interactions	5.311	2	2.656	0.340	0.999
HTYP MGR RAIN	5.311	2	2.656	0.340	0.999
Explained	728.344	12	60.695	7.769	0.001
Residual	5460.637	699	7.812		
TOTAL	6188.980	711	8.705		

TABLE 54 (Concluded)

INDIVIDUAL CELL REGRESSIONS

AR = (b)(SN40) + a

MGR Under 2.15

RAIN		HTYP 2LUA	HTYP MLUA	HTYP MLCA
RAIN	Under 12.5 hr	b = -0.10251 a = +8.12176 $\overline{AR}$ = 3.2700 $\overline{SN40}$ = 47.3302 N = 268	b = -0.08137 a = +6.62323 $\overline{AR}$ = 2.8612 $\overline{SN40}$ = 46.2339 N = 56	b = -0.00357 a = +0.93424 $\overline{AR}$ = 0.7792 $\overline{SN40}$ = 43.4338 N = 71
RAIN	Over 12.5 hr	b = -0.02117 a = +3.58183 $\overline{AR}$ = 2.6163 $\overline{SN40}$ = 45.6038 N = 78	b = -0.05908 a = +5.94432 $\overline{AR}$ = 3.5890 $\overline{SN40}$ = 39.8650 N = 20	b = -0.01388 a = +1.13208 $\overline{AR}$ = 0.5140 $\overline{SN40}$ = 44.5400 N = 5

MGR Over 2.15

RAIN		HTYP 2LUA	HTYP MLUA	HTYP MLCA
RAIN	Under 12.5 hr	b = -0.00699 a = +3.31055 $\overline{AR}$ = 2.9543 $\overline{SN40}$ = 50.9461 N = 141	b = -0.18774 a = +11.44225 $\overline{AR}$ = 2.1477 $\overline{SN40}$ = 49.5077 N = 13	b = -0.02655 a = +1.61532 $\overline{AR}$ = 0.2929 $\overline{SN40}$ = 49.8000 N = 17
RAIN	Over 12.5 hr	b = -0.14731 a = +9.54650 $\overline{AR}$ = 2.7906 $\overline{SN40}$ = 45.8613 N = 31	b = +0.04916 a = -0.81875 $\overline{AR}$ = 1.5362 $\overline{SN40}$ = 47.9000 N = 8	b = -0.04294 a = +2.29688 $\overline{AR}$ = 0.4525 $\overline{SN40}$ = 42.9500 N = 4

RESIDUALS FROM OVERALL REGRESSION

Sums of Squares	df
SS_t = 6062.51960	699
SS_1 = 5351.98475	688
SS_2 = 109.36505	11
SS_3 = 467.82416	10
SS_4 = 133.34564	1

F_1 = 6.99490 > F(11,699) OVERALL REGRESSION IS SIGNIFICANT
F_2 = 4.15180 > F(22,688) ALL INTERCEPTS ARE SIGNIFICANTLY DIFFERENT
F_3 = 1.27808 < F(11,688) ACCEPT COMMON SLOPE FOR ALL CELLS
F_4 = 5.98770 > F(10,699) NO SIGNIFICANT MEANS REGRESSION EXISTS

INVESTIGATION OF THE LACK OF CHANGE IN MEAN SKID NUMBER WITH RESURFACING OF THE TEST SECTIONS

The skid number of the 130 test sections studies in the Phase I (matched pair) analysis did not change significantly as a result of resurfacing. The mean skid number of these test sections was 48.64 in the before period and 47.97 in the after period--a net change of trivial size. The skid number of 60 test sections increased with resurfacing, while those of 70 sections decreased. This finding was unexpected because resurfacing is a countermeasure that is presumed to decrease accident experience by increasing skid number.

