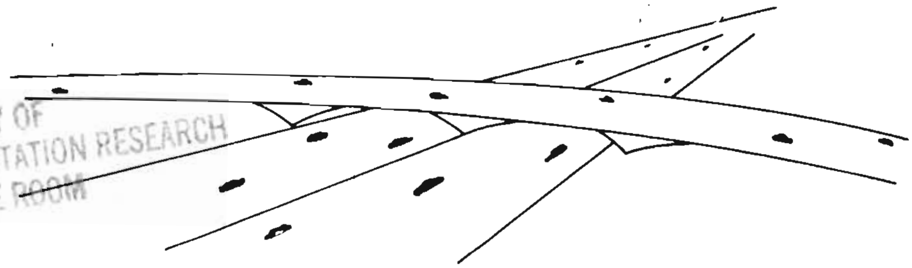

DEPARTMENTAL RESEARCH

Report Number: 133-3F

THE DEGREE OF INFLUENCE OF CERTAIN FACTORS PERTAINING TO THE VEHICLE AND THE PAVEMENT ON TRAFFIC ACCIDENTS UNDER WET CONDITIONS

TEXAS HIGHWAY DEPARTMENT

The Degree of Influence of Certain Factors Pertaining to the Vehicle and the Pavement on Traffic Accidents Under Wet Conditions

by

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Conducted By

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In Cooperation with the
U.S. Department of Transportation
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SUMMARY

Five variables believed to be closely associated with the friction available at the tire-pavement interface were analyzed by studying 501 wet weather vehicular accidents. Tire pressures and tread depths were obtained from the accident vehicles; vehicular speed from the investigating officer's report; and friction and macro texture from the pavement surface at the accident site. It was concluded that the lack of pavement texture, low pavement friction, high vehicle speed, worn tires, and large vehicle tire pressures all contribute to accidents occurring on wet pavement. The accidents were also categorized into several types and it was found that the above variables are even more significant for certain accident types. Studies should be directed toward cornering friction since some 40 percent of the accidents involved a turning maneuver.

Macro texture was found to be a significant contributor to accidents even when the skid number (50 mph), as measured with a skid test trailer, was considered. Considering the condition of the vehicle tires, the vehicle speeds involved, and the amount of water on the pavement surface a trailer test value alone is not sufficient to establish the skidding safety of a highway or for that matter a safe friction value for a highway. However, the skid number should be considered in skidding safety and cannot be taken lightly.

Efforts must be made to determine a tire-pavement interface friction which is more representative of the friction available to the driver at the time of a wet weather accident. The trailer skid number should be modified by a water depth, and a tire-pavement drainage characteristic which is more representative of the actual accident condition. The friction should be further modified with tread depths, tire pressures and speeds more representative of the actual accident vehicle. Once the actual available friction can be determined, better remedial procedures will result.

ABSTRACT

The Degree of Influence of certain factors pertaining to the vehicle and the pavement on Traffic Accidents Under Wet Conditions.

Project Number : HPR -1 (9), 1-8-69-133

Investigators : Morgan, Ashkar, Hankins, Tutt

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Sponsor : Texas Highway Department and Federal Highway Administration

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Started : September, 1968

Status : Completed - Final Report

Key Words : Wet Pavement Accidents

: Pavement Surface Macro Texture

: Pavement Surface Friction

: Accident Vehicle Tread Depth

: Accident Vehicle Tire Pressure

: Accident Vehicle Speed

This project was accomplished using the assistance and advice of the Texas Department of Public Safety. Some 500 wet weather accidents were studied and data collected on several vehicle, pavement and weather variables. It was found that small pavement texture, small vehicle tread depths, low surface friction, high vehicle speeds and high vehicle tire pressures were dominant in the accidents studied.

IMPLEMENTATION

The following items are suggested for implementation.

(1) Ways to obtain sufficient texture should be considered in highway design, construction, and maintenance. A minimum texture of 0.5 inch per 27 inches, measured with the SWRI texturemeter, equivalent to approximately 0.035 inch by the sand patch method, is suggested for design purposes. At this value, the numbers of accidents appeared to decrease to a relatively constant value (see Fig. 12). The suggested value does not provide an exceedingly coarse or harsh texture and, therefore, the high-speed friction should be optimized with road noise.

(2) Continuing effort should be made to maintain sufficient friction on the pavement surface. Efforts being made throughout the nation to specify a non-polishing aggregate for use in the pavement surface could be used to advantage.

(3) A method to reduce driving speeds in wet weather should be developed.

(4) Minimum tread depths should be required on vehicles which use public highways.

CHAPTER I. INTRODUCTION

The research reported herein was an attempt to determine the effect of certain vehicle and pavement factors on traffic accidents occurring during wet weather. The detailed roadway and wet weather accident data investigated and analyzed were collected by the Texas Department of Public Safety and the Texas Highway Department in a joint effort which represents the desire of both agencies to reduce the number and severity of accidents which occur on Texas Highways.

This report concerns only a portion of the data collected in a research project. Of several items studied, five variables were arbitrarily selected for reporting, however, these variables were thought to be closely associated to the tire-pavement interaction related to vehicular skidding on wet pavement. The variables analyzed were as follows:

(1) Vehicular speeds at the time of or immediately prior to the accident (SP).

(2) Tread depths of the tires of the accident vehicle(s) (TD).

(3) Tire pressures of the accident vehicle(s) (PR).

(4) Pavement friction (Skid Number) at the accident site (FR).

(5) Pavement texture (macro) at the accident site (TX).

The object of the analysis was to determine the degree of influence of each variable on wet weather accidents.

CHAPTER II. DATA COLLECTION

For this study, data were collected from 501 wet weather accidents which occurred from May 1968 through September 1969 in an area that consisted of 10 central Texas counties and covered portions of two highway Districts (Fig 1). The area contained approximately 2,460 miles of the state's highway system, on which the average daily vehicle travel was 3,086,099 miles (Ref. 1).

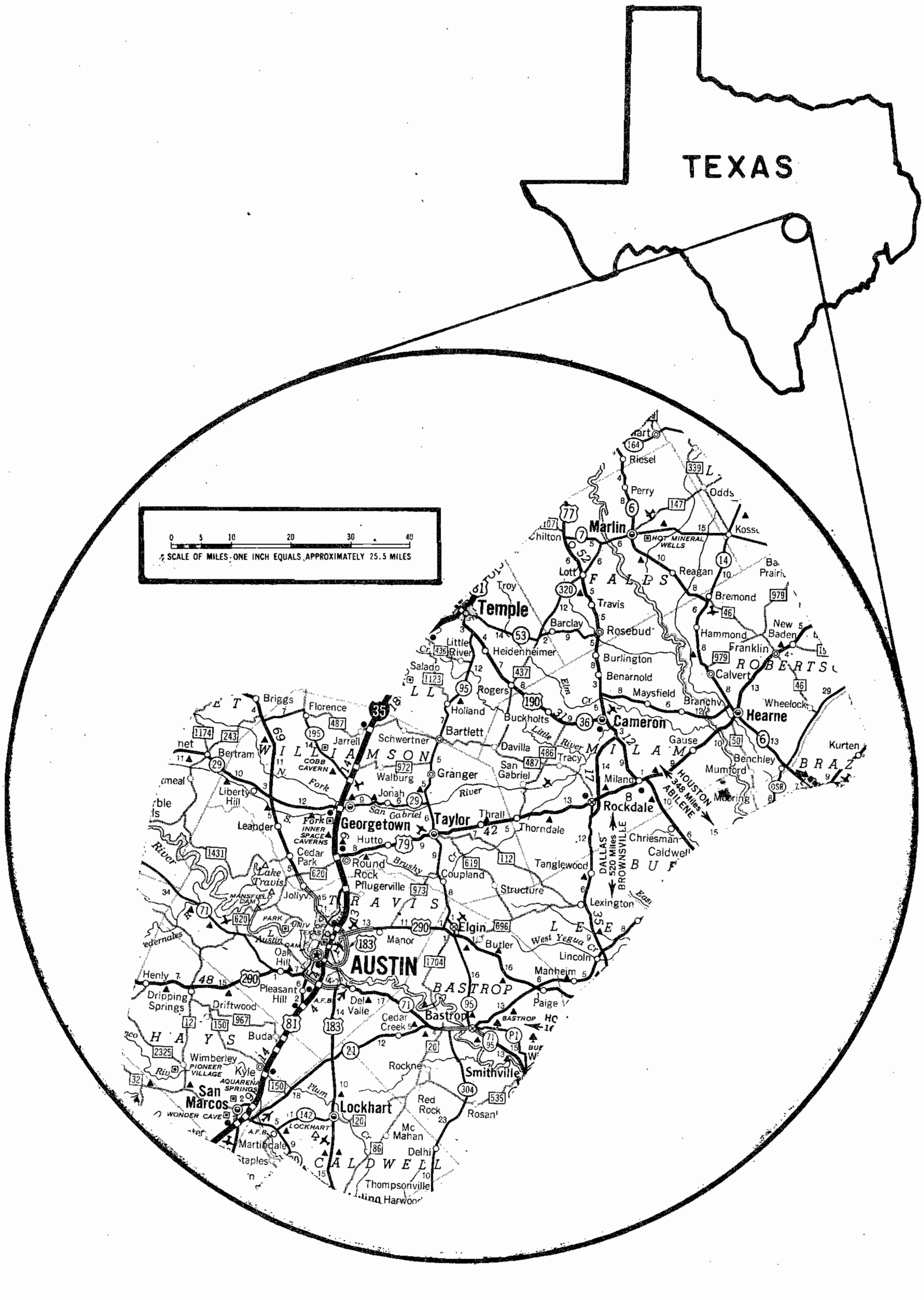
The study area was primarily rural in character. Urban areas with populations over 5,000 were not included, in order to simplify data collection; accident investigation and reporting for these areas are the responsibility of the municipalities involved rather than of the Texas Department of Public Safety.

Accident Data

The data were collected by the Department of Public Safety (DPS) and the Texas Highway Department (THD). The DPS, in addition to making the usual accident investigations and gathering documentation for the standard report, collected information for a second special report which contained the tire pressures and tread depths of the accident vehicles.

The pressure for each tire was measured with a commercially produced tire pressure gage with 2-psi divisions which was calibrated before use. In several instances a tire was so damaged that it was completely deflated, and often a tire appeared to be partially deflated as a result of the accident, especially when a broadside skid had occurred.

The tire tread depth of each tire on a vehicle involved in a wet weather



LOCATION OF STUDY AREA

Figure 1

accident was measured to the nearest 1/32 inch with commercially produced tread depth gages. The minimum and maximum tread depths were reported for each tire. One measurement was made near the edge of the tire and the other near the center of the tire.

The speed of the vehicle immediately prior to the accident was obtained from the standard investigating officer's report. DPS officials indicated that reported speeds could vary from actual speeds and could be biased by the individual officer, causing some measure of doubt in the values. They are believed to vary ± 10 mph and generally to be lower than the actual values for speeds above 50 mph.

As soon as possible after an accident, THD personnel investigated pavement and roadway conditions at the accident site, which had been conspicuously marked by the DPS investigating officer. Skid resistance was measured with a skid test trailer and texture with a modified Southwest Research Institute (SWRI) Texturemeter.

In this project attempts were made to treat surface macro texture and the skid number as separate entities. This was accomplished by measuring both variables using the separate instrumentation mentioned above.

Usually, a skid test was made at the marked location and three more tests were made over approximately one-half mile in both directions from the accident site (Total of 7 skid tests). On non-divided highways, tests were normally made on lanes in both directions of travel. On divided highways tests were usually made on all lanes in one direction of travel, but lanes in both directions were tested if vehicles involved in the accident were traveling in opposite directions.

Friction measurements were obtained at the accident site and one-half mile in either direction from the site because the initial postulation had been that a vehicle and driver could be affected by a sudden change in pavement friction; that is, if a vehicle traveling on a pavement with good friction characteristics suddenly maneuvered onto a section of pavement with poor friction, there could be problems in controlling the vehicle.

Skid resistance measurements were made at 50 mph. Occasionally the accident location, such as a "T" intersection, made skid testing unfeasible.

Texture measurements were made at two locations in an area in which a vehicle lost control and the average of the two measurements was reported. The readings were obtained with a modified version of a profilograph instrument developed at Southwest Research Institute (Ref. 2). The texture equipment used was described in a previous report and is actually a mechanical instrument which records the cumulative of the asperities of the texture and scribes a magnified profile of the texture.

