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RELATIONSHIP OF THE TIRE-PAVEMENT INTERFACE TO TRAFFIC ACCIDENTS OCCURRING UNDER WET CONDITIONS

TEXAS HIGHWAY DEPARTMENT

RELATIONSHIP OF THE TIRE-PAVEMENT INTERFACE TO TRAFFIC ACCIDENTS OCCURRING UNDER WET CONDITIONS

by

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for

"A Pilot Study to Determine the Degree of Influence of Various Factors Pertaining to the Vehicle and the Pavement on Traffic Accidents Under Wet Conditions"

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ABSTRACT

In many areas of Texas members of the Texas Highway Department and the Texas Department of Public Safety work together in studying traffic accidents. In some cases meetings of the two organizations is happenstance at the accident site and in others by plan. This study resulted from one such meeting when it was believed that vehicular characteristics contributed to the accident being studied.

Information was collected on the accident vehicles and sites in a ten county area as follows:

1. Tire pressure on all tires
2. Tire tread depth on all tires
3. Other pertinent tire information
4. Friction at the site and within a 1/2 mile length around the site.
5. Other pertinent accident information

It was found that the wet weather (total) accident rate was nearly double the rate for all weather conditions for the five months studied with the pavement being wet 6.70% of the time period. In certain areas the wet weather accident rate for all accidents could vary as much as six times the average wet weather rate for the ten county area.

Even though all tire factors are probably important in the operation of a vehicle on wet pavement, it was found that the lack of tread depth on the rear tires was of major importance in the accidents studied and particularly the skidding accidents.

Significant difference was found between the friction values within a one mile vacinity of the accident site and the friction values at the site. However, the actual differences are small and it is believed that a change in coefficient

of friction near the site has a small effect on wet weather accidents. A significant difference was found between a sample average of the state-wide friction values and the friction values at the accident sites. The state-wide average being 0.39 and the average coefficient of friction at the accident sites being 0.35.

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CHAPTER 1. INTRODUCTION

The traffic accident toll has continued to increase over the years and it has now reached alarming proportions. Motor vehicle accidents are now claiming more than 53,000 lives per year and causing approximately 35 to 40 times this many injuries each year (Ref 1). Traffic accidents also result in a tremendous economic loss. For traffic accidents occurring in 1964, the estimated costs including wage loss, medical expense, overhead costs of insurance, and property damage for all accidents averaged about $175,000 per fatality (Ref 2).

One obvious reason for the large and steadily increasing accident toll is that population, licensed drivers, motor vehicle registration, and vehicle miles of travel continue to increase at a rapid rate. Accident rates based on the number of vehicles and vehicle-miles of travel, however, have been gradually decreasing since the early 1940's. These trends are illustrated by the respective ratios of 1966 totals to 1950 totals in Table 1.

Highway safety has been a matter of concern for many years. Only recently, however, has a concerted effort been directed toward improving highway safety as evidenced by the 1966 Highway Safety Act (Ref 3) and the National Traffic and Motor Vehicle Safety Act of 1966 (Ref 4).

TABLE 1. GROWTH TRENDS - 1950 and 1966
(from Refs 1 and 6)

	1950	1966	Ratio 1966:1950
Population (millions)	152.3	195.9	1.29
Licensed Drivers (millions)	62.2	101.0	1.62
Motor Vehicle Registration (millions)	49.2	94.2	1.92
Vehicle miles of travel (billions)	458.2	930.5	2.03
Traffic Accident fatalities	34,800	53,000	1.52
Fatalities per 100,000 population	23.0	27.0	1.17
Fatalities per 10,000 motor vehicles	7.1	5.5	0.77
Fatalities per 100 million vehicle miles of travel	7.6	5.7	0.75

Skidding accidents are becoming a matter of special concern. In Northern Europe 15 to 20 percent of all traffic accidents reportedly involve skidding (Ref 5). Reliable skidding accident data, however, have been rather difficult to acquire in the United States. Nevertheless, indications are that 5 to 6 percent of all reported traffic accidents in the United States involve skidding. Research on the prevention of skidding accidents has been receiving far greater attention in Europe than in the United States.

It is well known that wet pavements are more slippery than dry pavements. Water lubricates the tire-pavement interface and reduces the available friction considerably. It would therefore appear that skidding accidents are more of a problem on wet pavements. A survey (Ref 7) of several state highway departments revealed that from 7 to 28 percent of all vehicle accidents during the period of 1960 to 1965 occurred on wet pavements. The same survey indicated that as many as 10 percent of all vehicle accidents were due to skidding on wet pavements. Often over 80 percent of the accidents occurring during wet weather involved skidding. Kummer and Meyer (Ref 8) report that a rather extensive accident study in Virginia identified skidding as a major cause in 35 to 41 percent of all accidents on wet pavements. Moyer (Ref 5) reports that European traffic accident records indicate the incidence of skidding accidents on wet pavements is two to three times greater than in the United States.

It is therefore evident that skid resistance is an important part of highway safety. The pavement wearing surface is one of the principal factors affecting skid resistance and is a matter of particular concern to highway engineers. The wearing surface should provide the maximum skid resistance possible while still satisfying the demands of comfort and economy. The objective of this research was to analyze detailed roadway and traffic accident data in an attempt to determine what effect wet weather had on accident rates and what factors pertaining to the tire-pavement interface contribute significantly to wet weather accidents.

CHAPTER 2. IMPORTANT CONSIDERATIONS IN SKID RESISTANCE AND SKIDDING ACCIDENTS

Skidding is a factor in many traffic accidents, especially for accidents occurring when the pavement is wet. An understanding of the tire-pavement interface and its relationship to skidding is therefore very important to highway safety.

It is by no means correct to assume that a skidding accident automatically indicates pavement slipperiness. Unfortunately, the problem is not that simple. Skidding involves a slipping or skidding at the tire-pavement interface and therefore involves the tire as well as the pavement. The pavement surface is, of course, a very important part of the friction pairing and obviously the lower the skid resistance, the more conducive conditions are to skidding accidents. Many factors other than tires and pavement are also involved in skidding accidents which further complicates the problem. Excessive speed, unbalanced brakes, wet or icy pavement, poor geometric design of the highway, and actions on the part of the driver can also be important factors in skidding accidents.

Several terms are commonly used to describe the tire-pavement friction pairing. Pavement skid resistance, pavement slipperiness, and pavement coefficient of friction are quite common. Terms such as these are somewhat misleading because friction is implied as being only a pavement property which is not the case. It should, therefore, be kept in mind that whatever terminology is used, it refers to the tire as well as the pavement.

Much of the theory concerning skid resistance is not entirely new. Slippery pavements have been known to exist for more than four decades. However, it has only been in the past 15 to 20 years that the causes of slipperiness, its measurement, and its effect on the safety of vehicular traffic have been matters of considerable concern (Ref 7). The importance of skid resistance has been emphasized recently by its inclusion in Federal-aid highway safety improvement projects (Ref 9).

SKID RESISTANCE

Factors Affecting Friction

Many factors pertaining to the roadway affect skid resistance. The texture of the pavement surface has the most direct influence. However, the age and the weathering of the surface, the presence of water or contaminants, and the geometrics of the highway are also important factors (Ref 10).

Several terms are commonly used to describe the texture or geometry of the pavement surface. The fineness or coarseness of the surface is sometimes described as being closed or open. Also, microscopic and macroscopic have become popular terms describing the relative roughness of the pavement surface.

Kummer and Meyer (Ref 7) divide macroscopic into large and small-scale macroscopic roughness. The large-scale macroscopic texture refers to the voids in the pavement surface. This determines the drainage properties of the surface which in turn affects the adhesion component of tire friction when the pavement is wet. The large-scale roughness also affects the damping losses within the tire tread rubber. On the other hand, the small-scale macroscopic roughness refers to the grittiness or abrasiveness of the surface. This aids the friction process by creating a mechanical interlock with the rubber thus shearing the rubber when skidding occurs. Microscopic texture refers to the very small-scale roughness of the pavement surface. It also is thought to have a measurable influence on friction (Ref 7).

Kummer and Meyer (Ref 7) have suggested a surface type classification recognizing the large and small macroscopic roughness scales which affect the drainage and friction properties of a pavement surface. The five categories proposed are as follows:

1. Smooth surfaces such as bleeding asphalt or highly polished pavements: Surfaces in this category would be deficient in both large and small-scale roughness and would therefore not provide adequate skid resistance even at low speeds.