In interpreting this finding it is important to recognize that the test sections were resurfaced for a variety of reasons--not necessarily including low skid number. Some sections were resurfaced to maintain the structural integrity of the pavement, some to improve rideability and some for the reasons not specified explicity. Also, as explained in Section II-D, the before and after skid tests were not made immediately before and after resurfacing. Before skid tests were made as much as 18 months before resurfacing and after skid tests as long as 18 months after resurfacing. Thus, the observed lack of change in mean skid number is not a completely unexpected result, and does not necessarily indicate that resurfacing has no effect on skid number. However, the important implications of the observed result for pavement surface management programs warrant further investigation.

A series of analyses were performed to determine if any readily identifiable factors were responsible for the observed lack of change in mean skid number. The factors considered were: (1) bias due to seasonal variation of skid number, (2) bias due to level of skid number before resurfacing, (3) bias due to geographical distribution of test sections, (4) bias due to difference in pavement type (AC or PCC) before resurfacing, and (5) bias due to variation in the length of time and traffic exposure between completion of resurfacing and skid measurement in the after period.

A. Bias Due to Seasonal Variation of Skid Number

Pavement skid numbers are known to vary with the season of the year. The highest skid number values are generally observed in the spring months and the lowest values in the fall. Extreme seasonal variations in skid number as high as 30 have been observed, with more typical variations in the range of 5 to 15.[18] This phenomenon is presumed to result from variations in temperature and precipitation.

An analysis was performed to determine whether a significant difference in the skid number of the test sections between the before and after periods could be masked by seasonal variation of skid number. The first step in this analysis was to examine the distribution of months when before and after skid tests were performed on the same test section. This analysis indicated that the distributions of months for skid tests in the before and after periods were significantly different and could produce a significant change in the mean skid number of test section if the seasonal variation of skid number was large enough. The second step in the analysis was to adjust the observed skid numbers on the basis of an assumed model for seasonal variation of skid number. This second step analysis found that it is unlikely that seasonal variation has masked a significant difference in mean skid number between the before and after periods.

The month of skid testing for each test section, both before and after resurfacing, was determined from the project data files. The month of skid testing in one or both periods was not available for 4 of the 130 test sections, so only 126 sections were used in this analysis. Table 55 is a frequency distribution (cross-tabulation) of the months of skid testing in the before and after periods for the 126 test sections. An evaluation of Table 55 by the Chi-square test shows that the monthly distributions of skid tests in the before and after periods are significantly different ($X^2(9) = 19.63$, $0.025 < p < 0.01$). Because this difference in the monthly distribution of skid tests exists, there is a possibility that month-to-month variations in skid number levels could produce a significant change in the mean difference of skid number between the before and after periods.

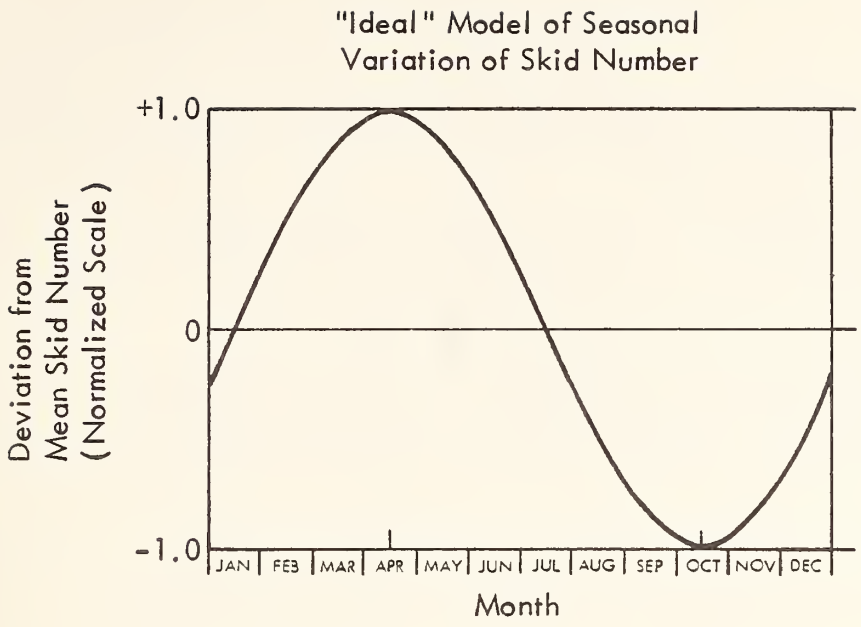
Further examination of the influence of seasonal variation of skid number on the Phase I analysis results requires a model to predict the variations. There is no model currently available that has been rigorously developed and validated. However, a recent study in Pennsylvania by Gramling and Hopkins[25/] presented an "ideal" model of the seasonal variation curve, presented in Figure 27. The Gramling and Hopkins model is roughly sinusoidal with unspecified amplitude. For the sake of simplicity the model shown in Figure 27 is arbitrarily assigned an amplitude of 1.0. This model was assumed to represent the seasonal variation of skid number on the test sections.