Comparison Sample Data

In order to have information with which to compare the accident data, and in order to determine how accident conditions differed from normal driving conditions, special sample data were gathered for each of the five items understudy.

Before the research reported herein, very little information had been gathered on wet weather driving speeds in Texas. The information contained in this report was obtained by the THD Design Division, Geometric Design Section, which monitored speeds on rural highways in the study area zoned at 70 mph, during periods of rainfall, with radar speed indicators. There was some doubt that the radar would read correctly in rainfall, but a test car was driven through the radar site during the rain and correct readings were obtained.

Sample tread depths and tire pressures from 250 parked vehicles were obtained in two large cities in the study area, Austin and Bryan; and in two smaller cities, Rockdale and Smithville.

A sample of the friction on the highways in the area was collected in routine friction tests performed during the period of this study. It should be noted that these routine tests were performed at 40 mph rather than the 50-mph test speed maintained at the accident sites. Experience in performing skid tests over the same test section at different speeds indicates friction differentials on the order of 0.02, or two skid numbers generally occur between 40 and 50 mph. Because of this small friction differential, no attempt was made to correct the comparison sample or the accident sample to a constant velocity.

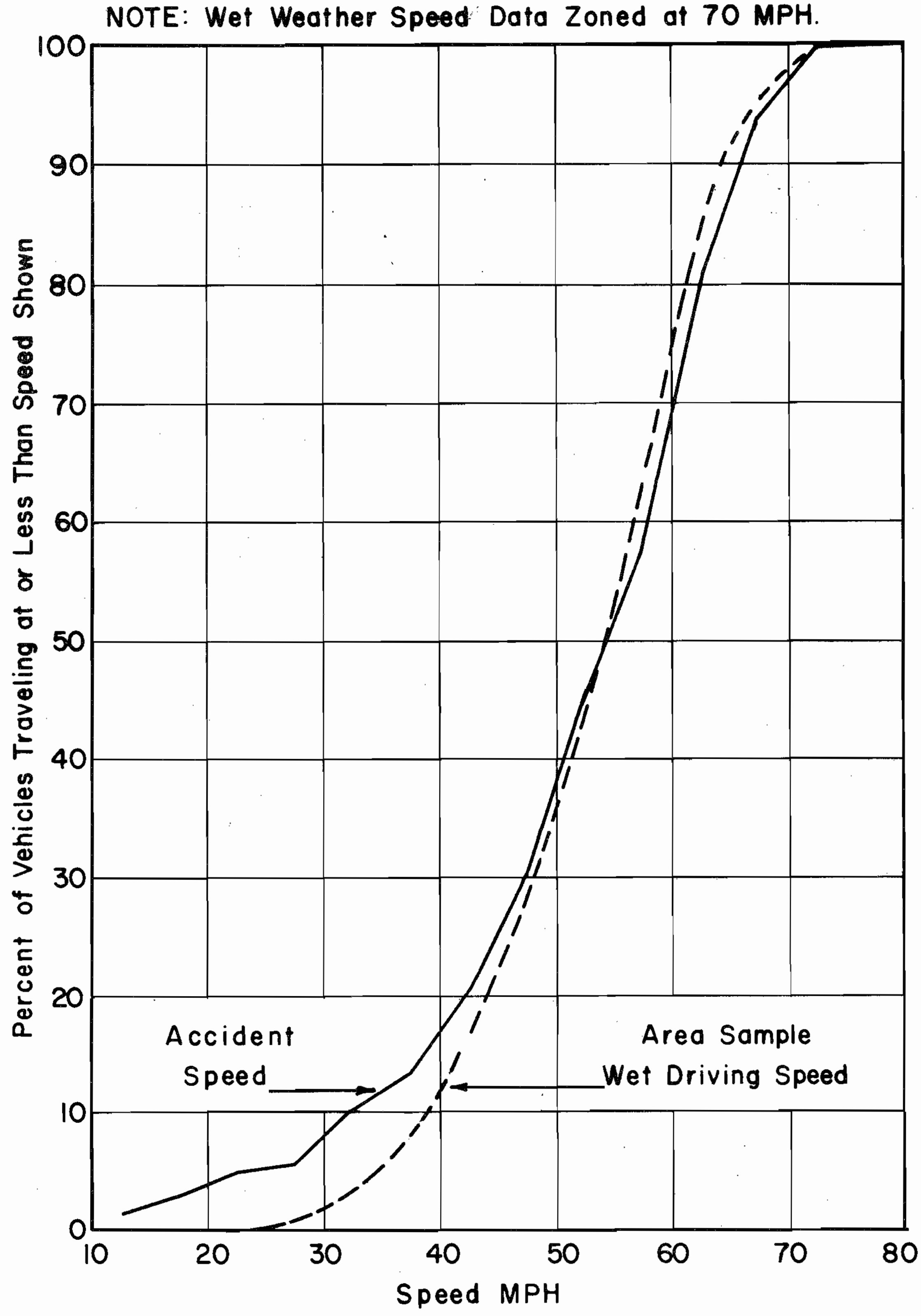
The texture sample for the area highways was determined from the type of pavement and the type of coarse aggregate used on the surface. The pavement and aggregate types were determined for every highway in the study area. The length of each highway segment containing a specific pavement material type was recorded with the average daily traffic count for each segment, and a daily vehicle miles of travel was calculated for each type. A texture value for each pavement material type was obtained from information collected by Gallaway in previous research (Project 2-8-69-138) (Ref. 3). Substituting texture values for pavement material types gave the daily vehicle miles of travel for each texture group.

CHAPTER III. ANALYSIS

The relationship of the accident data with the area sample, representing the normal driving conditions, may be found in Figures 2 through 12. Each figure is a plot of the cumulative frequency distribution of the data collected. Figure 2 treats vehicular speeds; Figures 3 through 6 treat the tread depths of each of four tires; Figures 7 through 10 reveal tire pressure data for four tire positions; Figure 11 indicates the information collected on the skid numbers and Figure 12 treats the pavement texture.

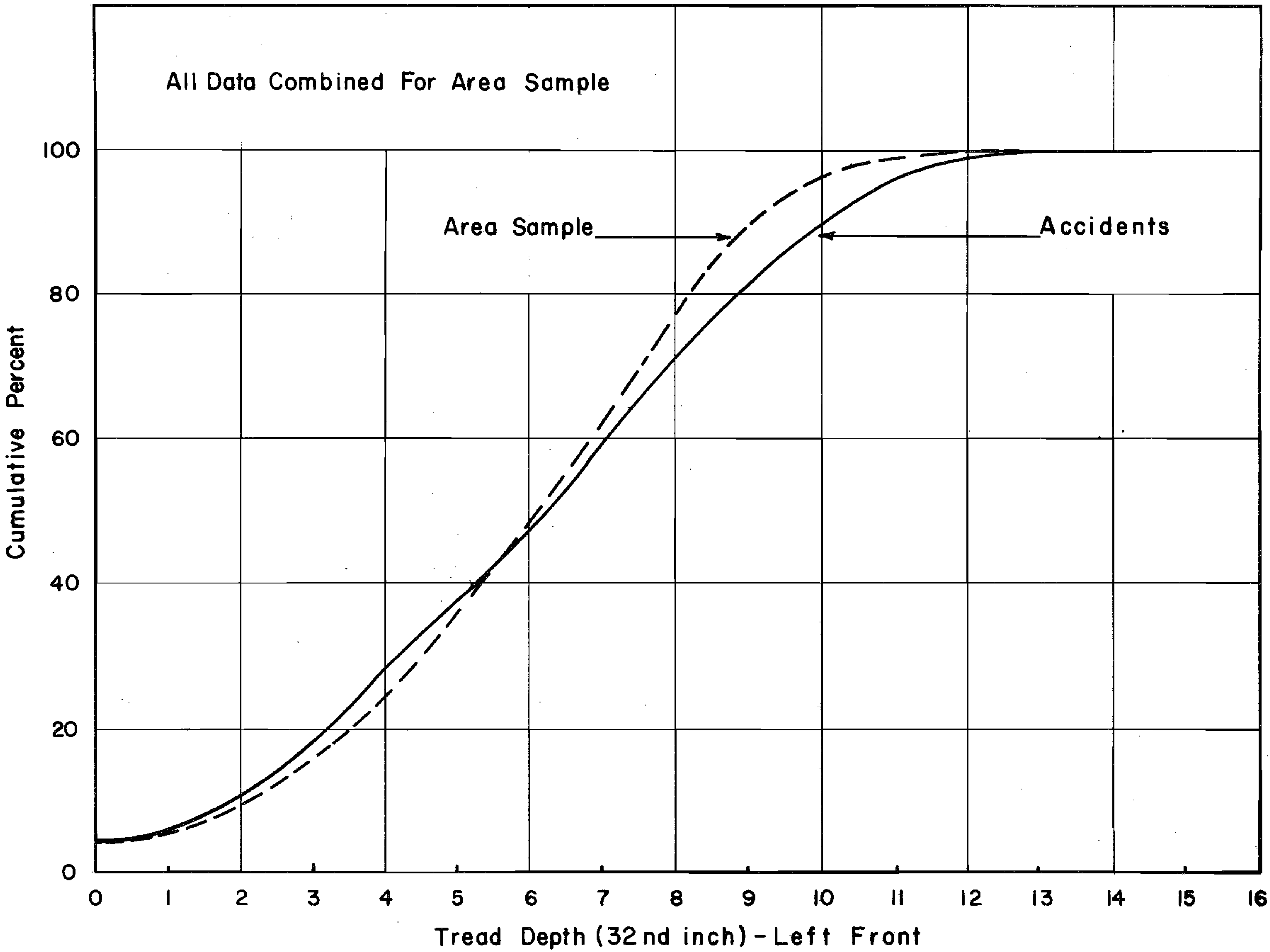
Figure 2 indicates the percentage of accident vehicles to be greater than the area sample vehicles up to a point around 54 mph. At this point, there are smaller percentages of accident vehicles as compared to the area sample. In other words, the accident vehicle was generally traveling at a slower velocity as compared to the usual or normal expected velocity. For example, only 2 percent of the vehicles in the area travel at speeds of 30 mph or less, wereas approximately 8 percent of the accidents occur at speeds of 30 mph or less. It must be admitted that this condition was not expected, however, it was noted that many of the accidents reported at low speeds were rear end collisions in which one vehicle had slowed for a turning maneuver.

Using the same method of analysis on Figures 3 through 6 it may be found that there are larger percentages of accident vehicles as compared to area sample vehicles at tread depths around 5/32 to 6/32 or less, at which point the opposite condition is indicated. Stated briefly, the accident vehicles generally had less tread depth as compared to the normal vehicle in the study area. This is particularly true for the rear tires, where around 10 percent of the rear tires of all accident vehicles are completely smooth.