2. Fine textured surfaces composed of rounded particles: Surfaces in this category would be somewhat deficient in large-scale roughness and very deficient in small-scale roughness. These types of surfaces might provide marginal skid resistance at low speeds but not at high speeds.
3. Fine textured surfaces composed of gritty particles: The gritty particles would satisfy the small-scale roughness requirements but the large-scale roughness would be missing. This would result in surfaces which provide excellent skid resistance at low speeds but not at high speeds.
4. Coarse textured surfaces composed of rounded particles: The large rounded particles would satisfy the large-scale roughness requirements but the small-scale roughness would be missing. Therefore, surfaces of this type would not provide adequate skid resistance at high or low speeds.
5. Coarse textured surfaces composed of gritty particles: Surfaces in this category would possess both of the needed small and large-scale roughnesses. In other words, the good skid resistance qualities of category three and the good drainage qualities of category four would be combined and both are important when the pavement is wet. This would best provide the skid resistance needed at both low and high speeds.

Tire and rubber properties are also very important to skid resistance. A study (Ref 11) by Moyer, who has done extensive research on skid resistance for more than three decades, concluded that different tire and rubber properties caused as much variation in skid resistance as did different pavement surfaces.

The total friction developed by the tire rubber is a combination of adhesion and hysteresis forces. Moyer and Sjogren (Ref 10) report that hysteresis is one of two tire factors having the greatest influence on the friction measured at the tire-pavement interface. The hysteresis component of friction is the result of damping losses within the rubber caused by the latter flowing over and around aggregate particles protruding from the pavement surface (Ref 7). The damping property of rubber is often referred to as resilience or plastic deformation. Tire rubber rebounds slowly from plastic deformation resulting in large energy losses as heat is generated in the rubber through internal friction or hysteresis (Ref 10). Tire rubber is also deformed elastically but the rebound is nearly instantaneous and very little energy is lost.

The magnitude of the hysteresis component depends on the rubber properties of the tire and the large-scale macroscopic roughness of the pavement. Butyl rubber, for example, has higher damping properties than natural rubber and thus provides higher hysteresis coefficients (Ref 7). Moyer (Ref 11) found that coefficients of friction measured on the same pavement at the same speed were as much as 40 percent higher with butyl rubber tires with good tread than for regular synthetic rubber tires with smooth or poor tread patterns. Reportedly, the British Road Research Laboratory has found a similar correlation between the resilience of rubber and the coefficients of friction on wet pavements (Ref 5).

Too much damping, however, could have some adverse effects. High damping causes heat generation in the rubber and increases the likelihood of tire failures. Also, with the higher tire temperature, the melting point of the tread rubber is more easily reached when the tire skids. The melting rubber serves as a lubricant, thereby reducing the friction. Another undesirable feature of high damping rubber is that the rubber stiffens in extreme cold and tends to become slippery (Ref 7).

Adhesion is the other component of tire friction. It represents the molecular adhesion at the points where the rubber and pavement are in molecular contact. Adhesion is sometimes referred to as true friction and is the dominant friction factor on dry surfaces (Ref 10). Adhesion increases with the area of contact. Therefore, providing the pavement surface is dry and clean, treadless tires and fine textured surfaces would result in high coefficients of friction.

Adhesion, however, is drastically reduced when the pavement is wet, especially with treadless tires and fine textured surfaces. In this case fluid films are trapped between the rubber and pavement, thus reducing the adhesive bond. Under these conditions angular aggregate particles protruding from the pavement surface aid the friction process considerably. The sharp particles pierce the water film and penetrate the rubber causing a shearing action when the tire skids. Small-scale macroscopic roughness provides the type of abrasiveness needed to accomplish this effect.

When the adhesion component is reduced by wetting, the importance of the hysteresis component increases. Therefore, large-scale macroscopic roughness is also needed to aid rubber damping. Coarse texture is also needed to provide surface drainage, thus decreasing the amount of water trapped between the rubber and the pavement. This would tend to minimize the reduction in the adhesion component. The likelihood of hydroplaning (the skiing of the tire on a film of water) at high speeds would also be lessened by large-scale macroscopic roughness which provides drainage and minimizes the water film thickness. The gritty particles provided by small-scale macroscopic roughness also aid in lessening the danger of hydroplaning as the result of their ability to pierce the water film.

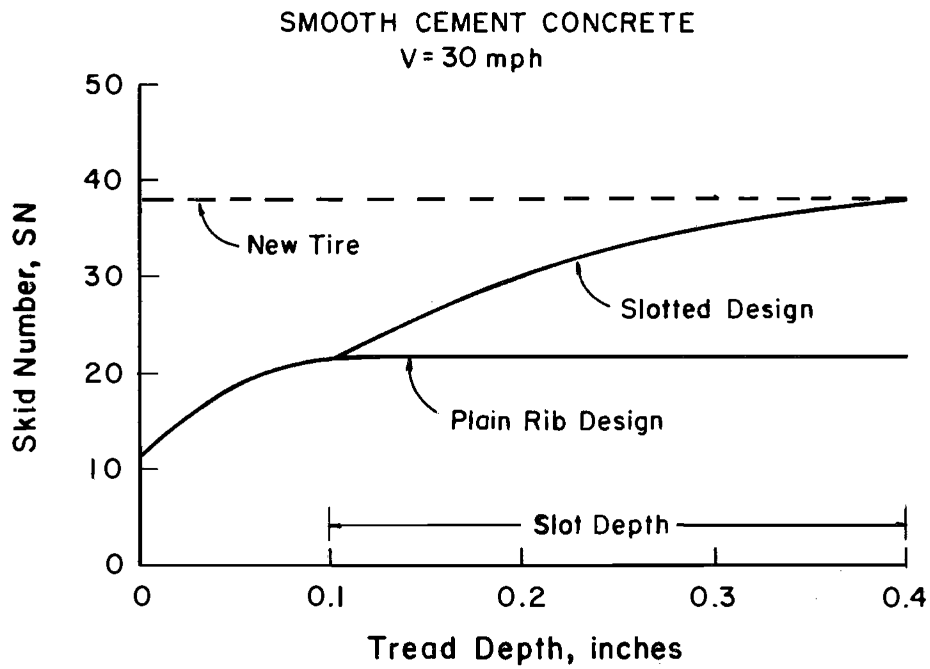
Moyer (Ref 10) reports that wetting can reduce the friction value 40 to 80 percent depending on the pavement texture, the rubber type, and the tread condition. Contamination of the pavement surface with mud, dust, oxidation film, and oil or grease drippings also reduces the adhesion component of friction (Ref 7). Moyer (Ref 10) also reports that contamination can reduce the total friction value from 40 to 60 percent. The pavement is most slippery during the very beginning of a rain, especially if there has been a long dry spell. Although wetting reduces the coefficient of friction, the skid resistance does tend to improve as the rain intensity and/or duration increases. Moyer (Ref 5) concluded there may be a need for a new type of cleansing and scouring treatment of slippery pavements.

In addition to hysteresis, Moyer and Sjogren (Ref 10) report that tread pattern or lack of tread pattern has a considerable influence on the friction measured at the tire-pavement interface. Kelley and Allbert (Ref 12) state that tread design is the most important of the tire variables affecting wet traction. This is apparent when one considers that the tire has to make contact through the wet film on the road before it can become effective. The tread design enables the tire to do this. Once the tire makes contact, the composition of the tread rubber and tire construction become important.

Tire tread should provide drainage paths so that a water film is not trapped between the rubber and the pavement. In this respect tread functions similarly to large-scale macroscopic roughness of the pavement. Kelley and Allbert (Ref 12) also report that tread design is the most influential tire variable in hydroplaning. They go on to state that new tires hydroplane very infrequently because its occurrence is limited to extreme cases of water flooded road surfaces although some danger does exist at high speeds. A much greater danger exists, however, for vehicles fitted with smooth or well-worn tires, since the speed and water depth requirements for hydroplaning are much lower for tires in this condition.

It is fairly evident that the importance of tread depends on the pavement surface texture and whether water is present. Figure 1 shows how tread depth and design can affect skid resistance. It can be noted that for these data a 50 percent reduction in the skid number (friction coefficient on wet pavement times 100) resulted from a tread depth decrease from about 1/16 of an inch to zero inches (Ref 7).

Kummer and Meyer (Ref 7) indicate that tread might be a secondary factor in skid resistance on pavements with coarse and gritty surface textures. In other words, the coarse surface texture provides the drainage channels for water to escape from beneath the tire. The gritty texture would provide the mechanical interlock to aid friction. They also state that tread gains in importance on smooth textured surfaces or on coarse textured surfaces with rounded particles. They point out, however, that a well treaded tire with high damping rubber should not be expected to fully compensate for a polished or smooth pavement surface with low skid resistance. Nevertheless, good tread can bring about significant improvement in skid resistance at higher speeds.