The literature indicates widely divergent values for the range of seasonal variation of skid number.[18/] For the purposes of this analysis it was decided to determine the effects of six possible ranges for seasonal skid number variation--5, 10, 15, 20, 25, and 30. Since the amplitude of a sinusoid is half its range, the six assumed ranges correspond to amplitudes of 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0. The effect of assumed seasonal variation on the mean change in skid number was then determined.

TABLE 55

FREQUENCY DISTRIBUTION OF MONTH OF SKID TESTING IN BEFORE AND AFTER PERIODS FOR 126 TEST SECTIONS

Month of Before Skid Test	Month of After Skid Test												Row
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
January	0	0	1	0	0	1	0	0	0	0	0	0	2
February	0	0	1	0	0	1	0	1	0	2	0	0	5
March	0	0	0	0	0	1	2	1	0	2	0	2	8
April	0	0	0	0	0	2	1	2	0	2	0	0	7
May	0	0	0	1	2	1	5	6	3	0	0	0	18
June	0	0	0	1	1	5	3	8	2	0	0	0	20
July	0	2	2	0	1	4	7	2	1	2	2	0	23
August	0	0	0	1	1	0	0	4	1	2	0	0	9
September	0	1	2	0	2	2	4	0	0	3	0	0	14
October	0	0	0	1	0	4	0	1	0	0	1	0	7
November	0	0	0	0	1	1	1	0	1	2	3	0	9
December	0	0	0	0	0	0	3	0	0	0	0	1	4
Column Totals	0	3	6	4	8	22	26	25	8	15	6	3	126



MONTHLY CORRECTION FACTORS (C_a and C_b)

MONTH	CORRECTION FACTOR	MONTH	CORRECTION FACTOR
January	-0.004	July	-0.044
February	-0.484	August	+0.458
March	-0.807	September	+0.822
April	-0.956	October	+0.978
May	-0.876	November	+0.844
June	-0.533	December	+0.473

Figure 27 - "Ideal" Model of Seasonal Variation of Skid Number

The change in skid number of a test section from the before to the after period is defined as:

$$\Delta SN = SN_a - SN_b$$

where ΔSN = difference in skid number at 40 mph between before and after periods,

SN_a = skid number at 40 mph after resurfacing, and

SN_b = skid number at 40 mph before resurfacing.

The mean change in skid number ($\overline{\Delta SN}$) for the 126 test sections is -0.72. Adjusted values of SN were computed for each test section under each assumed amplitude of skid number variation in the following manner

$$\Delta SN_{adj} = \Delta SN + (A)(C_a - C_b)$$

where ΔSN_{adj} = difference in skid number adjusted for seasonal variation,

A = assumed amplitude of seasonal variation,

C_a = skid number variation factor for month of skid testing in after period (see Figure 26), and

C_b = skid number variation factor for month of skid testing in before period (see Figure 26).