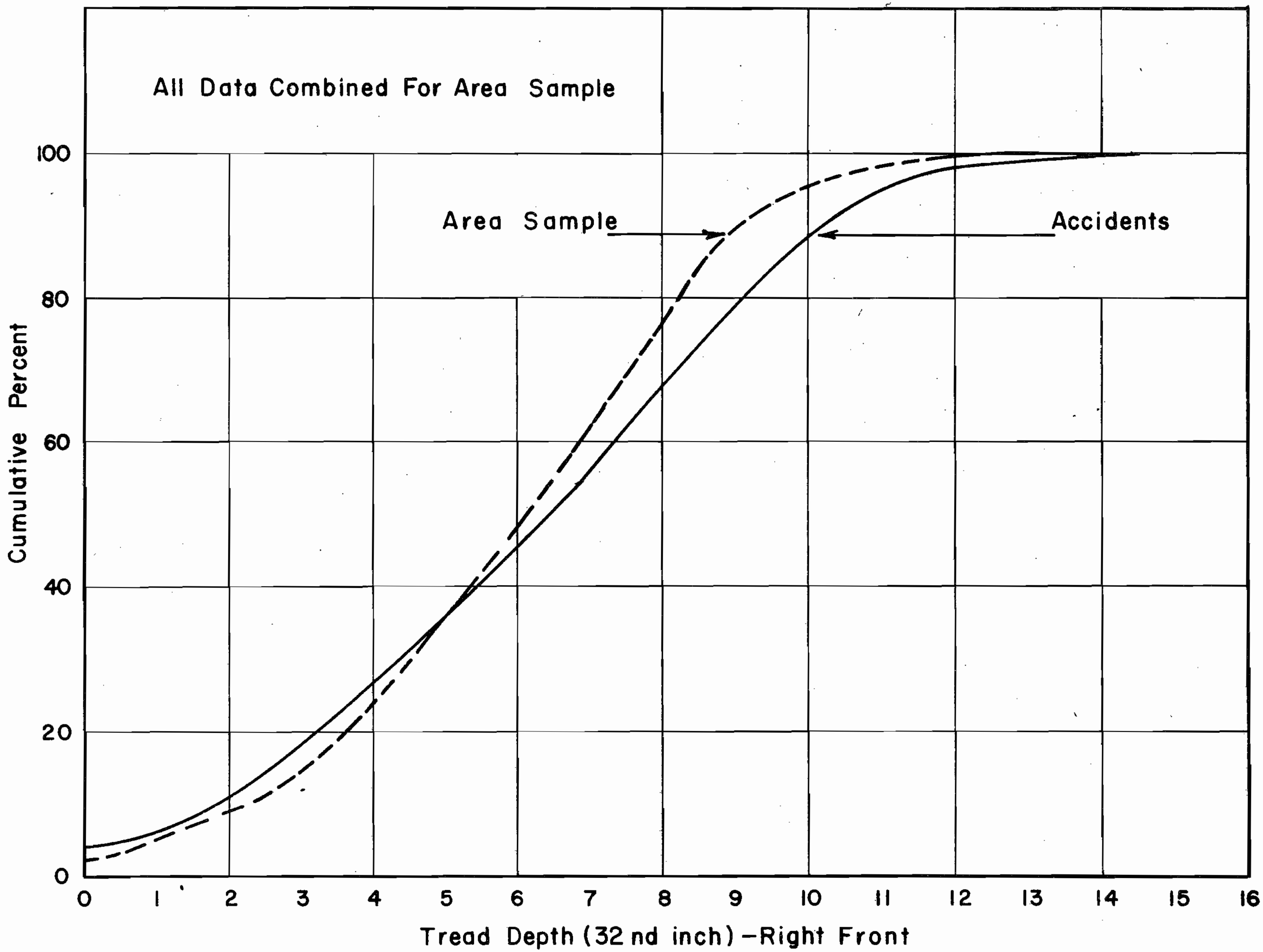
COMPARISON OF VEHICULAR SPEED—ACCIDENT AND AREA SAMPLE

Figure 2



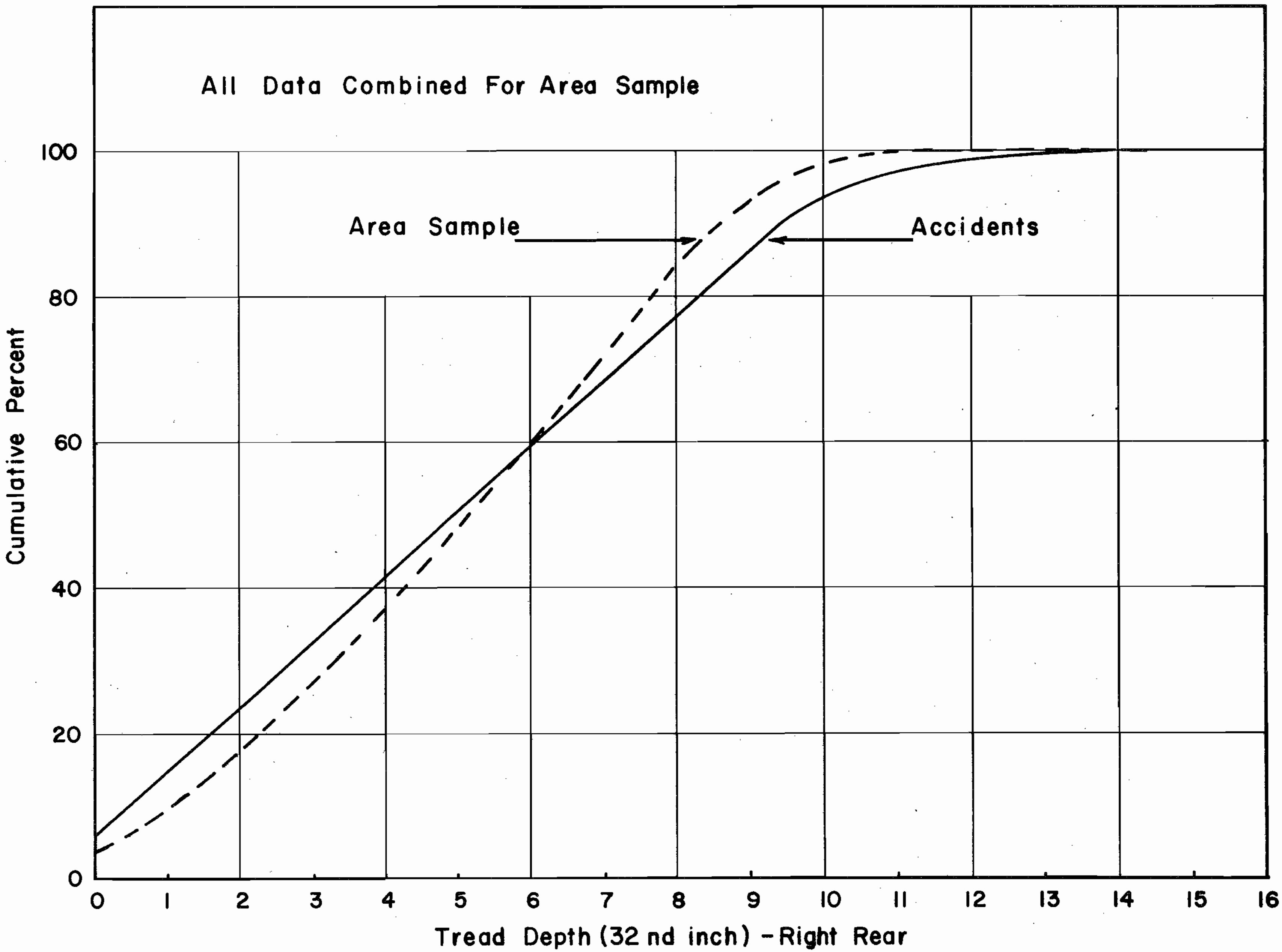
COMPARISON OF L.F. TREAD DEPTHS-ACCIDENTS AND AREA SAMPLE

Figure 3



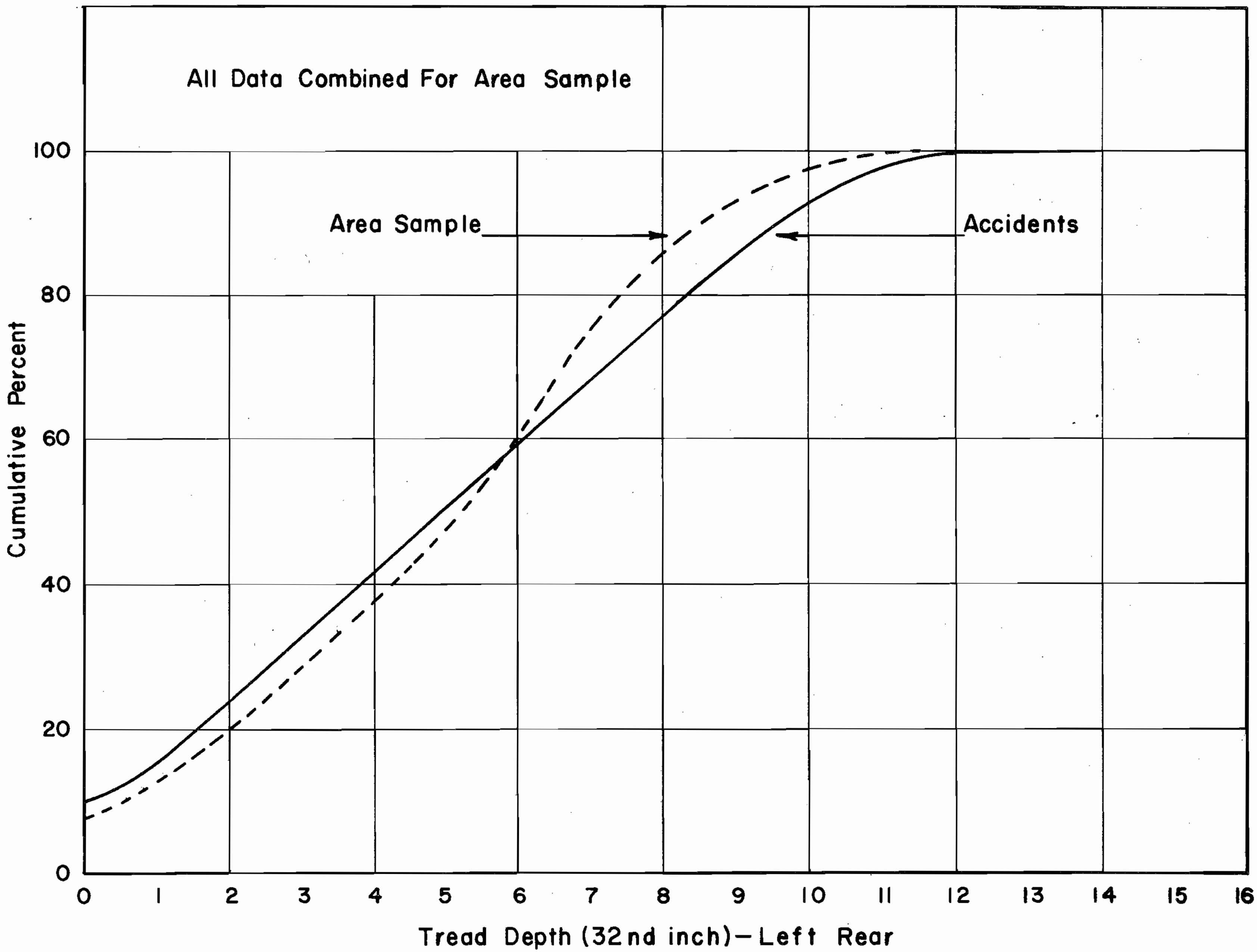
COMPARISON OF R.F. TREAD DEPTHS – ACCIDENTS AND AREA SAMPLE

Figure 4



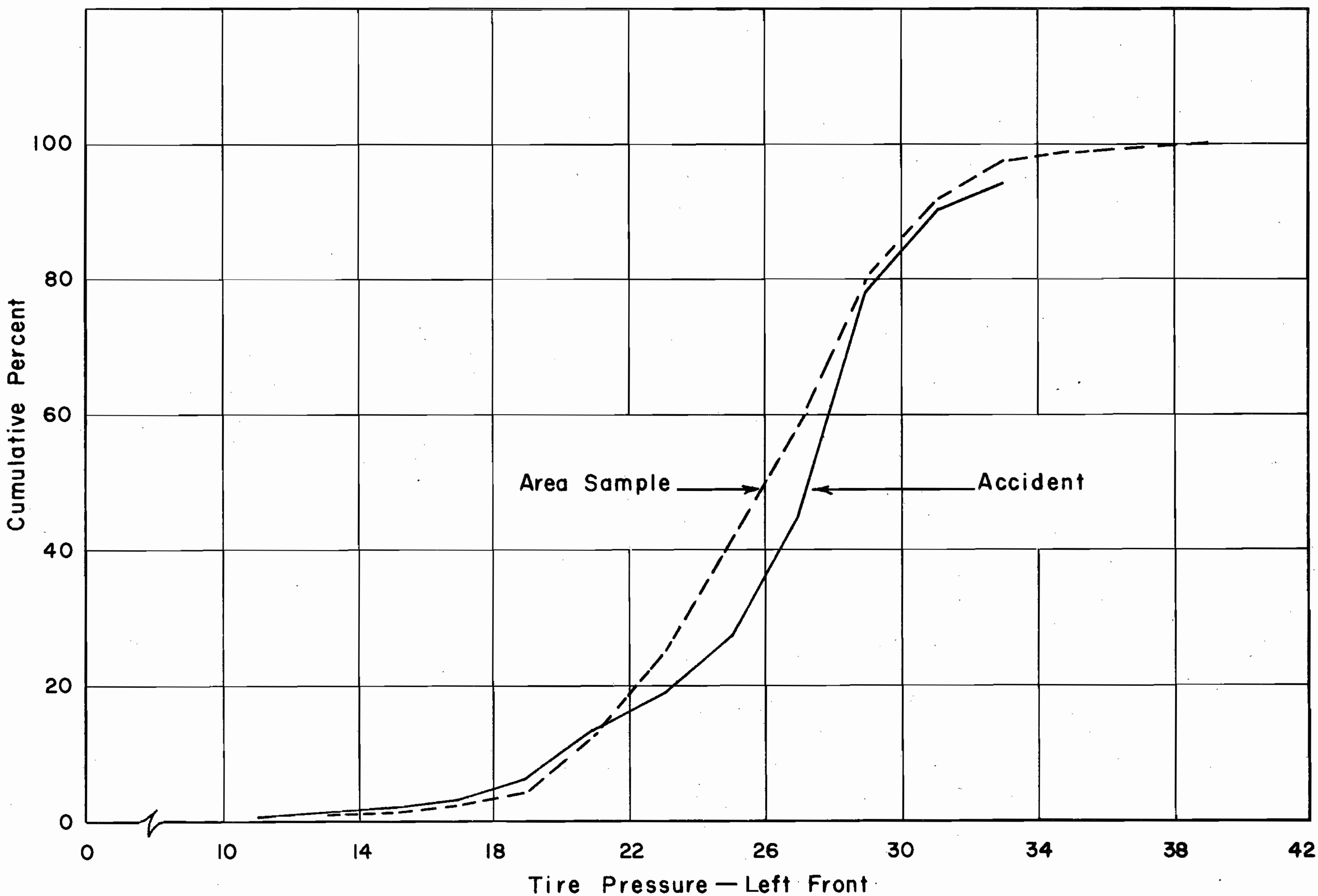
COMPARISON OF R.R. TREAD DEPTHS - ACCIDENTS AND AREA SAMPLE

Figure 5



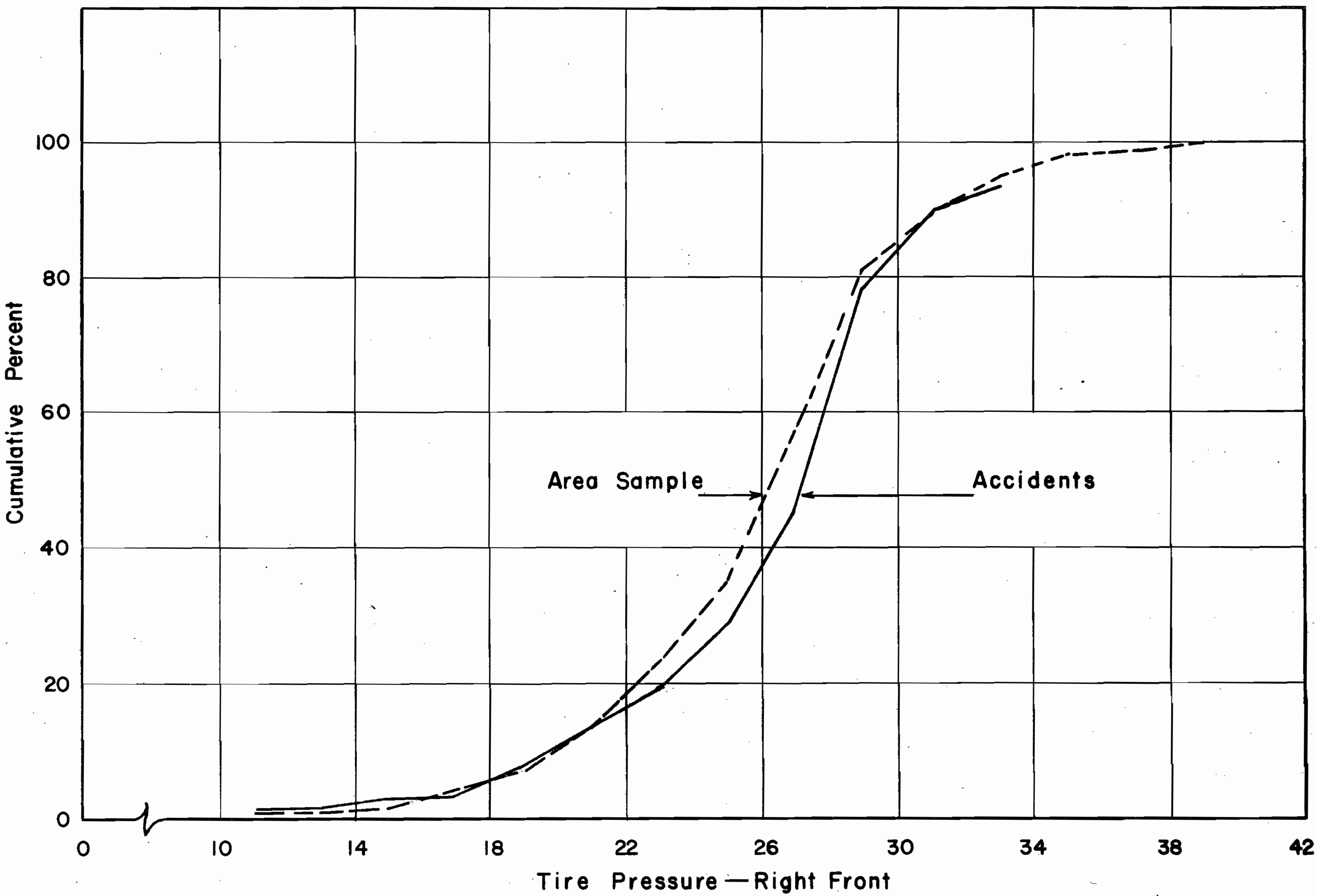
COMPARISON OF L.R. TREAD DEPTHS—ACCIDENTS AND AREA SAMPLE

Figure 6



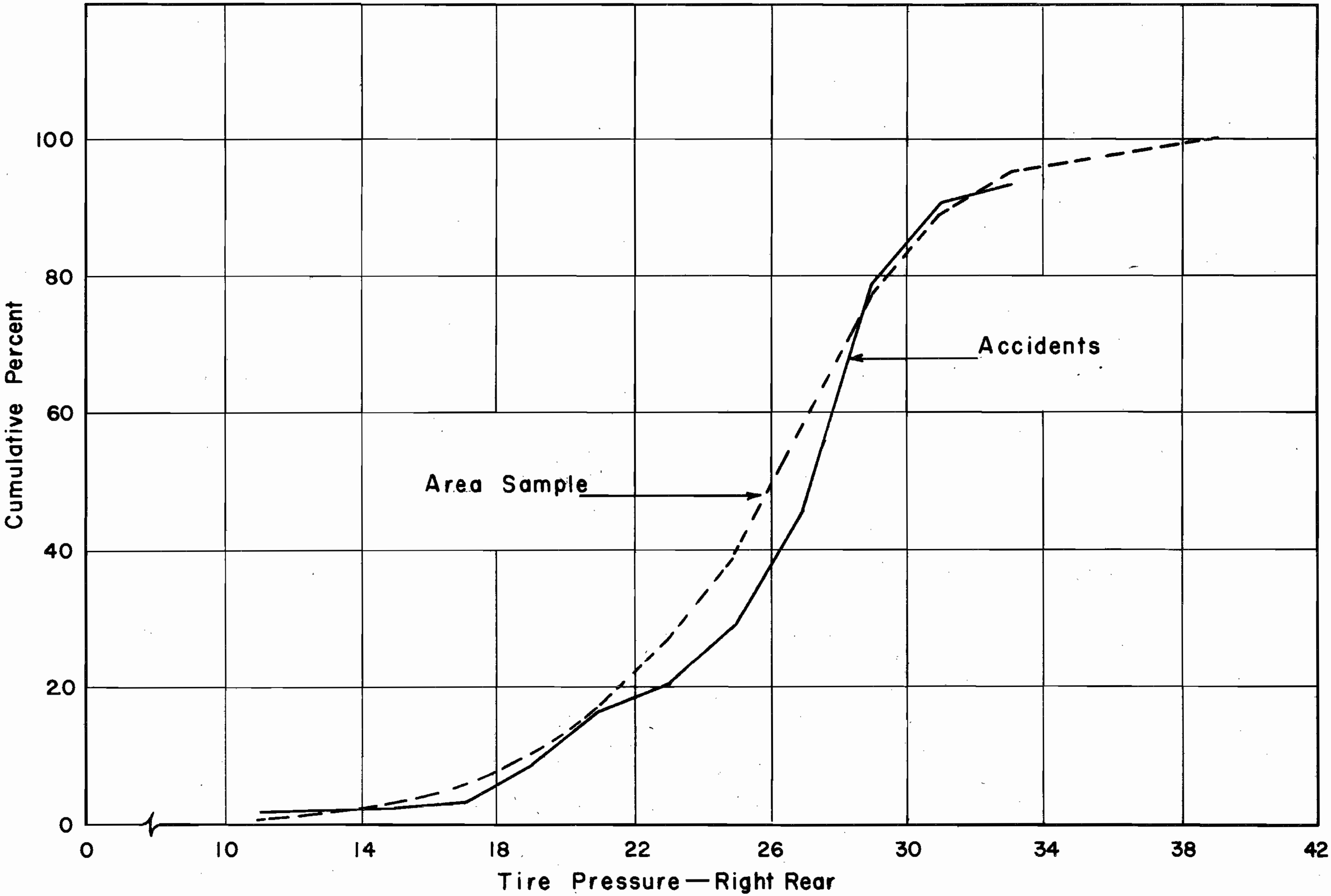
COMPARISON OF L. F. PRESSURES – ACCIDENT AND AREA SAMPLE

Figure 7



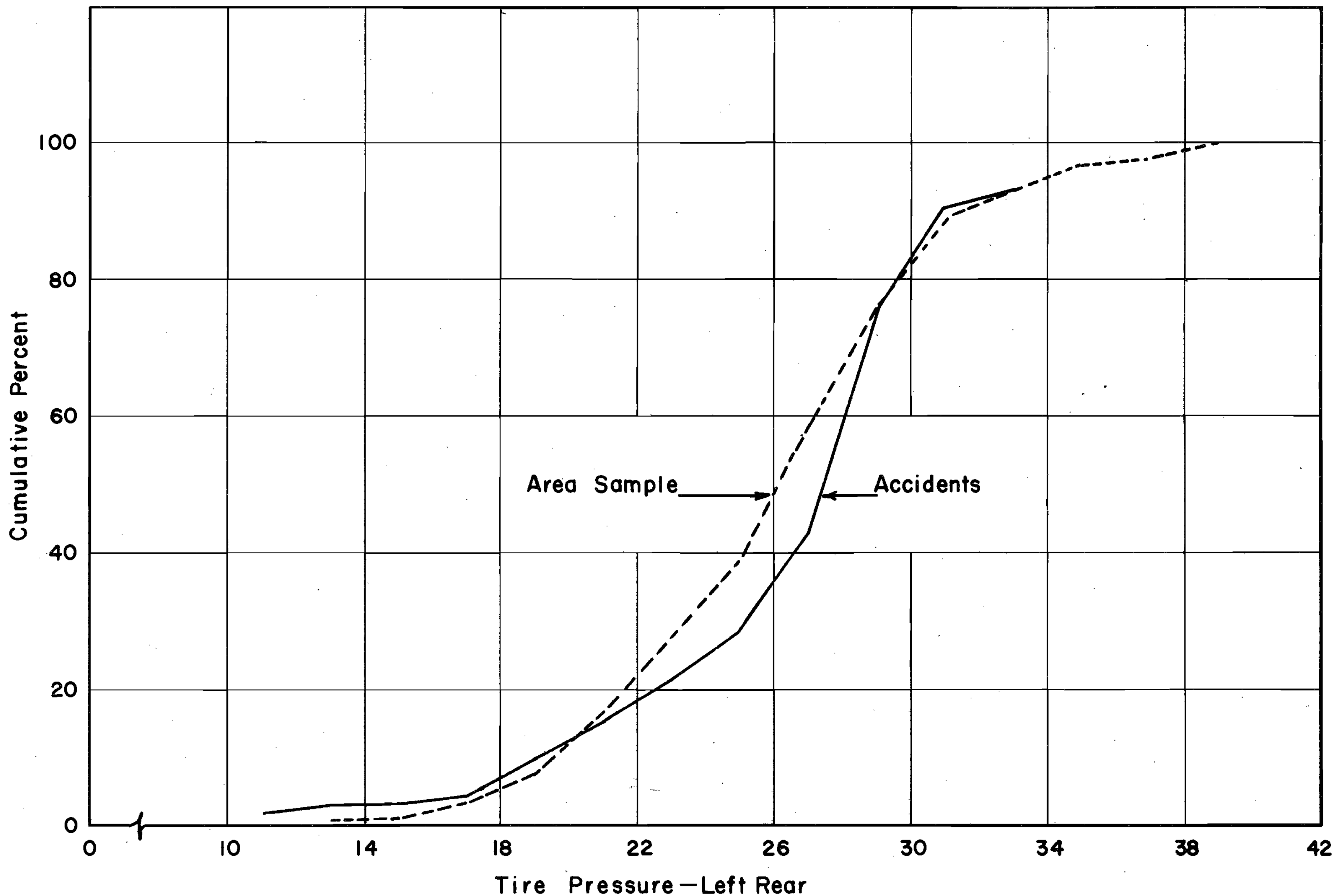
COMPARISON OF R.F. PRESSURES — ACCIDENT AND AREA SAMPLE

Figure 8



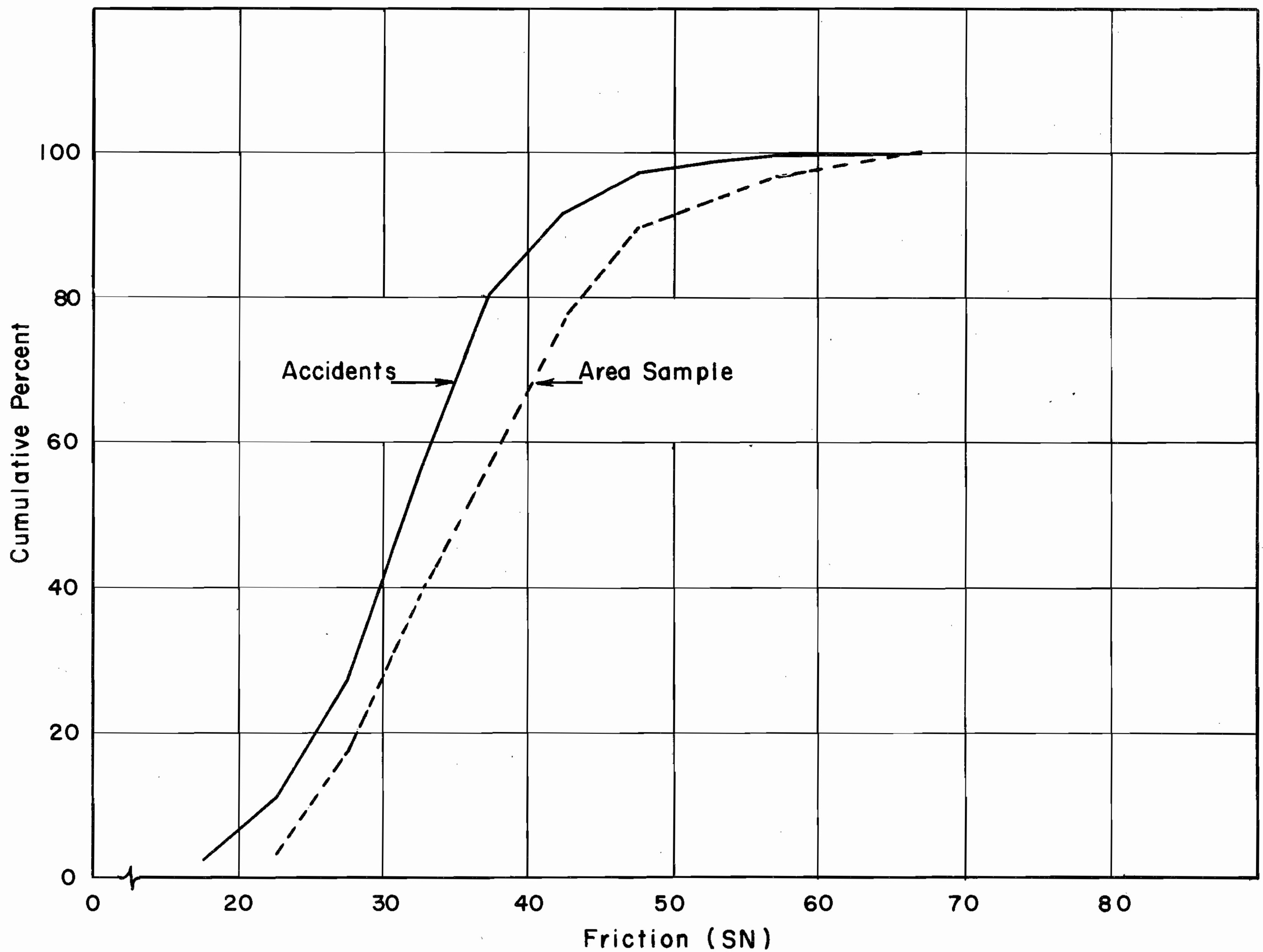
COMPARISON OF R.R. PRESSURES — ACCIDENT AND AREA SAMPLE

Figure 9



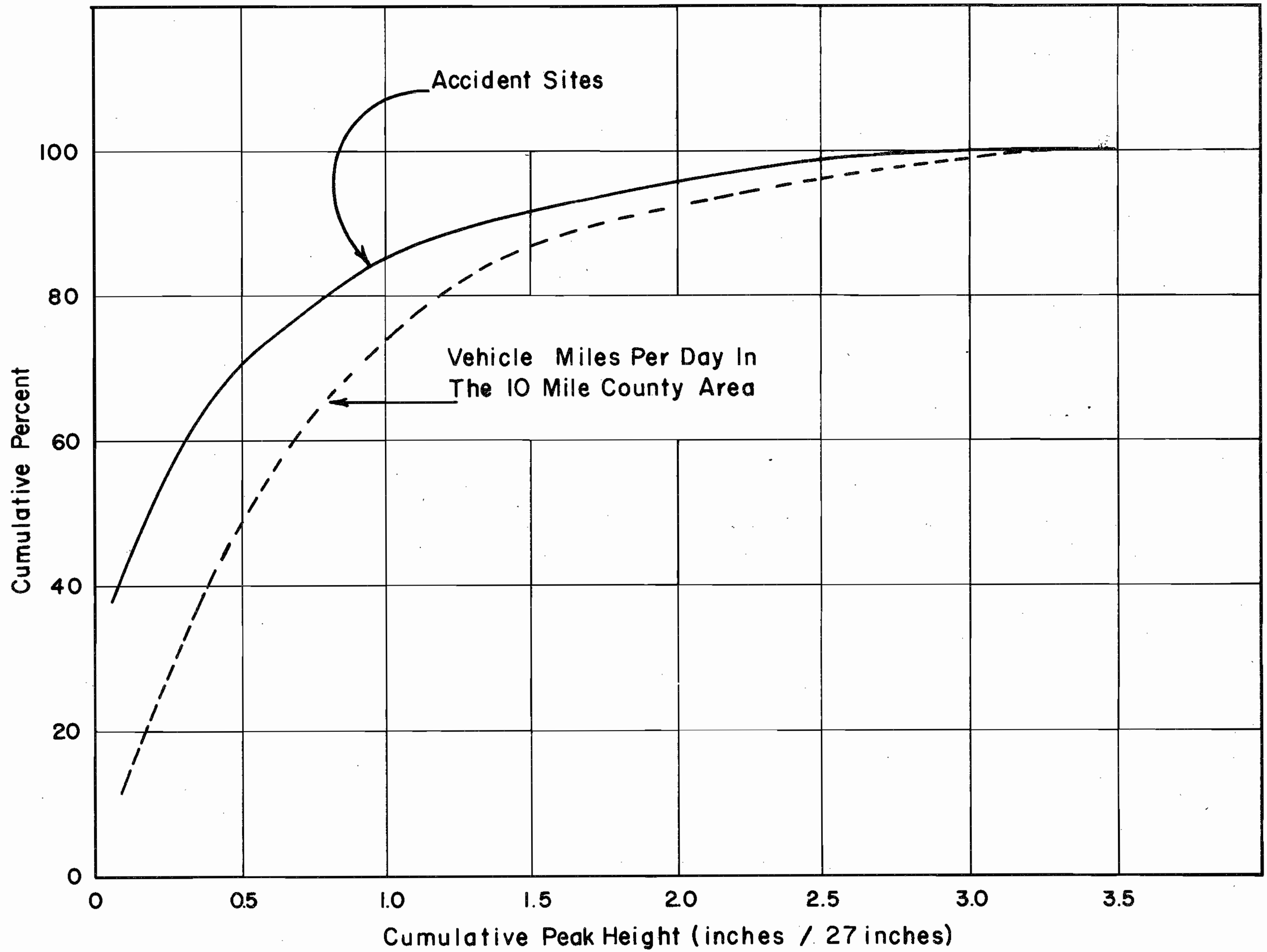
COMPARISON OF L.R. PRESSURES – ACCIDENT AND AREA SAMPLE

Figure 10



COMPARISON OF FRICTION VALUES - ACCIDENT AND AREA SAMPLE

Figure 11



COMPARISON OF MACRO TEXTURE—ACCIDENTS AND AREA SAMPLE
Figure 12

The same general treads of the above mentioned figures are evident in Figures 7 through 10 with the exception that there is a considerable increase in the number of accidents involving vehicles containing tire pressures around 28 to 29 psi as compared to the normal vehicle.

As stated previously, the skid number was measured with a trailer at the accident site and in the 1/2 mile area both up stream and downstream from the site. Dean, in a previous report for this project, has shown that, statistically, there is no significant difference between the average site skid number (35) and the average of a state-wide sample (39) consisting of over 2000 sections. (Ref. 4). It has since been found that the average friction for a sample of pavements in the study area is also 39, with the variance in the study area similar to the state-wide variance. The