SKID-RESISTANCE REDUCTION DUE TO TREAD WEAR
(from Ref. 7)

Figure 1

Methods of Measurement

Two principles can be used to measure the friction between two surfaces regardless of material types. One is based on the principle of energy conservation. The second and more frequently used method for measuring the tire-pavement friction involves simultaneously measuring the friction force and the load acting on a rubber slider or a tire (Ref 7).

In measuring skid resistance, the magnitude of the measurement depends on the operating mode of the tester: driving, cornering, rolling and slipping during braking, or skidding. For this reason skid resistance measuring devices are classified according to their mode of operation. These measuring devices can be broken down into skid (resistance) and slip (resistance) testers and the latter into brake, drive, and cornering slip testers. A drive slip tester has not yet been built, but devices representing the other modes are in existence (Ref 7).

Further differentiation must be made between carrying out a test under either steady-state or transient conditions. Steady-state implies that all factors influencing friction are constant such as the load acting on the tire, the sliding speed, and the temperatures of each material in sliding contact. In a transient test one or more factors may vary with time. Table 2 shows the classification of the various pavement friction testers used in the United States (Ref 7).

TABLE 2. CLASSIFICATION OF PAVEMENT FRICTION TESTERS USED IN THE UNITED STATES (from Ref 7)

	Classification[a]			
	Slipping Mode		Skidding Mode	
Tester	Steady State	Transient	Steady State	Transient
British pendulum tester				L,V,T
Penn State (Keystone) drag tester			L,V,T	
N.Y. Thruway skid test cart			L,V,T	
Skid trailers (all)			L,V,T[b]	T
Stopping distance cars (all)			W	L,V,T
FAA runway friction tester	L,V	S_b,T		
NASA friction cart	L,V,T,S_b			
Swedish "skiddometer"	L,V,T,S_b			
Penn State road friction tester[c]	L,V	S_b,T	L,V,T	

[a] L = slider or wheel load, W = vehicle weight, V = sliding or vehicle speed, T = rubber temperature, S_b = brake slip.

[b] Depends on duration of skid, T transient if skid below 2 sec.

[c] Modification of the single-wheel skid trailer permits measurement of transient slip or steady-state skid resistance.

The British Pendulum Tester, the Penn State Drag Tester and the New York Thruway skid test cart, all available in the United States, are considered to be portable devices. The Leroux Rugosimeter is another portable tester available in France (Ref 7).

There are several versions of trailer-type friction testers. Except for the National Aeronautics and Space Administration tire friction cart and the Federal Aviation Agency runway friction tester, all pavement friction trailers presently used in the United States measure skid resistance. In addition, the design of testers utilizing the same operating mode can vary widely and the differences can influence the magnitude of the measured friction (Ref 7).

Most friction testing methods provide for artificially wetting the pavement surface. There are several reasons for this. Accident records show that skidding is a factor in a large percent of accidents occurring on wet pavements. Also, test results indicate that skid resistance is lower on wet pavements than on dry pavements; therefore, artifically wetting the pavement is necessary in order to measure the lower friction values.

Most trailer-type testers employ locked wheel skidding. One of the main reasons for measuring friction with a locked wheel skidding device rather than incipient skidding is that this approximates the situation when a driver panics and skids with locked brakes while attempting to stop (Ref 10). With locked wheel skid trailer testing, an added benefit of wetting the pavement is that less equipment maintenance is required (Ref 5).

At one time some trailer designs measured the friction value by forces transmitted through the hitch but they have proved unsatisfactory and are no longer in use. There are three basic trailer types presently in use. The methods of measuring the force are as follows: (a) bending moment is measured at a point between the hitch and the front of the trailer, (b) wheel torque trailers measure the force in a restraining link that serves as an anchor for the brake backing plate, which is otherwise free to rotate, (c) parallelogram-type trailers measure the force in a link connecting the hitch of the towing vehicle to the backing plate which again is otherwise free to rotate. The trailers of General Motors, the Michigan State Highway Department, and the Virginia Highway Research council as originally developed in 1957 were of type (a). In 1962 they were converted to measure wheel torque as in type (b). Test trailers of type (b) were developed by Cornell Aeronautical Laboratories and are being used by the Bureau of Public Roads, the New York State Department of Public Works and the Portland Cement Association. Test trailers of type (c) were built by Pennsylvania State University and are being used jointly with the Pennsylvania Department of Highways (Ref 7). It is expected that trailer-type testers, rather than portable testers, will be used even more extensively in coming years (Ref 8).

Several methods for measuring the texture of the pavement surface have been explored. They vary from visual and touch examination by experienced personnel to photographic techniques and methods of measuring the voids or openness in the surface (Ref 10). Full-scale photographs have been used by Moyer (Ref 11). The British Road Research Laboratory has worked with such methods as: surface texture imprints, micro-profile, and the sand patch (Ref 10). Moore (Ref 13) developed an outflow meter which measures the drainage properties of the surface texture. Other texture measuring methods include a stereophotogrammetric process and a grease smear technique.

CHANGING CHARACTER OF TRAFFIC

The average travel speed of passenger cars on primary rural highways has increased from 48.5 mph in 1950 (Ref 8) to 56.9 mph in 1964 (Ref 2), which represents an increase of over 17 percent. Frictional demand increases with the square of the vehicle speed (Ref 7) providing the required stopping distance remains constant. Or another way of stating it, is that the required stopping distance increases with the square of the vehicle speed if the available friction remains constant. Required cornering friction also varies with the square of the vehicle speed. Therefore, for a 17 percent increase in vehicle speed the frictional demand has increased nearly 38 percent. The cumulative increase in speed and frictional demand in recent years is shown in Table 3.

TABLE 3. AVERAGE PASSENGER SPEEDS ON PRIMARY RURAL HIGHWAYS (from Refs 2 and 8)

Year	Average speed (mph)	Cumulative Increase in Speed (%)	Required Increase in coef (%)
1950	48.5	0	0
1951	50	3.1	6.4
1952	51	5.2	10.5
1953	51.5	6.2	12.6
1954	51.5	6.2	12.6
1955	52	7.2	15.1
1956	52	7.2	15.1
1957	52.2	7.6	16.0
1958	52.8	8.9	18.5
1959	53.2	9.9	20.0
1960	53.8	10.9	23.0
1964	56.9	17.3	37.7

Traffic density is another factor which is also working in opposition to skid resistance. Vehicle-miles of travel are increasing at a much more rapid rate than highway mileage. This results in an increase in the number of miles traveled on one mile of highway per year. During the period of 1950 to 1966 the net increase for vehicle-miles traveled per mile of road was nearly 83 percent. Trends in highway mileage and vehicle miles of travel are shown in Table 4. More vehicle travel per mile of road represents a like increase in the rate at which traffic polishes the pavement surface causing a decrease in the available friction. The decrease in friction is not linear with the frequency of passes. Nevertheless, it is cause for concern since aggregate polish is one of the main causes of pavement slipperiness (Ref 8).

Higher operating speed has another damaging effect on skid resistance. Not only does the frictional demand increase with the square of the vehicle speed, but the available or effective skid resistance between the tire and the pavement decreases with speed when the pavement is wet (Ref 7). Several factors which influence the skid resistance at any given speed include the geometric texture (openness, grittiness, or angularity) of the pavement, the tread of a particular tire, and the slope of the friction coefficient versus speed curve under wet conditions. Kummer and Meyer (Ref 8) report that tests with various combinations of tires and pavements indicate that a coefficient drop of 0.5 to 3 percent per mph (based on a sliding

TABLE 4. TOTAL VEHICLE MILES AND MILES TRAVELED PER MILE OF ROAD (from Refs 2 and 8)

Year	Total Miles of Roads (10^6)	Total Vehicle Miles Traveled Annually (10^6)	Annual Miles Traveled per Mile of Road (10^3)	Cumulative Increase Since 1950(%)		
				Miles of Roads	Vehicle Miles Traveled	Vehicle Miles Traveled per Mile of Road
1950	3.322	458,250	138	0	0	0
1951	3.327	491,090	148	0.135	7.17	7.25
1952	3.343	513,580	153	0.633	12.06	10.86
1953	3.366	544,430	162	1.32	18.80	17.40
1954	3.395	560,860	165	2.20	22.4	19.55
1955	3.418	603,430	176	2.99	31.7	27.50
1956	3.430	627,840	183	3.25	37.0	32.60
1957	3.453	642,580	186	3.94	40.2	34.80
1960	3.510	720,000	205	5.66	57.1	48.50
1966	3.698	930,500	252	11.32	103.1	82.61

coefficient at 35 mph) can be expected. Other tests (Ref 7) have shown that the dry friction level is nearly independent of vehicle speed.