The adjustment for seasonal variation produces a change in the mean skid number difference, i.e., $\overline{\Delta SN}_{adj}$ is not equal to $\overline{\Delta SN}$. This increase in variance becomes greater with increasing amplitude of skid number variation. The adjusted mean skid number difference, $\overline{\Delta SN}_{adj}$, also increases with increasing amplitude. As the assumed amplitude for seasonal variation increases from 0 to 15.0, the value of $\overline{\Delta SN}_{adj}$ increases from -0.72 to 1.69. However, over the span of amplitudes considered $\overline{\Delta SN}_{adj}$ is never significantly greater than zero (t_{max} = 1.17). A subsequent analysis determined that an amplitude of 32.3, corresponding to a range of seasonal variation in skid number of 64.6, would be required to make $\overline{\Delta SN}_{adj}$ significantly greater than zero. Such a high range of seasonal variations in skid number is considered unlikely, since it is more than twice the maximum range reported by any state highway department. Therefore, it was concluded that no reasonable range of seasonal variation in skid number could lead to a mean difference in skid number of the test sections between the before and after periods that is significantly different from zero.

B. Bias Due to Level of Skid Number Before Resurfacing

Another possible explanation suggested for the lack of change in mean skid number with resurfacing of the test sections is the variation in the levels of skid number before resurfacing. Nearly half of the test sections experienced an increase in skid number with resurfacing, while the remainder decreased. It is possible that test sections with low skid number in the before period may have increased with resurfacing, while test sections with high skid number in the before period may have decreased with resurfacing. An analysis was performed to test this postulate by identifying any influence of the level of skid number before resurfacing on the difference in skid number between the before and after periods.

Discriminant analysis is used to identify factors that distinguish between two (or more) explicitly defined groups of data. This distribution is accomplished by constructing a discriminant function--the linear combination of factors that maximize the ratio of between-group variance to within-group variance. The analysis can test whether the discriminant function is significant and can estimate the standard error for the coefficient of each factor in the discriminant function. Thus, discriminant analysis can identify factors as significant or nonsignificant. The data for these analyses were available for 129 test sections. These data were divided into two groups. Group 1 contained the data from 60 sections that increased in skid number with resurfacing and Group 2 contained the data from 69 sections that decreased in skid number with resurfacing.

The discriminant function between the two groups was found to be:

$$D = -6.633 + 0.136\ SN_b \quad .$$

This discriminant function is significant, as indicated by the value of Wilke's $\lambda = 0.929$ ($p = 0.002$). This finding means that the distribution of skid number in the before period are different for the two groups. The mean before skid number for the test sections that increased with resurfacing is 46.58; the mean before skid number for the test sections that decreased is 50.45.

A regression analysis was performed to explore further the relationship of skid number before resurfacing, SN_b, and difference in skid number between the before and after period, ΔSN. Regression lines were computed for both groups and for the combined data set. The results were:

Group 1: $\Delta SN = 20.120 - 0.292\ SN_b$; $r = -0.41$; $p < 0.01$

Group 2: $\Delta SN = -4.175 - 0.054\ SN_b$; $r = -0.08$; not significant

All: $\Delta SN = 18.061 - 0.385\ SN_b$; $r = -0.34$; $p < 0.01$

Significant regressions were found in the group where skid number increased with resurfacing and in the entire data set, but the regression in the group where skid number decreased with resurfacing is not significant. Thus, the hypothesis that sections with low skid number in the before period increased with resurfacing is valid, but the hypothesis that sections with high initial skid resistance decreased with resurfacing is not.

The skid number before resurfacing has a highly significant effect on difference in skid number between the before and after periods. The regression analysis described above suggests that only the portion of the data where skid number increased with resurfacing is responsible for this effect. Despite its high significance, the magnitude of the effect is not large--an improvement of 3.5 units in SN_b produces a change in ΔSN of only one unit. It appears unlikely that an effect of this magnitude could bias the results of the Phase I analysis.

C. Bias Due to Geographical Distribution of Test Sections

An analysis of variance was conducted to determine if the state or region of the country in which a test section is located influenced the observed change in skid number. A state or regional effect could result from climatic differences, variation in pavement surfacing materials used or variations in the procedures used to select sections for resurfacing. The results of this analysis of variance are presented in Table 56. The states used in the analysis are represented by the state codes shown in the table, but will not be identified here by name. The 129 test sections used in the analysis are located in 13 states. However, two states contain only one and two test sections, respectively. Since these two states are located in the same region of the United States, these three sections have been combined into a single group (State Code 3) in Table 56.