average for the one-mile vicinity is 36, therefore, it is concluded that there is no significant difference between the accident site skid number and the one-mile vicinity, or between the accident site and area sample. The skid numbers in Figure 11 were obtained at the accident site and it may be observed that the accidents generally occurred on pavements with lower skid numbers as compared with the normal condition of the area sample.

Perhaps the most striking data collected were those of surface texture. Texas had never before obtained the quantity of texture readings collected in this project and the distribution of data was the cause of immediate concern. The data indicated that a very large percentage of the wet weather accidents occurred on pavement surfaces with small macro texture values.

The cumulative frequency distribution of daily vehicle miles of travel for each texture grouping is shown in Figure 12 together with the cumulative frequency data for the accident sites. There is a large difference in percentages in the lower texture values. Near the 0.1

texture group, it appears that 40 percent of the accidents occurred on 10 to 15 percent of the pavements.

Categorization of Accidents

Research personnel are sometimes accused of dividing data into increasingly smaller groups until a point can be satisfactorily supported. This may seem true at times, but here the data was believed to require certain groupings and the exclusion of some accidents in order to avoid bias. Accidents involving drinking drivers were removed from consideration, and vehicles with more than four tires were not included. If a multiple vehicle accident occurred which involved a vehicle with more than four tires, this vehicle was omitted from study because of the obviously large tire pressure and tread depth considerations but the other four wheeled vehicles were retained. This left a total of 396 accidents, involving 540 vehicles, to be categorized.