The skidding problem will probably become more serious in coming years. The upward trend in vehicle speeds and traffic densities will undoubtedly continue (Ref 7). To add to the problem, paving materials which initially provide high skid resistance, and also resist polishing, are becoming increasingly more scarce in many areas of the country.

HIGHWAY SAFETY ASPECTS

It has been pointed out that many characteristics of traffic are working in opposition to skid resistance. Given that existing pavements are being polished or slickened at a faster rate than they can be de-slicked and that vehicle speeds and frictional demands will continue to increase, it seems logical that skidding accidents will become a more serious problem than at present.

The relationship of pavement slipperiness and skidding accidents is a matter for concern. Considerable attention is currently being given to establishing a minimum coefficient or skid number on main rural highways. A skid number of 37 (coefficient of friction times 100) as measured with a skid trailer in accordance with ASTM Method E-274 at 40 mph is currently recommended by Kummer and Meyer (Ref 7). Opinions differ somewhat as to a reasonable and economical minimum value.

Table 5 shows minimum values currently used by several states. Some authorities believe a skid number of 37 is too high for a reasonable minimum at this time because too much of the existing street and highway systems would be deficient. They seem to believe a lower value would be more attainable in the beginning, while at the same time devoting more attention to improving the skid resistance properties of tires.

Several studies have related accident rates to such factors as roadway geometrics, traffic volumes, and vehicle speeds (Refs 14, 15, and 16). In a study completed in 1966 (Ref 17), the Texas Highway Department investigated the relationship of skid resistance with accident rates in an effort to establish a guide for a minimum skid resistance value. In their pilot study, they investigated accidents of three types in urban areas; skidding accidents, rain accidents, and total accidents. The data from the pilot study indicated that the accident frequency distributions with respect to skid resistance were similar for each of the three accident types. For the main portion of the study, they investigated both total accident and fatal plus injury accident rates for rural areas.

The Texas study (Ref 17) recommended that composite minimum coefficients of 0.4 and 0.3 at testing speeds of 20 and 50 mph, respectively, be used as guidelines for considering pavement surface improvements. In addition, skid resistance values of 0.31 and 0.24 at 20 and 50 mph, respectively, were recommended as absolute minimum values. When the roadway skid

TABLE 5. COMPARISON OF MINIMUM FRICTIONAL REQUIREMENTS FOR MAIN RURAL HIGHWAYS WITH THE GUIDELINES CURRENTLY USED BY STATE HIGHWAY DEPARTMENTS (from Ref 7)

	Skid Trailers		Stopping Distance Car		British Pendulum Tester
Agency	SN	V (MPH)	SDN	V_v (MPH)	BPN
Arkansas					45
Connecticut			43	30 or 40	
Florida			40	40	
Georgia					50
Kentucky			45	30	
Louisiana					55
Maryland			47	40	
Michigan	40	40			
Mississippi	40	40	40	a	
New York	32	30			
N.Carolina			45	a	
Pennsylvania	40	35			
Tennessee	40	40			
Texas	35	40			
Virginia	35	40	40	40	
Recommendation	37	40	46	40	60

[a]Not stated, presumably 40 mph.

resistance decreases below the absolute minimum values, immediate surface improvement should be undertaken.

Establishing minimum friction levels to be maintained would no doubt be a significant contribution to reducing skidding accidents. At the same time there is considerable need for improving tire designs which would increase the friction between the tire and the pavement. The vehicle condition and the condition of the tires are also very important and improvement in this regard could be made in many vehicle inspection programs (Ref 7). New York State (Ref 18), for example, has a minimum tread depth requirement of 2/32 of an inch. Tread depth and overall physical condition of tires are included in New York State motor vehicle inspection procedures. Excessive play in the steering gear, in the suspension system, and in the wheel bearings, in addition to shock absorbers, wheel balance, and the condition of the braking system are also important factors which should be included in inspection programs (Ref 7).

The role of the driver cannot be overlooked because any theory as to the cause of accidents must be phrased in terms of the driver. Motor vehicles are the responsibility of their drivers; his abilities, habits, expectations, and reactions in different driving situations are very important. In other words, a lot depends on the perception, judgment and actions of the driver. It is obvious that better informed motorists would be an improvement to the overall highway safety effort. Therefore, it would appear that a worthwhile contribution to the skidding accident problem could be accomplished by making the motorist more aware of how tire tread, vehicle speed, and the presence of water affect skid resistance (Ref 7).

SUMMARY

Many factors influence skid resistance. The actions of the driver, especially during periods of inclement weather, further complicate the problem. More attention is being devoted to the problem of skidding accidents. In order to thoroughly investigate skidding accidents more factors than just the skid resistance of the pavement should be considered. The objective of this study is an attempt in that direction. A few of the factors pertaining to the pavement, the vehicle, the tires and the driver are being analyzed for accidents occurring under wet conditions.

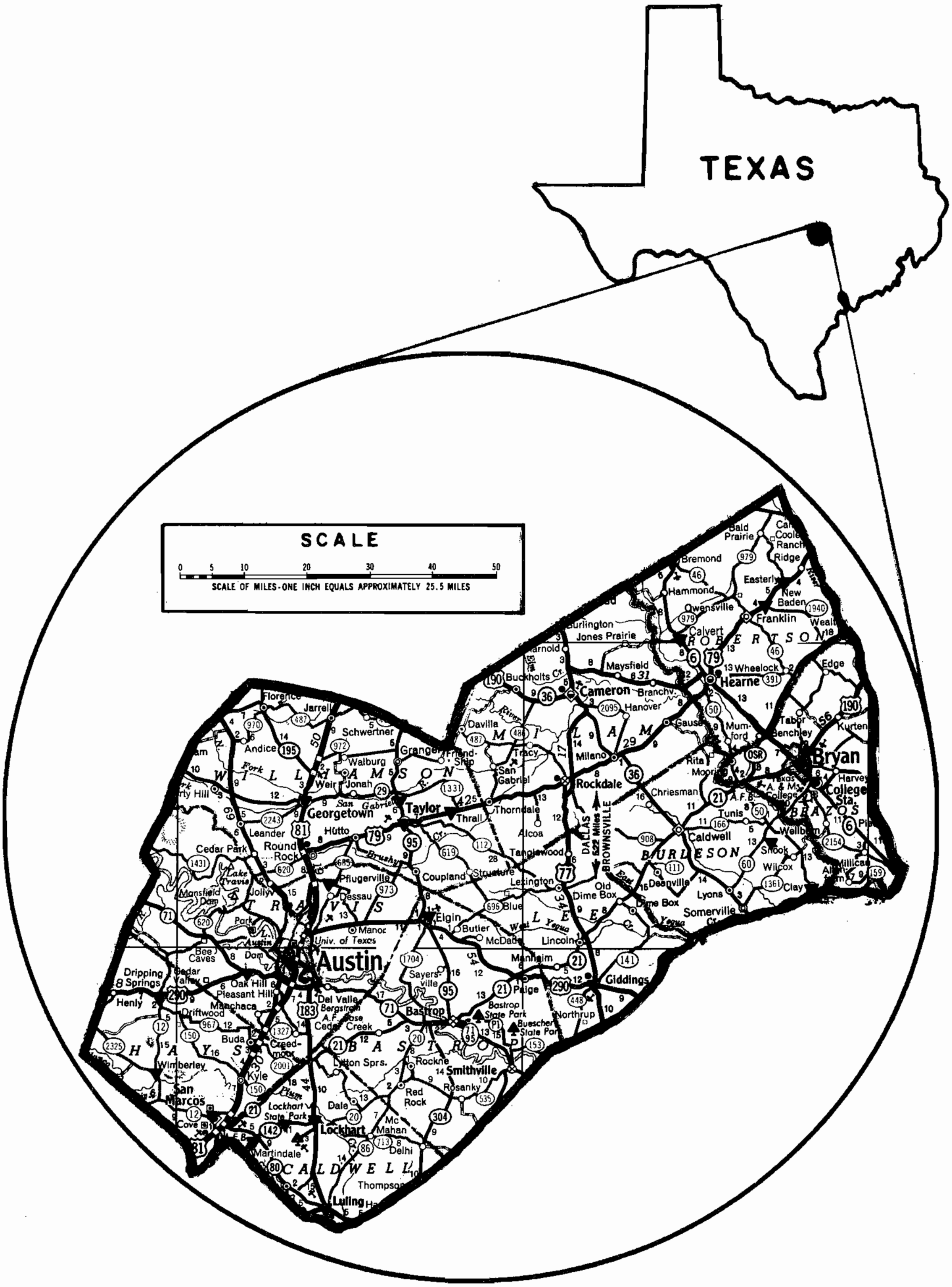
CHAPTER 3. STUDY DESCRIPTION AND METHOD OF ANALYSIS

STUDY DESCRIPTION

The purpose of this research was to investigate and analyze detailed roadway and accident data for traffic accidents occurring during wet weather. Data from 181 wet weather accidents, covering the period from May 1 through September 30, 1968 were included in the analysis.