The analysis results indicate that the state does have a significant effect on the change in skid number with resurfacing ($F(11,117) = 6.21$, $p < 0.001$). The Fisher procedure was used to separate the 12 states into four groups. The states within each group are not significantly different from each other in ΔSN, but do differ significantly in ΔSN from the states in each of the other groups. The four groups in order of increasing ΔSN are:

TABLE 56

ANALYSIS OF VARIANCE OF THE EFFECT OF STATE ON CHANGE IN SKID NUMBER WITH RESURFACING (ΔSN)

Dependent Variable	$\Delta SN = SN_a - SN_b$
Independent Variable	State
Number of Levels of Independent Variable	12
Number of Cases	129

State Code	Number of Cases	Change in Skid Number with Resurfacing (SN) Mean	Standard Deviation	Standard Error
1	12	1.78	5.26	1.52
2	17	-9.78	6.35	1.54
3	3	-8.47	3.95	2.28
4	8	4.89	4.23	1.50
5	11	6.71	7.21	2.18
6	16	-0.79	10.40	2.60
7	7	-1.94	5.16	1.95
8	11	-2.85	7.41	2.23
9	9	1.49	4.47	1.49
10	15	-2.18	6.22	1.61
11	15	5.07	7.99	2.06
12	5	-5.22	1.66	0.74
Total	129	-0.65	8.30	0.73

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Between States	11	3248.46	295.31	6.21
Within States	117	5565.97	47.57	
Total	128	8814.43		

Group	State(s)	Number of Cases	Mean Change in Skid Number with Resurfacing ($\overline{\Delta SN}$)
1	2, 3	20	-9.58
2	12	5	-5.22
3	1, 6, 7, 8, 9, 10	70	-0.79
4	4, 5, 11	34	5.59
Total		129	-0.65

The mean change in skid number with resurfacing, $\overline{\Delta SN}$, for the 70 test sections in Group 4 is not significantly different from zero; Groups 1 and 2 have $\overline{\Delta SN}$ significantly less than zero and Group 4 had $\overline{\Delta SN}$ significantly greater than zero. These four groups were formed strictly on the basis of statistical association between the test sections. The groups do not have any recognizable geographical pattern.

Since it was previously shown that the level of skid number before resurfacing has an influence on ΔSN, a subsidiary analysis was performed to determine whether the observed state effect could be explained by state-to-state differences in the level of skid number before resurfacing. This determination was made in an analysis of covariance with state as a factor and before skid number, SN_b, as the covariate. The state variable is significant in the analysis of covariance ($F(11,16) = 10.012$, $p < 0.001$) and a significant ΔSN-SN_b regression was found ($F(1,116) = 72.89$, $p < 0.001$). The slopes of the ΔSN-SN_b regression lines for the 12 states are not significantly different ($F(11,105) = 1.55$), i.e., there is a common slope that does not vary from state-to-state. The adjustment of $\overline{\Delta SN}$ for each state for the effect of SN_b did not result in a significant reduction in the dispersion of the $\overline{\Delta SN}$ for the states ($F(11,11) = 1.13$). All of this evidence supports the conclusion that the effects of state and before skid number on ΔSN are independent, i.e., neither variable is to any significant extent a surrogate for the apparent effect of the other.

In summary, despite the lack of change in mean skid number, ΔSN, with resurfacing when all test sections are considered together, there are six states where the mean change in skid number with resurfacing is significantly different from zero. In three of these states, the skid number increased significantly with resurfacing, while in three others the skid number decreased significantly with resurfacing. This state effect cannot be explained by a difference in the level of skid number before resurfacing or any other available variable. Thus, the cause of this state effect cannot be explained, but it does not appear large enough to bias the results of the Phase I analysis.