The classifications of accidents were arbitrarily selected, but it was believed that information was particularly needed on hydroplaning, stopping friction, and cornering friction, because these are items by which remedial action can be established and which seem much more pertinent to the engineer as compared to the usual categorization of fatal, personal injury, etc. Also several research projects were planned for the skidding accident area and it was desired to determine the urgency of needed information for each friction type in order to establish priority ratings.

The categorization was accomplished by close study of the reports of the investigation officers, especially the accident diagrams. With the classifications established, each accident was categorized into one of the following types:

(1) accidents occuring on a tangent or straight roadway section with no braking involved,

(2) accidents occuring on curves,

(4) accidents occurring on a tangent with braking involved,

(5) multiple vehicle accidents,

(6) accidents occurring while passing, and

(7) miscellaneous accidents.

Originally the accidents occurring on curves were separated into those which involved skidding to the inside of the curve, toward the radius point, and those skidding to the outside. However, little information related to the accident event was provided, with the number skidding inside the curve approximately equal to those skidding outside. In a large number of cases it appeared that the rear end lost traction causing the vehicle to spin around. Subsequently, all accidents occurring on curves were included in Type 2 with Type 3 being omitted.

Types 1, 2, 4, and 6 are those thought to be closely associated with a skidding or out-of-control vehicle. These tend to be single vehicle accidents, with Types 2 and 6 generally involving some measure of cornering friction, Type 4 involving braking friction, and Type 1 involving a drive friction mode, with skidding believed to be initiated near the hydroplaning point.