The data analyzed were supplied by the Texas Highway Department from a pilot study concerned with an evaluation of the influence that various vehicle and pavement factors have on traffic accidents occurring under wet pavement conditions. This pilot study is expected to continue until data on approximately 500 wet weather accidents have been obtained.

The study area consisted of 10 counties, covering portions of two highway districts, located in central Texas and generally encompassing the area between and around the cities of Austin and Bryan-College Station as shown in Figure 2. Urban areas with a population in excess of 5,000 were not included. This was done to simplify data collection inasmuch as accident investigation and reporting for cities over 5,000 population are the responsibility of the respective municipalities rather than of the Department of Public Safety. Thus the study area was primarily rural in character. The study area contained 2,460.5 miles of the state highway system, on



LOCATION OF STUDY AREA

Figure 2

which 3,086,099 daily vehicle miles of travel took place (Ref 19).

The Texas Department of Public Safety assisted in the data collection by obtaining special information pertaining to the condition of the accident vehicles. In addition to their usual accident investigation and documentation, the Department of Public Safety obtained the following information for wet weather accidents occurring within the study area:

1. Tire pressure
2. Tire tread depth
3. Tire trade name, manufacturer, and size
4. Description of tire wear
5. Description of tire tread pattern
6. Weather information at the time of the accident
7. Pavement conditions at the time of the accident (such as ice, puddles, mud, roughness, etc.)
8. Vehicle power brakes and steering

As soon as possible after each accident, highway department personnel investigated pavement and roadway conditions at each of the accident sites, which were conspicuously marked by the investigating officer. Their initial investigation consisted mainly of making skid resistance measurements using a skid test trailer. The usual procedure consisted of making a skid test at the marked location of the accident and three tests for approximately one-half mile in each direction from the accident site. Tests were normally made in both directions of travel on non-divided highways. On divided highways, tests were usually made on all lanes in one direction of travel. Both directions of travel, however, were tested if both roadways were involved in the accident.

The skid resistance measurements were made at 50 mph unless restricted by the geometrics of the highway. Occasionally the accident location was such that skid testing was not feasible, such as at a tee intersection. Initially, measurements were also made at 20 mph but this had to be abandoned due to the heavy work load.

METHOD OF ANALYSIS

The data were analyzed in terms of four main categories: (a) accident rates, (b) skid resistance values, (c) tire tread depth, and (d) the relationship of accident rates to skid resistance and tread depth.

Accident Rates

Accidents are normally expressed in terms of a rate based on some unit of population or vehicle-miles of travel. Accidents per 100 million vehicle miles (100 MVM) are commonly used and will be used in this report.

The study was designed specifically to investigate only wet weather accidents. Therefore, it was decided to determine accident rates on the basis of wet conditions. In order to do this, it was necessary to make a reasonable estimate of the percent of time that the pavement was wet.

To obtain an estimate of the percentage of time that the pavement surface could be expected to be wet, US Weather Bureau records listing hourly amounts of precipitation (Ref 20) were reviewed. Unfortunately, Austin was the only weather station in the study area for which hourly records of precipitation were available. It was recognized that precipitation data for Austin could vary considerably from other parts of the study area on any given day. However, the entire study area receives similar annual rainfall amounts, so over a long period of time Austin was thought to be representative of the area.

A procedure used by the Texas Highway Department for an unpublished study (Ref 21) was used to determine the expected total hours of wet pavement. The following describes the criteria used for determining the hours of wet pavement: (The hourly listing of rainfall includes traces and all measurable amounts of 0.01 inches and greater).

1. On a given day, if a string of consecutive hours of trace rainfall occurs with no measurable rainfall (0.01 or greater) within the string, the first and last hours were not counted.
2. If within a string of consecutive hours of rainfall traces there occurs an hour of measurable rainfall (0.01 or greater), then the last hour of trace rainfall was counted. The first hour again was not counted.

3. If the first hour of a string of traces was a measurable rain (0.01 or greater), the first hour and every other hour of rain in that string, traces included, were counted.

4. If the last hour of a string of measurements was a rainfall of 0.01 inch or greater, that hour was counted plus one additional hour to allow for drying time.

The following example illustrates these criteria:

Day	Hours 1	2	3	4	5	6	Wet Pavement Hours
1	T	T	T	T	T		3
2	T	0.01	T	T	T	T	5
3	T	0.01	T	T	0.01	T	5
4	0.01	T	T	T			4
5	T	T	T	0.01			4
6	0.01	T		T	0.01	T	4
7	T	T		T	T	T	1
8	T	0.01		T	T	0.01	5
9	0.01	T	T	T	T	0.01	7

Using the criteria just described, a review of precipitation records for May through September of 1968 revealed the pavement was wet for a total of 246 hours. Therefore, the pavement was wet approximately 6.70 percent of the time (246 hours divided by 153 days x 24 hours per day). This percentage will be referred to as the wet pavement factor.

Accident rates were expressed in terms of accidents per 100 million vehicle-miles of travel for a given section of highway during a given time period and were calculated as follows:

$$\text{Accident Rate} = \frac{\text{Number of Accidents} \times 10^8}{(\text{DVM})\ (153\ \text{days})\ (0.0670)}$$

where DVM is the daily vehicle-miles of travel.

For certain analyses, wet weather accidents were divided into four classes. Three of the classes, A, B, and C, were considered to be skidding accidents. Class A skidding accidents included those vehicles going out of control with no apparent braking involved. Class A skidding accidents usually involved only one vehicle. Class B included those accidents in which braking apparently took place before the vehicle went out of control. Class C included those accidents in which braking was involved before colliding with another vehicle. Class C skidding accidents generally involved either rear end or intersection collisions. Class O accidents were those in which skidding was not involved.

Wet weather accident rates were determined for the following four accident categories:

1. All wet weather accidents (all four accident classes combined)
2. Wet weather skidding accidents - Class A
3. Wet weather skidding accidents - Classes A and B combined.

4. Wet weather skidding accidents - Classes A, B, and C combined.

Accident rates were determined by highway control-sections established by the Texas Highway Department for identification purposes to aid in various accounting and record keeping procedures. There were 317 control-sections in the study area. Wet weather accidents were recorded on 80 of these sections. The identification, length and daily vehicle-miles of travel for each control-section in the study area were obtained from the 1967 listing of traffic accidents in Texas (Ref 19). The four categories of accident rates for each control-section are shown in Appendix A. Several control-sections were grouped together for various analyses. This was done primarily because the variations in the length of and daily vehicle-miles of travel for the control-sections were considerable which added to the variation in accident rates.

A record of all traffic accidents for May through September of 1968, which included the wet weather accidents, was obtained from the Texas Highway Department. This permitted direct comparisons to be made between wet weather, dry weather, and overall accident rates for the same area and time interval. Comparisons were made by county and highway districts since these organizational subdivisions are of significance to the Texas Highway Department. Also, it was thought the accident rates would be more reliable if large DVM quantities were considered. Similar comparisons were made between certain routes, but in this case segments which were thought to have similar characteristics other than pavement surface type were selected.

Skid Resistance Values

At most of the accident sites, skid resistance measurements were made over a one-mile length of highway. Usually seven measurements were made on each lane for the one-mile length. The middle measurement of the seven measurements was obtained as near as possible to the actual accident site. Only those measurements made at 50 mph were used for analysis. In addition, for each accident, average friction values representing the actual accident site and the overall one-mile vicinity were used for analysis. Later in the report these values will be referred to as the accident site average and the one-mile vicinity average. Both average friction values are shown for each accident listed in Appendix A.

The accident site average friction values were statistically compared with the one-mile vicinity average friction values to determine whether the friction values at the site were significantly different from the values within the adjacent one-half mile sections.

The Texas skid trailer measures the skid resistance parallel to the direction of travel. In order that a comparison could be made with the side friction or cornering friction, a correlation was made between trailer friction and cornering friction values. This was done by calculating the cornering friction developed from spin out tests conducted by The Texas Transportation Institute (Ref 22) and correlating with skid trailer friction values made by The Texas Highway Department on the same test sections. Using the spinout speeds and geometric data from the Texas Transportation Institute study, values for cornering friction were obtained from the relationship:

$$f = \frac{V^2}{14.95R} - e$$

where

V = speed of vehicle in mph

R = radius of horizontal curvature in feet

e = superelevation (e = 0 for spin out test sections).