D. Bias Due to Difference in Pavement Type Before Resurfacing

Although all of the test sections were overlayed with asphalt concrete, both asphalt and portland cement concrete surfaces were present prior to resurfacing. Nineteen of the test sections were portland cement concrete before resurfacing and 110 were asphalt concrete. An analysis of variance was performed to determine whether this difference had a significant effect on the change in skid number of the test sections with resurfacing (ΔSN). Table 57 illustrates the results of the analysis of variance. The analysis results indicate that the effect of pavement type before resurfacing is not significant ($F(1,127) = 0.94$, $p = 0.334$).

E. Bias Due to Variation in the Length of Time and Traffic Exposure Between Completion Resurfacing and Skid Testing in the After Period

Because of difficulties encountered by the states in scheduling skid tests after resurfacing of the test sections the after skid tests range in time from 2 to approximately 24 months after resurfacing was completed. The skid resistance is known to vary in the initial period after resurfacing due to traffic passages and weather. The form of such variation is not well specified. Discriminant analysis was used to determine whether the number of months or cumulative number of traffic passages per lane had a significant effect on the change in mean skid number.

The first discriminant analysis determined the ability of the variable months of traffic exposure between resurfacing and skid testing in the after period to discriminate between two groups of test sections--one that increased and the other that decreased in skid number with resurfacing. The discriminant function for this analysis is not significant, as indicated by the value of Wilkes' $\lambda = 0.99$.

The second discriminant analysis determined the ability of the variable cumulative traffic passages per lane between resurfacing and skid testing in the after period to discriminate between the same two groups of test sections. The discriminant function for this analysis is not significant, as indicated by the value of Wilkes' $\lambda = 0.99$. A simple linear regression of cumulative traffic passages per lane, CT, with ΔSN is marginally significant ($F(1,127) = 2.81$, $p < 0.10$). However, the partial correlation coefficient of CT and ΔSN, controlling for the value of skid number before resurfacing is not significant ($r = -0.035$). This finding indicates that there is no true correlation between CT and ΔSN. The apparent correlation between CT and ΔSN is explained by the skid number before resurfacing, SN_b. Since there is no obvious relationship between CT and SN_b, this finding probably results from some other factor, such as traffic volume, that is related to both. Thus, neither the time nor number of cumulative traffic

TABLE 57

ANALYSIS OF VARIANCE OF THE EFFECT OF PAVEMENT TYPE BEFORE RESURFACING ON CHANGE IN SKID NUMBER WITH RESURFACING (ΔSN)

Dependent Variable	$\Delta SN = SN_a - SN_b$
Independent Variable	Pavement Type Before Resurfacing
Number of Levels of Independent Variable	2
Number of Cases	129

Pavement Type Before Resurfacing	Number of Cases	Mean	Standard Deviation	Standard Error
Asphalt Concrete	110	-0.36	7.68	0.73
Portland Cement Concrete	19	-2.36	11.35	2.61
Total	129	-0.65	8.30	0.73

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ration
Between Pavement Types	1	64.79	64.79	0.94
Within Pavement Types	127	8749.55	68.89	
Total	128	8814.33		

passages between completion of resurfacing and skid testing in the after period has a significant effect on the change of skid number between the before and after periods.

F. Summary

The effects of five factors on change of skid number between the before and after periods were examined. These five factors are: seasonal variation of skid number, level of skid number before resurfacing, geographical distribution of test sections, pavement type before resurfacing, length of time and cumulative traffic exposure between resurfacing and skid testing in the after period. Two factors--level of skid number before resurfacing and geographical distribution of test sections--have a significant effect on the change of skid number with resurfacing. However, neither effect is great enough in magnitude to have a substantial impact on the results of the Phase I analysis. The relationship of the remaining factors to the change in skid number is not significant. Thus, none of the factors considered introduce bias into the Phase I analysis finding that resurfacing produced no change in the mean skid number of the test sections. It should be reiterated, however, that a change in skid number was not necessarily expected since the test sections were not resurfaced primarily because of low skid number.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

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This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.