Type 5 accidents included many rear-end collisions, in which at least one vehicle was moving much slower than the other vehicles involved. Type 7 accidents are those which did not fit any other specific type.

Each accident was placed in a group according to the decision of the researcher. A duplicate set of information was categorized by another member of the staff, with conflict occurring for several accidents. The conflicting categorization was reviewed by both staff members and a final grouping selected. The number of accidents falling into each group is shown in Table 1.

Table I reveals 25 percent of the accidents studied were single vehicle accidents occurring on tangents. In many instances the Type I accidents contained officers notes indicating possible hydroplaning and slick tire comments. Some 38.6 percent of the accidents involved some sort of turning or cornering manuever (Type 2 and Type 6) and 14.2 percent were multivehicle. Five multivehicle accidents occurred on curves but were retained in the Type 5 category. Finally, 22.2 percent were placed in the miscellaneous category. This category (Type 7) involved several accidents on which no decision could be reached concerning the grouping; for example, an accident was reported in which the vehicle was washed down a stream while attempting to negotiate a low water crossing.

Analysis of Accidents by Type

The advantage of studying accidents by type became immediately apparent. Large differences were found in each of the five variables for a given accident type as compared to the study of all accidents (Type 9). For example, during the course of this project it was desired to obtain information from the data concerning tread depths. It was found that many states require tires to exhibit 2/32-inch tread depth at the time of vehicular inspection. It was decided to determine the percentages of vehicles with 2/32 or less and compare the accident vehicle sample with the area sample, or the normal vehicle in the study area. The results were found as follows:

TABLE I

CLASSIFICATION OF ACCIDENTS

Classification		Number of Accidents	Percent
Tangent No Braking	(Type 1)	57	14.4
Curves	(Type 2)	125	31.5
Tangent With Braking	(Type 4)	42	10.6
Multivehicle	(Type 5)	56	14.2
Passing Maneuver	(Type 6)	28	7.1
Miscellaneous	(Type 7)	88	22.2
		396	100.0

Percent of Vehicles With 2/32-Inch
or Less of Tire Tread Depth

	L.F.	R.F.	R.R.	L.R.
Normal Vehicle	7%	7%	13%	16%
Accident Vehicle	8%	9%	23%	24%

where L.F. = Left Front R.R. = Right Rear
R.F. = Right Front L.R. = Left Rear

In other words, only 7 percent of the public in the study area maintain vehicles with 2/32-inch or less tread depth on the front tires. Some 8 to 9 percent of the accident vehicles had tires with 2/32-inch or less. This would indicate that there is not much difference between the normal vehicle and the accident vehicle; however, the rear tires revealed a degree of concern because almost a quarter of the vehicles which had an accident on wet pavement in the study area also had tires with 2/32-inch or less. In comparison, the rear tire tread depth of the normal vehicle appears much better with 13 to 16 percent indicated.

Almost as an after thought, the tread depths of the accident vehicles were studied by accident type. The results are as follows:

Percent of Vehicles With 2/32-Inch or
Less of Tire Tread Depth

	L.F.	R.F.	R.R.	L.R.
Accidents on a Tangent with No Braking Type 1	19%	22%	54%	52%
Accidents on Curves Type 2	12%	15%	38%	35%
Accidents on a Tangent While Braking Type 4	12%	19%	26%	23%
Multivehicle Accidents Type 5	8%	5%	5%	11%
Accidents While Passing Type 6	7%	21%	32%	46%

The results indicated that over 50 percent of the vehicles which had wet weather accidents on a tangent with no braking also had rear tires with 2/32-inch or less. In comparison, the multivehicle accidents (predominately where one vehicle had slowed or stopped on the pavement) had tires with strikingly greater tread depths.

The rolling friction mode found in the Type I accident requires less friction to maintain a vehicle in a selected path than an accident related to any other friction mode. Yet this friction was not available or the accident would not have occurred. The fact that the percentages of vehicles are ordered as shown above is considered significant in that:

1. tread depth is a factor to be considered in the friction of the tire-pavement interface.
2. the categorization of each individual accident (which was possibly biased by the selection determined by the researcher) was accomplished with some degree of success.
3. the data is an example of the necessity of tire inspection.

The remaining four variables could be treated as explained above; however, it was decided to use a different statistical treatment in order to analyze the five variables in combination.

The Degree of Influence of Factors by Accident Type

The five variables were studied by use of a statistical analysis of variance procedure. Each of the accident classes was studied separately, and finally all classes were combined.

The analysis was conducted in the following manner:

(1) The 50-percentile value for each variable was found for the samples collected in the study area.

(2) For each accident class each accident was reviewed and each variable was placed in one of two groups, either greater than the 50-percentile value (+) or less (-).

(3) The groups for each variable were combined into tables similar to the summary shown in Table II.

(4) An analysis of variance study was conducted on the assembled data.

Two additional accident types were defined for this part of the study. Type 8 consists of cumulative information for Types 1, 2, 4, and 6, all of which were believed to be closely associated with a skidding (out-of-control) vehicle. Type 9 represents all accidents categorized; that is, those involving four-wheeled vehicles and no drinking drivers.

The 50-percentile values of the samples were used because the samples represent "that which was available to the driver." Any percentile point could be selected for study but the 50-percentile value represented the midway point; that is, 50 percent of the pavement available to the driver was below the point and 50 percent above; and 50 percent of the vehicles in the area were predicted to have tread depths and tire pressures above the point and 50 percent below, etc. Then, after finding the number of accidents which occurred when the variable studied was greater than, or less than the established 50-percentile point, it was possible to estimate the influence of the variable. Also, by combining the variables, an estimate could be made of the influence of a combination of variables. It should be noted that the tire pressures and tread depths for the four wheel positions of a given vehicle were averaged for this study.

The results of the 50 percentile grouping are shown in Table II. The results are indicated for each accident type where both the number of accidents and the percent represented by the number may be found. The numbers in the right most columns were obtained by cumulating the numbers in corresponding rows. For example, in the first row, it may be found that 13 of the Type I accidents occurred where speed and tire pressures were greater than the 50 percentile value and where tread depths, friction (SN_{50}) and pavement texture are less than the 50 percentile values. These 13 accidents represent 22.7 percent of the 57 Type I accidents. In using this method of analysis, it may be noted that the accident sites and accident vehicles are compared to the area sample pavements and vehicles which represent the normal driving condition.

Using the information in Table II it is possible to analyze individual variables; that is, the number of accidents involving a positive variable (one with a greater than 50-percentile value) may be summed and compared to the sum of the negative variable (less than 50-percentile values). Table III is a list of the single variables.

Type 9 reflects all 396 accidents categorized. Of these, 212 accidents (54 percent) involved vehicles traveling above the 50-percentile wet weather speed of the area; 63 percent involved vehicles which carried tire pressures greater than the 50-percentile pressure of the collected sample of area vehicles; 221 accidents (56 percent) involved vehicles with tread depths less than the 50-percentile value; 248 accidents (63 percent) occurred at sites

TABLE II ACCIDENT VARIABLE ANALYSIS

(No. of Acc. — % of Total)

Acc. Type	+ SPEED																− SPEED																
	+ PRESS								− PRESS								+ PRESS								− PRESS								
	+ TD				− TD				+ TD				− TD				+ TD				− TD				+ TD				− TD				
	+ f		− f		+ f		− f		+ f		− f		+ f		− f		+ f		− f		+ f		− f		+ f		− f		+ f		− f		
	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	+ Tx	− Tx	
Type 1	2	2	0	6	1	4	2	13	0	0	0	2	1	3	1	7	0	0	0	0	0	1	1	3	1	2	0	1	0	2	0	2	57
% of Total	3.5	3.5	0	10.4	1.8	7.0	3.5	22.7	0	0	0	3.5	1.8	5.3	1.8	12.2	0	0	0	0	0	1.8	1.8	5.3	1.8	3.5	0	1.8	0	3.5	0	3.5	100.0
Type 2 & 3	2	3	6	5	4	2	4	19	1	2	4	1	5	7	5	5	1	3	5	2	6	5	4	5	0	2	0	2	2	3	4	6	125
% of Total	1.6	2.4	4.8	4.0	3.2	1.6	3.2	15.2	0.8	1.6	3.2	0.8	4.0	5.6	4.0	4.0	0.8	2.4	4.0	1.6	4.8	4.0	3.2	4.0	0	1.6	0	1.6	1.6	2.4	3.2	4.8	100.0
Type 4	0	0	2	6	0	2	2	4	2	0	0	2	0	1	0	1	1	3	2	1	0	1	2	4	0	0	1	0	0	1	1	3	42
% of Total	0	0	4.8	14.2	0	4.8	4.8	9.4	4.8	0	0	4.8	0	2.4	0	2.4	2.4	7.1	4.8	2.4	0	2.4	4.8	9.4	0	0	2.4	0	0	2.4	2.4	7.1	100.0
Type 5	1	0	2	4	0	0	1	0	0	0	0	3	1	0	0	0	3	4	4	11	1	0	2	4	0	2	2	5	1	2	2	1	56
% of Total	1.8	0	3.6	7.1	0	0	1.8	0	0	0	0	5.4	1.8	0	0	0	5.4	7.1	7.1	19.5	1.8	0	3.6	7.1	0	3.6	3.6	8.9	1.8	3.6	3.6	1.8	100.0
Type 6	0	0	1	1	0	3	0	0	0	1	1	1	2	2	2	5	0	0	0	2	0	2	0	0	0	0	0	1	0	1	0	3	28
% of Total	0	0	3.6	3.6	0	10.7	0	0	0	3.6	3.6	3.6	7.1	7.1	7.1	17.9	0	0	0	7.1	0	7.1	0	0	0	0	0	3.6	0	3.6	0	10.7	100.0
Type 7	5	4	2	4	1	4	2	4	4	1	1	2	3	0	2	1	6	6	5	4	1	3	4	6	0	3	1	3	0	3	1	2	88
% of Total	5.8	4.5	2.3	4.5	1.1	4.5	2.3	4.5	4.5	1.1	1.1	2.3	3.4	0	2.3	1.1	6.9	6.9	5.8	4.5	1.1	3.4	4.5	6.9	0	3.4	1.1	3.4	0	3.4	1.1	2.3	100.0
Type 8 = 1 - 4,6	4	5	9	18	5	11	8	36	3	3	5	6	8	13	8	18	2	6	7	5	6	9	7	12	1	4	1	4	2	7	5	14	252
% of Total	1.6	2.0	3.6	7.0	2.0	4.4	3.2	14.1	1.2	1.2	2.0	2.4	3.2	5.2	3.2	7.0	0.8	2.4	2.8	2.0	2.4	3.6	2.8	4.8	0.4	1.6	0.4	1.6	0.8	2.8	2.0	5.5	100.0
Type 9 All	10	9	13	26	6	15	11	40	7	4	6	11	12	13	10	19	11	16	16	20	8	12	13	22	1	9	4	12	3	12	8	17	396
% of Total	2.5	2.3	3.3	6.6	1.5	3.8	2.8	10.0	1.8	1.0	1.5	2.8	3.0	3.3	2.5	4.8	2.8	4.0	4.0	5.1	2.0	3.0	3.3	5.6	0.3	2.3	1.0	3.0	0.8	3.0	2.0	4.3	100.0

TABLE III
SINGLE VARIABLE STUDY

Variable	Type 9	Type 1	Type 2	Type 4	Type 5	Type 6	Type 7
+ Speed	212	44	75	22	12	19	40
- Speed	184	13	50	20	44	9	48
+ Pressure	248	35	76	30	37	9	61
- Pressure	148	22	49	12	19	19	27
+ Tread Depth	175	16	39	20	41	10	51
- Tread Depth	221	41	90	22	15	18	37
+ Friction	148	19	48	11	15	11	44
- Friction	248	38	77	31	41	17	44
+ Texture	139	9	53	13	20	6	38
- Texture	257	48	72	29	36	22	50

where the friction was less than the 50-percentile value for the area; and 257 accidents (65 percent) occurred at sites where textures were less than the 50-percentile value for the area. These percentages indicate that high speeds, high tire pressures, small tread depths, low friction, and small macro textures were present in the majority of accident cases. The order of these variables, from maximum to minimum percentage is:

(1) texture, 65 percent;

(2) and (3) friction and pressure, 63 percent;

(4) tread depth, 56 percent; and

(5) speed, 54 percent.

This ordering is similar to the information shown in Figures 2 through 12, however, there is some conflict which can be explained in the 105 accidents removed from study.