Using the trailer friction and cornering friction correlation, the available cornering friction on certain horizontal curves was calculated from skid trailer values. The available cornering friction was then compared with the cornering friction developed by vehicles involved in skidding accidents on certain curves. The estimated speed listed on the accident report was used as the vehicle speed although it was realized that the speeds were estimated and could be considerably in error. The degree of curvature was determined from design plans and the superelevation was measured on the roadway. Also, the cornering frictions developed by a sample of non-accident vehicles for dry and wet conditions were determined after making spot speed studies.

Tire Factors

Tread depth was the main tire factor considered in this report. The distribution of tread depth was determined for all tires on automobiles and pickup trucks involved in wet weather accident categories 1, 2, and 4 (page 34). The tire tread depths are included in the wet weather accident data listed in Appendix A.

Tread depth distributions were also determined for a sample of non-accident vehicles from the study area. The tread depth distributions by individual wheels for accident and non-accident vehicles were compared with data from a tire study made in Illinois by Northwestern University (Ref 23). A similar comparison was made for all automobile and pickup truck tires without regard for the position of the tire on the vehicle. For this case, data from a tire study representing the Western United States made by Southwest Research Incorporated were included in the comparison (Ref 24).

The distribution of tire pressure for vehicles involved in class A skidding accidents was the only other analysis done with tires.

Relationship of Skid Resistance and Tread Depth to Skidding Accident Rates

Two approaches were used to investigate these relationships. One involved comparing skidding accident rates with the coefficient of friction at the accident site and also with the tread depth for the skidding accident vehicle. This was done

using several characteristic tread depths for the accident vehicles: the worst tire, the average of the rear tires, and the average of all four tires. Only those accidents involving automobiles and pickup trucks were considered. Several variations in lengths of highway were also considered: by individual highway control-sections (control-sections as designated by the Texas Highway Department), by route number, and by county.
A previous study in Texas investigated the relationship between overall accident rates and coefficient of friction values (Ref 17).

The other approach involved using a statistical control technique, analogous to those employed in industrial quality control. This technique was investigated by Norden, Orlansky, and Jacobs (Ref 25) and later by Rudy (Ref 26). The method, however, as used for this analysis included a slight modification as suggested by Morin (Ref 27).

The technique involves establishing statistical control limits above and below an average accident rate for a given length of highway based on a Poisson probability distribution. This establishes a band or range within which an observed accident rate could be expected to vary from the average value due to chance alone (Ref 27). The control limits for a given section length can be determined from the following equations:

$$\text{Upper control limit} = \lambda + t\sqrt{\frac{\lambda}{m}} + \frac{1}{2m}$$

$$\text{Lower control limit} = \lambda - t\sqrt{\frac{\lambda}{m}} - \frac{1}{2m}$$

where

λ = average accident rate for the highway

m = vehicle-miles of travel on a given section

t = constant depending on the probability level selected.

The probability level selected depends on the percent of false detection which can be tolerated. It is analogous to the level of significance commonly used in statistical tests. A probability level of one percent (t = 2.576) was chosen for this analysis. This means there is a one percent probability that the observed accident rate could fall beyond the control limits (one-half of one percent above the upper limit or one-half of one percent below the lower limit) due to chance even though nothing was out of the ordinary (Ref 27).

For the statistical control limit analysis, all US and state numbered highways were grouped together. The combined length of these 96 control-sections was 843.9 miles on which 1,852,094 daily vehicle miles of travel occurred. Wet weather accidents were recorded on 54 control-sections. Routes with Interstate and Farm-to-Market designations were not included because they were thought to be generally in different design and traffic categories. Wet weather accident rates were determined for the four previously mentioned accident categories (page 34) for the entire 844 miles. These rates were used as the average (λ) for their respective categories in determining the upper and lower statistical control limits. These data are listed in Appendix B.

The original objective of the control limit analysis was to compare accident data for those highway control-sections having observed accident rates falling above the statistically established upper control limits (out of control on the high side) with those control-sections having observed rates falling below the lower control limits (out of control on the low side). Most of the sections out of control on the low side had zero accident rates, thus no data were available for comparison. Therefore, accident data representing those sections out of control on the high side were compared with the overall accident data for the same accident category. Comparisons were made between the respective distributions of tire tread depths and friction values for the class A skidding accident category. Class A skidding accidents were used for this comparison because skidding was thought to be more definitely a factor in these accidents (no apparent braking involved and usually single vehicle accidents).

A further comparison was made utilizing the control limit technique. The US and state numbered highways were divided into three pavement surface types: asphaltic concrete containing lignite slag; other types of asphaltic concrete; and bituminous surface treatments. Statistical control limits were then determined for each of the four accident categories according to surface type. Here again, comparisons of the respective tread depth and friction distributions were made.

Miscellaneous

Wet weather accident frequency distributions were determined by month, time of day, and vehicle speed. The percentage of power steering, power brakes, vehicle age and driver sex were determined for all wet weather accidents.

CHAPTER 4. PRESENTATION AND DISCUSSION OF RESULTS

The main portion of the analysis consisted of (a) determining accident rates and making certain comparisons, (b) comparing various distributions of skid resistance values, (c) comparing various distributions of tire tread depths, and (d) examining the relationship of accident rates to skid resistance and tread depth.

ACCIDENT RATES

Accident rates were determined on the basis of wet weather, dry weather, and the combination of both conditions. To determine the wet weather rates, the wet pavement factor of 6.70 percent was applied to the wet weather accident data for the period of May 1 through September 30, 1968. The number of dry weather accidents were determined by subtracting the number of wet weather accidents from the total number of accidents for the same time interval.

Throughout this report accident rates are listed with reference to counties, highway districts, and route numbers. Counties are referenced with numbers 1 through 10, highway districts as A and B, and routes as A, B, C, etc.

Fatalities, fatal accidents, fatal plus injury accidents, and total accidents, for wet and dry conditions are listed in Table 6. Both the number of accidents and the acci-

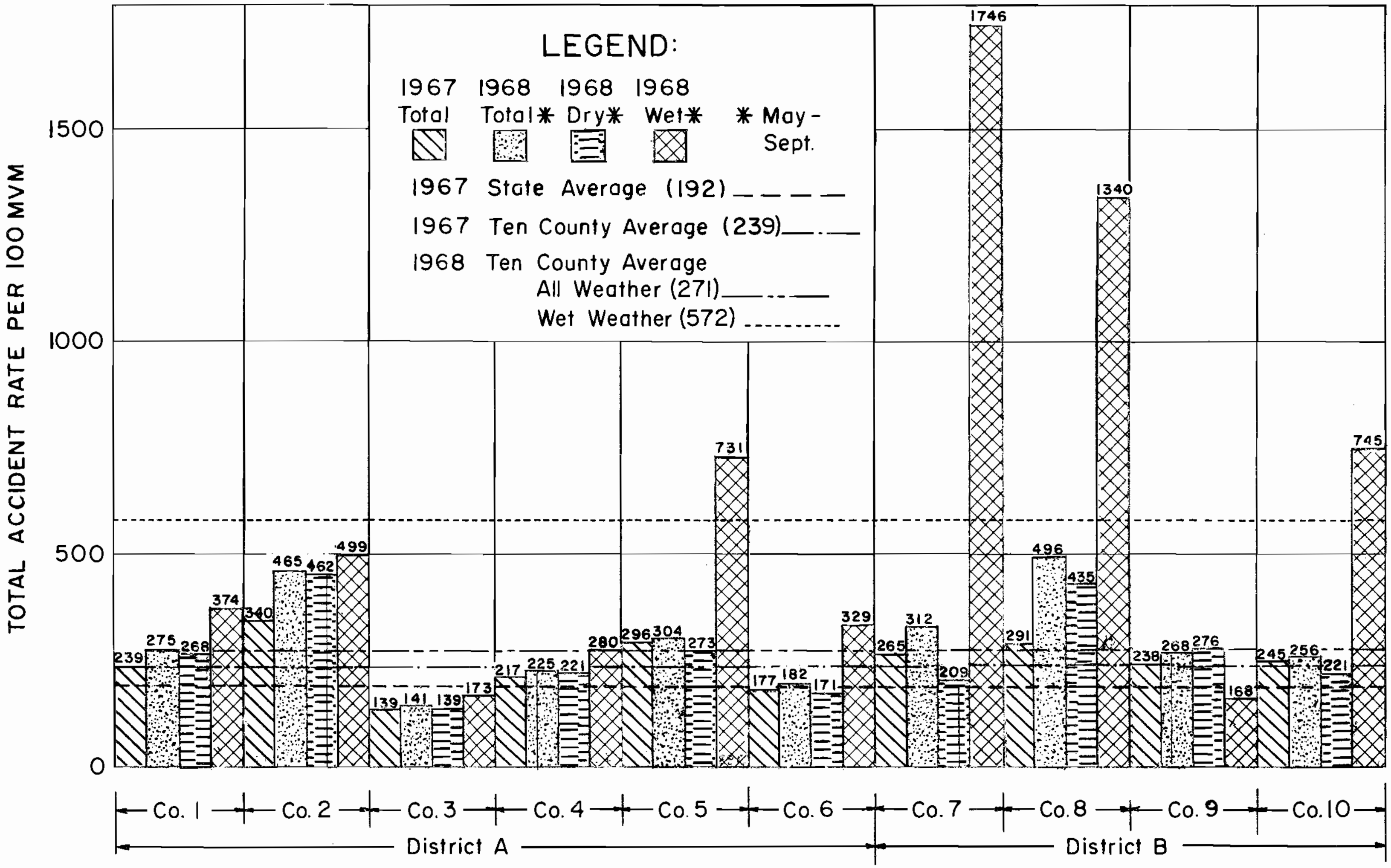
TABLE 6. COMPARISON OF WET AND DRY WEATHER FATALITY AND ACCIDENT NUMBERS AND RATES (May-Sept. 1968)
(Rates per 100 MVM)
LEGEND: 1. Fatality 2. Fatal accident 3. Fatal plus injury accident 4. Total accident