The order of variables for the individual accident types as an indication of the influence of each variable is given below.

Type 1 - Accidents Occurring on a Tangent Section - No Braking

1.	- Texture	48/57 = 84%
2.	+ Speed	44/57 = 77%
3.	- Tread Depth	41/57 = 72%
4.	- Friction	38/57 = 67%
5.	+ Pressure	35/57 = 61%

Type 2 - Accidents Occurring on Curves

1.	- Tread Depth	90/125 = 72%
2.	- Friction	77/125 = 62%
3.	+ Pressure	76/125 = 61%
4.	+ Speed	75/125 = 60%
5.	- Texture	72/125 = 58%

Type 4 - Accidents Occurring on a Tangent - With Braking

1.	- Friction	31/42 = 74%	
2.	+ Pressure	30/42 = 71%	
3.	- Texture	29/42 + 69%	
4.	+ Speed	22/42 = 52%	- Tread Depth 22/42 = 52%

Type 5 - Multivehicular Accidents

1.	- Speed	44/56 = 79%	
2.	+ Tread Depth	41/56 = 73%	- Friction 41/56 = 73%
3.	+ Pressure	37/56 = 66%	
4.	- Texture	36/56 = 64%	

Type 6 - Accidents Occurring While Passing

1.	- Texture	22/28 = 79%	
2.	+ Speed	19/28 = 68%	- Pressure 19/28 = 68%
3.	- Tread Depth	18/28 = 64%	
4.	- Friction	17/28 = 61%	

Type 7 - Miscellaneous Accidents

1.	+ Pressure	61/88 = 69%
2.	+ Tread Depth	51/88 = 58%
3.	- Texture	50/88 = 57%
4.	- Speed	48/88 = 54%
5.	Friction	44/88 - 50%

For types 1, 2, and 4 the variables were the same as for Type 9; that is, the larger percentages of accidents occurred at high speeds, high tire pressures, small tread depths, low friction, and low textures. Type 6 accidents were found to have the same variables as Types 9, 1, 2, and 4 except that the larger percentage of tire pressures was in the less than 50-percentile range.

Type 5 accidents reflected low speeds (speeds prior to the accident, for all vehicles involved, were averaged), high pressures, large tread depths, low friction, and small textures. Again, it should be noted that many of the multivehicle accidents occurred when one or more vehicles were stopped or were traveling at slow speeds, which accounts for the large percentage occurring below the 50-percentile speed.

Type 7 accidents had high tire pressures, good tread depths, low textures, low speeds and friction measurements were about average. The results found for the Type 7 and Type 5 accidents again stresses the importance of studying the individual accident types since these results are quite different as compared to the other accident types.

In Table II, blocks which have higher numbers of accidents seem to appear randomly, but closer study shows there is a pattern. As an example, the largest number for a Type 1 accident was 13 (22.7 percent), which occurred at the combination mentioned above (high speed, high pressure, small tread depths, low friction, and small textures). The largest number for Type 2 occurred at the same combination of events. This kind of pattern is believed to be the interaction of variables. Generally, every fourth block, observed horizontally across the table, has a higher number of accidents. This pattern shows the importance and danger of the combination of three variables: small tread depths, low friction, and small textures. However, based on these data, there would not be much danger from a Type 1 accident if low speed, high pressure, and good tread depths were maintained, since none of the 57 accidents studied occurred under these conditons.

Probably the best way to analyze the interaction of variables is through the use of the statistical analysis of variance procedure. The data found in Table II actually conform to a 2^5 factorial, which can be easily used in a computer program developed for this purpose. The computer program selected was the step-wise regression program developed by the University of California (Ref. 5). The program calculates the sum of squares for each variable or combination of variables studied. For a factorially designed experiment, the sum of squares value can be used to reveal the amount each variable or combination of variables explains, or contributes to, the number of accidents found in the study. By accumulating the sum of squares values for each variable a total sum of squares can be determined. Since it was desired to determine the significance of each variable or combination of variables the sum of squares for each individual variable was divided by the total sum of squares to determine the percent contribution. These percentages are listed in Tables IV through XI.

In discussing Tables IV through XI, an inadequacy of the method of analysis, the small number of observations or accidents available for study, should be noted. There were five original variables and 26 other possible combinations of the original variables, and counting the number of accidents as the variable for study (the dependent variable) there is a total of 32 variables.

TABLE IV

Percent of Contribution of Five Variables
Toward Accidents on Tangents With No Braking

(Type 1)

Variable	Sum of Squares	Percent	Cumulative Percent
TX	47.5	21.5	21.5
SP	30.1	13.6	35.1
TD	19.5	8.8	43.9
SP-TX	13.8	6.1	50.0
FR-TX	13.8	6.1	56.1
FR	11.2	5.1	61.2
SP-PR	11.3	5.1	66.3
TD-TX	11.3	5.1	71.4
SP-FR-TX	11.3	5.1	76.5
SP-FR	9.0	4.1	80.6
SP-TD	7.0	3.2	83.8
TD-FR	7.1	3.2	87.0
PR	5.3	2.4	89.4
SP-PR-TX	5.2	2.4	91.8
PR-FR	3.8	1.7	93.5
SP-TD-TX	2.5	1.1	94.6
PR-FR-TX	2.6	1.1	95.7
PR-TX	1.5	.7	96.4
PR-TD-FR	1.5	.7	97.1
SP-PR-FR-TX	1.6	.7	97.8
PR-TD	.8	.4	98.2
SP-PR-TD	.7	.4	98.6
SP-TD-FR	.8	.4	99.0
TD-FR-TX	.8	.4	99.4
SP-PR-TD-FR	.8	.4	99.8
PR-TD-TX	.3	.1	99.9
SP-TD-FR-TX	.2	.1	100.0
SP-PR-FR	.1		
SP-PR-TD-TX			
PR-TD-FR-TX			
SP-PR-TD-FR-TX			
	221.5	100.0	

Note: TX indicates Texture, SP-Speed, TD-Tread Depth, PR-Tire Pressure, and FR-Friction

TABLE V

Percent of Contribution of Five Variables Toward Accidents Occurring on Curves

(Type 2)

Variable	Sum of Squares	Percent	Cumulative Percent
TD	69.0	20.2	20.2
FR	26.3	7.8	28.0
TD-FR-TX	26.3	7.8	35.8
PR	22.8	6.8	42.6
SP-PR-FR	22.8	6.8	49.4
SP	19.5	5.8	55.2
SP-PR-TD-FR	19.5	5.8	61.0
SP-PR-FR-TX	19.5	5.8	66.8
PR-TD-FR-TX	16.6	4.8	71.6
SP-PR-TX	13.8	4.0	75.6
TX	11.2	3.3	78.9
PR-FR	11.3	3.3	82.2
SP-FR	9.0	2.6	84.8
TD-TX	9.1	2.6	87.4
SP-TD-TX	9.0	2.6	90.0
PR-FR-TX	9.0	2.6	92.6
SP-TD-FR-TX	5.3	1.6	94.2
PR-TD-TX	3.8	1.1	95.3
SP-PR-TD-FR-TX	3.8	1.1	96.4
SP-TD	1.5	.5	96.9
SP-TX	1.5	.5	97.4
TD-FR	1.6	.5	97.9
FR-TX	1.5	.5	98.4
SP-TD-FR	1.5	.5	98.9
SP-PR-TD-TX	1.6	.5	99.4
PR-TX	.8	.2	99.6
PR-TD-FR	.7	.2	99.8
SP-PR	.3	.1	99.9
PR-TD	.3	.1	100.0
SP-PR-TD			
SP-FR-TX			
	342.7	100.0	

TABLE VI

Percent of Contribution of Five Variables Toward
Accidents on Tangents With Braking

(Type 4)

Variable	Sum of Squares	Percent	Cumulative Percent
FR	12.5	18.7	18.7
PR	10.1	15.2	33.9
TX	8.0	12.1	46.0
SP-TD-FR-TX	6.2	9.4	55.4
PR-FR	4.5	6.8	62.2
SP-PR-FR	4.5	6.8	69.0
SP-TD-FR	4.5	6.8	75.8
SP-FR-TX	3.1	4.6	80.4
PR-TX	2.0	3.0	83.4
TD-TX	2.0	3.0	86.4
SP-PR-TD-FR	2.0	3.0	89.4
SP-TD	1.1	1.6	91.0
FR-TX	1.1	1.6	92.6
SP-PR-TD	1.1	1.6	94.2
SP-FR	.6	.9	95.1
SP-TX	.5	.7	95.8
TD-FR	.5	.7	96.5
SP-PR-TX	.4	.6	97.1
SP-TD-TX	.5	.7	97.8
PR-TD-TX	.6	.9	98.7
SP	.1	.1	98.8
TD	.1	.1	98.9
SP-PR	.1	.1	99.0
PR-TD	.2	.3	99.3
PR-FR-TX	.1	.1	99.4
TD-FR-TX	.1	.1	99.5
SP-PR-FR-TX	.1	.1	99.6
PR-TD-FR-TX	.2	.3	99.9
SP-PR-TD-FR-TX	.1	.1	100.0
PR-TD-FR			
SP-PR-TD-TX			
	66.9	100.0	

TABLE VII

Percent of Contribution of Five Variables
Toward Multivehicular Accidents

(Type 5)

Variable	Sum of Squares	Percent	Cumulative Percent
SP	32.0	20.0	20.0
TD	21.1	13.1	33.1
FR	21.2	13.1	46.2
TD-TX	10.1	6.3	52.5
PR	10.1	6.3	58.8
TX	8.0	5.0	63.8
PR-TD	8.0	5.0	68.8
TD-FR	8.0	5.0	73.8
FR-TX	6.1	3.8	77.6
SP-TX	4.5	2.8	80.4
PR-FR	4.5	2.8	83.2
TD-FR-TX	4.5	2.8	86.0
SP-PR-FR-TX	4.5	2.8	88.8
SP-PR	3.2	2.0	90.8
SP-TD	3.1	2.0	92.8
SP-FR	3.1	2.0	94.8
SP-PR-TD	2.0	1.3	96.1
PR-FR-TX	2.0	1.3	97.4
SP-PR-TX	1.1	.7	98.1
SP-TD-TX	1.2	.7	98.8
SP-PR-FR	.5	.3	99.1
SP-PR-TD-TX	.5	.3	99.4
PR-TX	.1	.1	99.5
SP-FR-TX	.1	.1	99.6
PR-TD-FR	.1	.1	99.7
SP-PR-TD-FR	.2	.1	99.8
PR-TD-FR-TX	.1	.1	99.9
SP-PR-TD-FR-TX	.1	.1	100.0
SP-TD-FR	.0		
PR-TD-TX	.0		
SP-TD-FR-TX			
	160.0	100.0	

TABLE VIII

Percent of Contribution of Five Variables
Toward Accidents Occurring While Passing

(Type 6)

Variable	Sum of Squares	Percent	Cumulative Percent
TX	8.0	17.7	17.7
TD	4.5	9.9	27.6
PR-TD-FR	4.5	9.9	37.5
PR-TD-FR-TX	4.5	9.9	47.4
SP	3.1	6.9	54.3
PR	3.2	6.9	61.2
PR-TD	3.1	6.9	68.1
SP-PR	2.0	4.5	72.6
PR-FR	2.0	4.5	77.1
TD-TX	2.0	4.5	81.6
PR-FR-TX	2.0	4.5	86.1
FR	1.1	2.5	88.6
SP-TD	1.1	2.5	91.1
TD-FR	1.1	2.5	93.6
SP-PR-TD	.6	1.1	94.7
SP-FR-TX	.5	1.1	95.8
SP-PR-TD-TX	.5	1.1	96.9
SP-TD-FR-TX	.5	1.1	98.0
SP-TX	.1	.2	98.2
PR-TX	.1	.2	98.4
FR-TX	.1	.2	98.6
SP-PR-FR	.2	.2	98.8
SP-TD-TX	.1	.2	99.0
PR-TD-TX	.1	.2	99.2
TD-FR-TX	.1	.2	99.4
SP-PR-TD-FR	.2	.2	99.6
SP-PR-FR-TX	.1	.2	99.8
SP-PR-TD-FR-TX	.1	.2	100.0
SP-FR			
SP-PR-TX			
SP-TD-FR			
	45.5	100.0	

TABLE IX

Percent of Contribution of Five Variables
Toward the Miscellaneous Accident Type

(Type 7)