			Wet Weather				Dry Weather				Combined Total			
	DVM		1	2	3	4	1	2	3	4	1	2	3	4
Co.No. 1	287,021	No.	6	2	4	11	2	2	25	110	8	4	29	121
		Rate	203.9	68.0	136.0	373.9	4.9	4.9	61.0	268.5	18.2	9.1	66.0	275.5
Co.No. 2	195,569	No.	0	0	1	10	3	3	30	129	3	3	31	139
		Rate	0	0	49.9	498.9	10.7	10.7	107.5	462.1	10.0	10.0	103.6	464.5
Co.No. 3	337,122	No.	0	0	3	6	4	4	28	67	4	4	31	73
		Rate	0	0	86.8	173.6	8.3	8.3	58.2	139.2	7.8	7.8	60.1	141.5
Co.No. 4	139,122	No.	0	0	2	4	2	1	12	44	2	1	14	48
		Rate	0	0	140.2	280.5	10.1	5.0	60.4	221.5	9.4	4.7	65.8	225.5
Co.No. 5	667,267	No.	5	2	11	50	4	4	100	260	9	6	111	310
		Rate	73.1	29.2	160.8	731.1	4.2	4.2	105.0	273.0	8.8	5.9	108.7	303.6
Co.No. 6	592,097	No.	0	0	5	20	4	4	57	145	4	4	62	165
		Rate	0	0	82.4	329.5	4.7	4.7	67.4	171.5	4.4	4.4	68.4	182.1
Dist. A	2,218,295	No.	11	4	26	101	19	18	252	755	30	22	278	856
		Rate	48.4	17.6	114.4	444.2	6.0	5.7	79.6	238.4	8.8	6.5	81.9	252.2
Co.No. 7	201,199	No.	1	1	6	36	1	1	18	60	2	2	24	96
		Rate	48.5	48.5	290.9	1745.6	3.5	3.5	62.7	208.9	6.5	6.5	78.0	311.8
Co.No. 8	167,462	No.	0	0	8	23	2	2	22	104	2	2	30	127
		Rate	0	0	466.0	1340.0	8.4	8.4	92.0	435.1	7.8	7.8	117.1	495.7
Co.No. 9	289,720	No.	0	0	1	5	13	6	43	114	13	6	44	119
		Rate	0	0	33.7	168.4	31.4	14.5	104.0	275.6	29.3	13.5	99.3	268.4
Co.No. 10	209,423	No.	0	0	2	16	1	1	19	66	1	1	21	82
		Rate	0	0	93.1	745.4	3.3	3.3	63.6	220.8	3.1	3.1	65.5	255.9
Dist. B	867,804	No.	1	1	17	80	17	10	102	344	18	11	119	424
		Rate	11.2	11.2	191.1	899.4	12.9	7.3	82.3	277.7	12.8	7.5	89.6	319.3
Total	3,086,099	No.	12	5	43	181	36	28	354	1099	48	33	397	1280
		Rate	37.9	15.8	135.9	572.2	8.2	6.4	80.3	249.5	10.2	7.0	84.1	271.1

dent rates are shown by county and state highway district. The total accident rates for both wet and dry conditions for the 5-month study period are illustrated in Figure 3. The total accident rates for the study area for the entire year of 1967 are also shown for comparison.

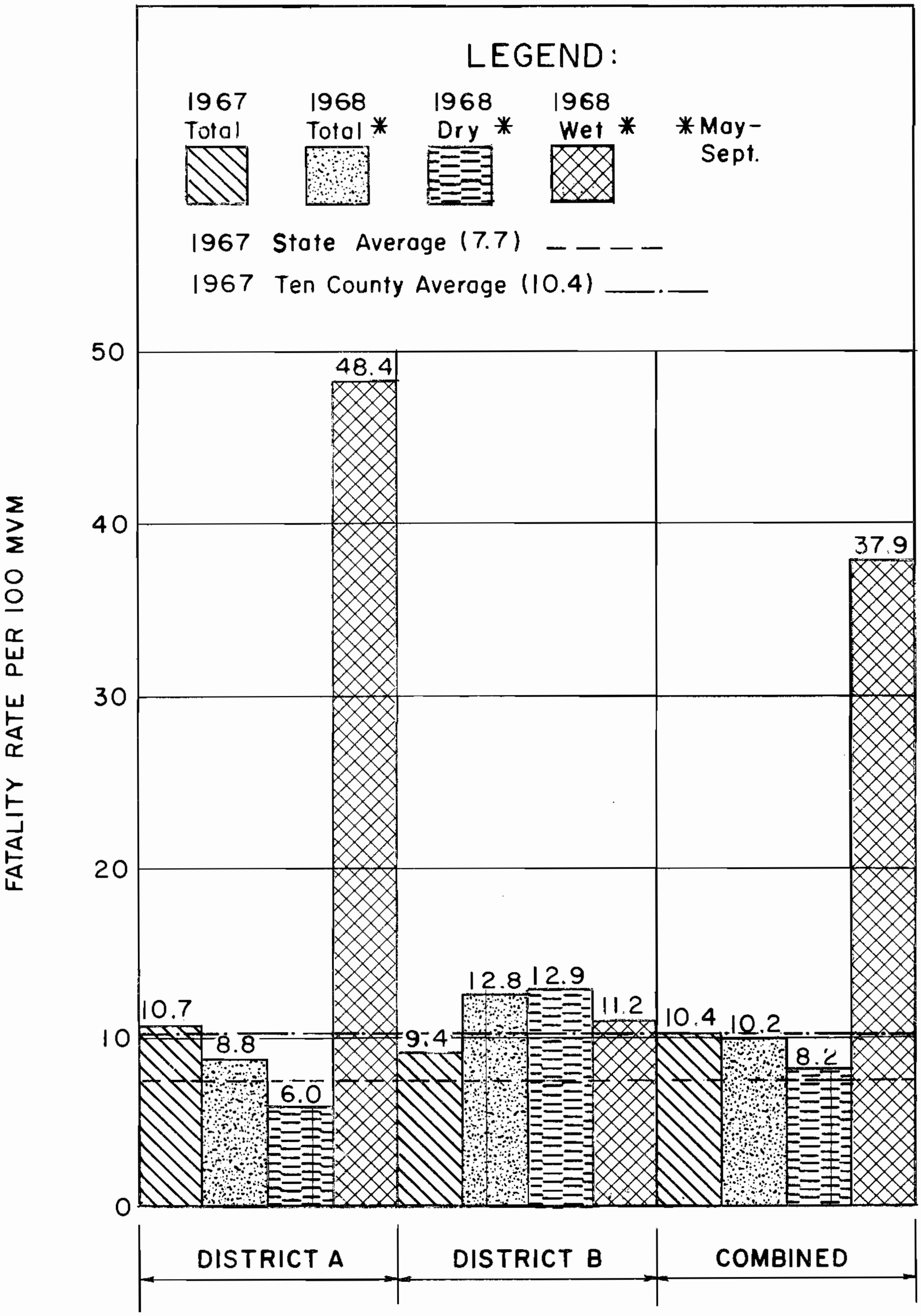
During 1967 the 10 counties included in this study registered a total accident rate of 239 per 100 million vehicle-miles (MVM) which was somewhat above the average of 192 per 100 MVM for the entire state. The total accident rate of 271 per 100 MVM for the study area for the 5-month study period in 1968 was slightly higher than in 1967. The rate of 271 accidents per 100 MVM includes all accidents recorded from May through September in 1968. When considering only wet weather accidents for the 10 county area for 5-months in 1968, the rate increased to 572 accidents per 100 MVM, nearly double the rate for all weather conditions. It can be noted from Figure 3 that the wet weather rates by individual counties varied considerably from the average wet weather rate for the 10 counties. The highest wet weather rates were registered by county numbers 7 and 8 with rates more than double the 10 county average wet weather accident rate.