Variable	Sum of Squares	Percent	Cumulative Percent
PR	36.1	36.1	36.1
SP-PR-TX	10.1	10.1	46.2
TD	6.2	6.2	52.4
TD-FR	6.1	6.1	58.5
TX	4.5	4.5	63.0
SP-TX	4.5	4.5	67.5
SP-FR-TX	4.5	4.5	72.0
PR-TD-FR	4.5	4.5	76.5
PR-TD-TX	5.0	5.0	81.5
SP-PR	2.6	2.6	84.1
SP	2.0	2.0	86.1
SP-FR	2.0	2.0	88.1
PR-TD	2.0	2.0	90.1
SP-PR-TD-FR	2.0	2.0	92.1
PR-TX	1.2	1.2	93.3
TD-TX	1.1	1.1	94.4
TD-FR-TX	1.1	1.1	95.5
SP-PR-FR-TX	1.1	1.1	96.6
SP-TD-FR-TX	1.2	1.2	97.8
FR-TX	.5	.5	98.3
SP-PR-TD	.5	.5	98.8
SP-PR-TD-FR-TX	.5	.5	99.3
SP-TD	.1	.1	99.4
PR-FR	.1	.1	99.5
SP-PR-FR	.1	.1	99.6
SP-TD-FR	.2	.2	99.8
SP-TD-TX	.1	.1	99.9
PR-FR-TX	.1	.1	100.0
FR			
SP-PR-TD-TX			
PR-TD-FR-TX			
	100.0	100.0	

TABLE X

Percent of Contribution of Five Variables
Toward Skidding Accidents

(Type 8)

Variable	Sum of Squares	Percent	Cumulative Percent
TX	253.1	18.2	18.2
TD	231.2	16.6	34.8
FR	171.1	12.2	47.0
SP	144.4	10.3	57.3
TD-TX	84.6	6.0	63.3
PR	72.0	5.1	68.4
SP-FR	45.1	3.2	71.6
SP-PR-FR	45.1	3.2	74.8
SP-PR-TX	45.1	3.2	78.0
FR-TX	40.5	2.9	80.9
SP-FR-TX	40.5	2.9	83.8
PR-FR	36.2	2.6	86.4
SP-PR-FR-TX	32.0	2.3	88.7
SP-TX	28.1	2.0	90.7
TD-FR-TX	28.1	2.0	92.7
SP-TD-TX	18.0	1.3	94.0
SP-TD	15.1	1.1	95.1
TD-FR	12.5	.9	96.0
SP-PR-TD-FR	12.5	.9	96.9
PR-TX	10.2	.7	97.6
SP-PR	8.0	.6	98.2
PR-FR-TX	8.0	.6	98.8
PR-TD-FR-TX	6.1	.4	99.2
SP-PR-TD-TX	4.5	.3	99.5
PR-TD	2.9	.2	99.7
PR-TD-TX	2.0	.1	99.8
SP-TD-FR-TX	1.1	.1	99.9
SP-PR-TD-FR-TX	1.2	.1	100.0
SP-PR-TD	.1		
SP-TD-FR	.0		
PR-TD-FR			
	1399.5	100.0	

TABLE XI

Percent of Contribution of Five Variables
Toward All Accidents Studied

(Type 9)

Variable	Sum of Squares	Percent	Cumulative Percent
TX	435.1	24.9	24.9
PR	312.5	17.9	42.8
FR	312.5	17.9	60.7
FR-TX	91.2	5.2	65.9
SP-PR-TX	78.1	4.4	70.3
PR-FR	72.0	4.1	74.4
TD	66.1	3.8	78.2
SP-FR-TX	66.1	3.8	82.0
TD-TX	50.0	2.9	84.9
SP-TD	36.1	2.0	86.9
PR-TD	36.2	2.0	88.9
SP-PR-FR	32.0	1.8	90.7
SP	24.5	1.4	92.1
SP-TD-TX	24.5	1.4	93.5
PR-TX	21.1	1.3	94.8
PR-FR-TX	15.1	.8	95.6
SP-FR	12.5	.7	96.3
PR-TD-TX	12.5	.7	97.0
TD-FR	10.1	.6	97.6
SP-PR-TD-TX	8.0	.5	98.1
PR-TD-FR	6.2	.4	98.5
SP-PR-FR-TX	6.1	.4	98.9
TD-FR-TX	4.5	.3	99.2
PR-TD-FR-TX	4.5	.3	99.5
SP-PR-TD	3.1	.2	99.7
SP-PR-TD-FR	3.1	.2	99.9
SP-TX	1.2	.1	100.0
SP-PR	.5		
SP-TD-FR	.1		
SP-TD-FR-TX	.0		
SP-PR-TD-FR-TX			
	1745.5	100.0	

This inadequacy was especially bad for Type 6, for which there were only 28 accidents or observations. Here the attempt to solve for the contribution of 32 variables was made using the distribution of only 28 accidents. Therefore, little confidence can be placed in the results of the analysis of variance for accident types with small numbers of accidents and greater confidence in those with larger numbers of observations. As an indication of what to accept and what not to accept, the authors arbitrarily selected as significant any analysis of variance study containing at least 32 observations.

In Tables IV through XI, it is obvious that each of the five variables is an important contributor to the accidents studied and that some are more important to certain types of accidents than others. For example, in regard to the interactions of variables, the more complex interactions, four and five-way, are shown to be not as important as the less complex, two and three-way interactions. In each case a single variable is most important. The Type 2 accidents and the Type 7 accidents appear to be the most complex because of the more complex interactions. It is possible that this complexity is associated with the miscellaneous nature of the Type 7 accident and with the variables selected for measurement in the Type 2 accident. For example, the cornering slip friction may not be directly related to the SN_{50}).

The first six variables generally contain a cumulative percentage of contribution ranging from 50 to 70 percent and were selected for closer study. For Type 1 accidents texture, speed, tread depth, and friction are shown to be important. The interactions of speed with texture and friction with texture are ranked high in importance. For some reason, tire pressure does not appear to be too significant, and texture must be considered very important.

For Type 2 accidents (Table V) tread depth, friction, tire pressure, and speed are large contributors, but texture occurs only in an interaction with tread depth and friction. Tread depth is of extreme importance.

For Type 4 accidents (Table VI), friction, tire pressure, and texture are large contributors, and speed and tread depth are minor contributors. The interaction of speed, tread depth, friction, and texture explains some 9.4 percent; and the interaction of speed, tire pressure, and friction is involved in 6.8 percent.

All five single variables appear in the Type 5 accidents (Table VIII), along with the tread depth and texture interaction. Speed is revealed to be the most significant contributor, with tread depth and friction following closely.

Some 36.1 percent of the Type 7 accidents (Table IX) involve tire pressure. It is interesting to note that speed and, especially, friction play minor roles in this accident type.

For Type 8 (Table X) texture appears as the most important variable, with 18.2 percent. Tread depth, friction, and speed follow with 16.6, 12.2 and 10.3 percent respectively. The interaction of tread depth and texture is next with 6.0 percent, with tire pressure following at 5.1 percent.

Table XI covers Type 9, all the accidents studied. Texture is again shown to be most important, followed by tire pressure, friction, a friction-texture interaction, the speed-pressure-texture interaction, and a pressure-friction interaction. Tread depth was in the seventh place and speed in the thirteenth place.

CHAPTER IV. CONCLUSIONS

The results of this study have led to the conclusions discussed here.

Macro texture, vehicle tread depth, pavement surface friction (SN at 50 mph), vehicle speed, and vehicle tire pressure were found to be important variables in the wet-weather accidents studied.

Compared to the sample data, the accident data indicated that a larger number of accidents occured under the following conditions:

(1) the texture of the pavement at the accident site was small (or fine macro texture),

(2) the tread depths of the vehicle involved were small,

(3) the friction value of the pavement at the accident site was low,

(4) the speed of the vehicle immediately prior to the accident was high, and

(5) the tire pressures of the accident vehicle were high.

The relative importance of the five variables was found to depend on the type of general accident situation.

Single variables were the most significant contributors to wet-weather accidents. Complex interactions of the five variables studied did not influence accidents to a great degree, but several two and three-way interactions contributed significantly.

Approximately 40 percent of the vehicles involved in wet-weather accidents were in a turning maneuver, about one-third on horizontal curves and 7.1 percent while passing. It is apparent that research efforts should be directed toward obtaining more information on cornering friction and that remedial measures should be directed to horizontal curves.

For a skidding accident in wet weather (Type 8), the order of importance of the five variables studied would be

(1) texture,

(2) tread depth,

(3) friction,

(4) speed, and

(5) tire pressure.

Little difference was found in the percent of contribution of each variable, with values ranging from 5.1 to 18.2 percent.

One of the purposes of collecting accident information should be to detect trouble areas in order that remedial measures may be developed. It would seem to the Design Engineer that the sole purpose of maintaining accident records is to determine the number of people killed or injured per year in order to compare each years events. In most records, the sex of the drivers may be found in order that one can determine whether females are better-or worse drivers as compared to males-except generally there is no basis for comparison. This type of record has been filed for years yet, in most states, there are no records maintained to indicate the number of accidents which involved skidding. Of course, records of fatalities and injuries are important because remedial measures should be directed toward reducing the severity of accidents. However, the results of this report indicated close study of the reports of the investigating officers should help to categorize accidents into preselected types. It is believed that the categorization of wet weather accidents into types which contain the various friction modes would be of benefit since these friction modes are also used in highway design. It is concluded that accident information should also be reported in terms useful to the engineer.

The most striking result of the study was the importance of texture. As stated previously, few texture measurements had been obtained prior to this project, and the first indication of the effect of texture was the distribution of texture values, found in Fig. 12. Then when texture at the accident site was compared to the texture available on the roadways in the area, an even greater importance was indicated. The texture sampling procedure for the area was poor since funds sufficient to sample the study area had not been provided, but the evidence accumulated appeared to offer cause for concern.

It should be noted that macro texture of the surface itself is not the item of interest; the minute water drainage channels that texture provides when a tire passes over it are the significant effects. A porous surface through which the water could drain when the tire passes (or under its own head) would be as beneficial, but a textured surface would probably be the most economical type of construction in this state.

The distribution of accidents shown in Tables II and III is considered to be significant and to show the benefit of studying accident types. Except for tire pressures, the distribution is as expected. The most dangerous combination of variables is high speeds, low tread depths, low friction, and small textures. Each of these variables helps to bring about a very low available friction between the tire and the pavement under wet-weather conditions.

The absence of low tire pressures in the accidents is puzzling.

According to hydroplaning theory, low tire pressures are directly related to the velocity of dynamic hydroplaning; that is, the lower the tire pressure the lower the speed at which hydroplaing occurs (Ref. 6 and 7). When a vehicle is hydroplaning, the available tire-pavement friction must be very low and, prior to this study, it would have seemed that all proven principles associated with hydroplaning would also hold for tire-pavement friction. Yet in only one accident type, passing, were low tire pressures found to be significant. Apparently, the absence of low tire pressures from the group of significant variables can be explained by viscous hydroplaning, which is generally associated with slick pavements, small water depths, and high tire pressures. It is possible that both viscous and dynamic hydroplaning are involved in these accidents and the two could not be separated with the methods used in this analysis. However, it does appear that the accidents occurring due to hydroplaning cannot be separated from accidents occurring at a low friction level. It other words the situation is dangerous whenever friction is reduced to a low level. It is also obvious that the pavement is not the only contributor to low friction. Low tread depths and high speeds, contribute to an accident. A good measure of water film depth on the pavement at the time of the accident was not obtained in this study, but all the evidence when combined with theory leads to the importance of this variable. Water depths greater than those emitted by the skid trailer must be present at the time of the accident.

Accidents are complex, and in many cases no remedial measure is available as far as design, construction, and maintenance of highways or in enforcement with the present laws of this state. Highway departments and law enforcement agencies can do much to reduce accidents, but the evidence in this study indicates the driver must also act independently to prevent the accidents analyzed here.

Skid trailer values must be considered in skidding safety and cannot be taken lightly. However, a skid trailer test value alone is not sufficient to establish the skidding safety of a highway, or for that matter, a safe friction value for a highway. Efforts should be made to provide a tire-pavement interface friction value which is more representative of the friction available to the driver at the time of a wet-weather accident. The trailer skid number should be modified by a water depth factor and a factor for the tire-pavement drainage characteristic to give a skid number that is more representative of the actual accident conditions. The friction should be further modified by use of tread depths, tire pressures, and speeds more representative of the actual accident vehicle.

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