Similar comparisons of fatality, fatal accident, fatal plus injury, and total accident rates by highway district and for the entire study area are illustrated in Figures 4, 5, 6, and 7, respectively. Here again the greatest deviation from

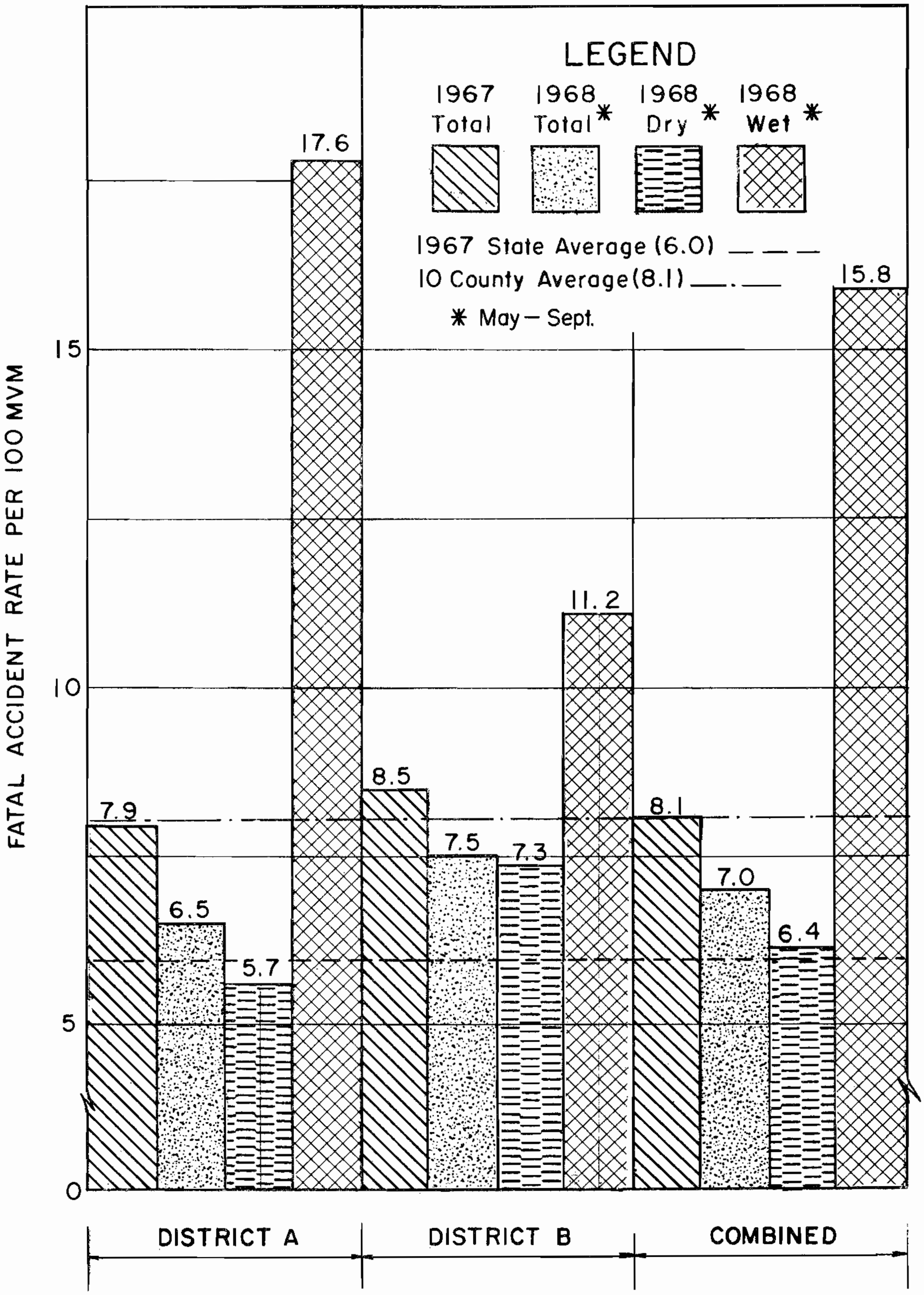


TOTAL ACCIDENT RATES PER 100 MILLION VEHICLE MILES

Figure 3

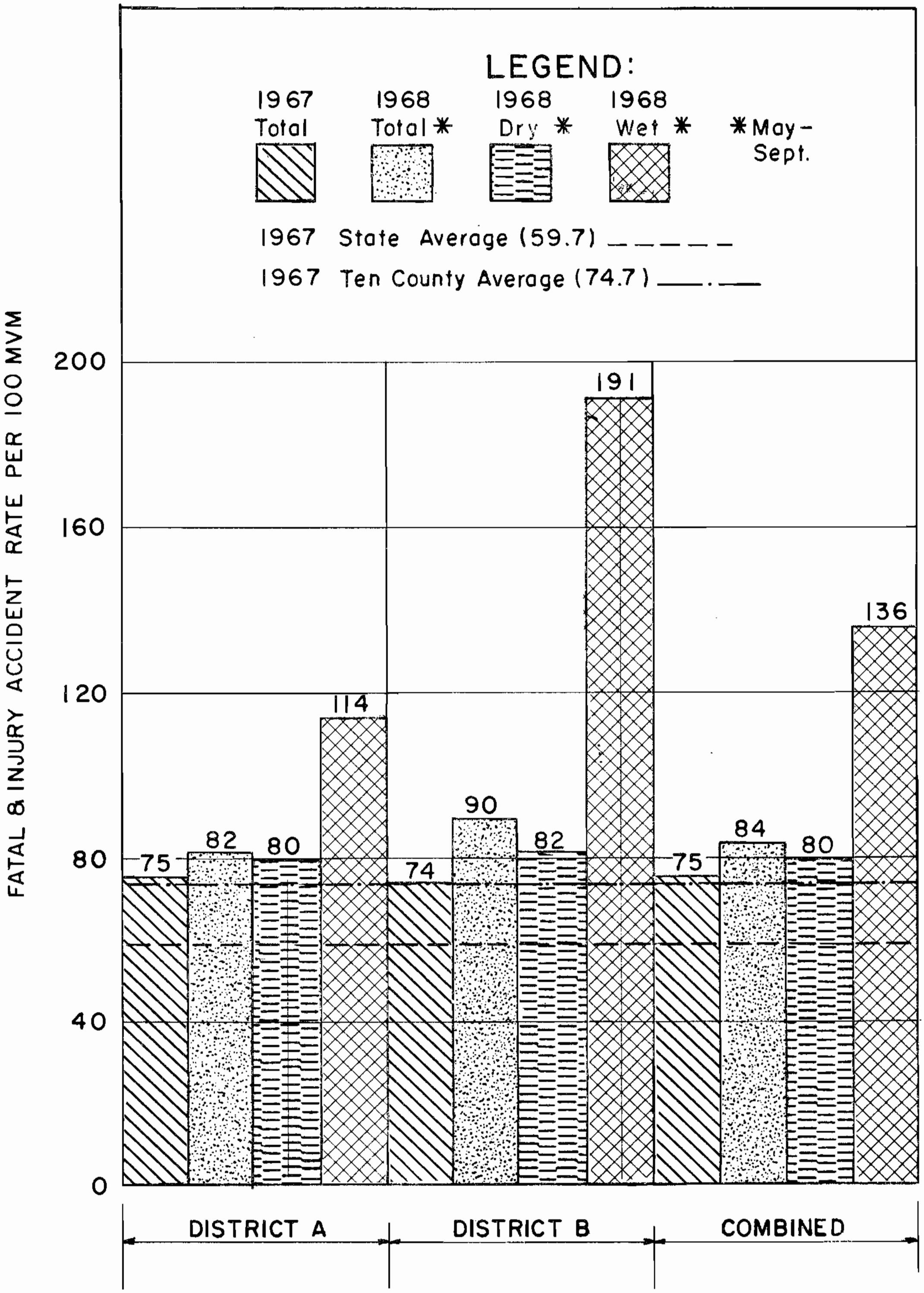


FATALITY RATES PER
100 MILLION VEHICLE MILES
Figure 4



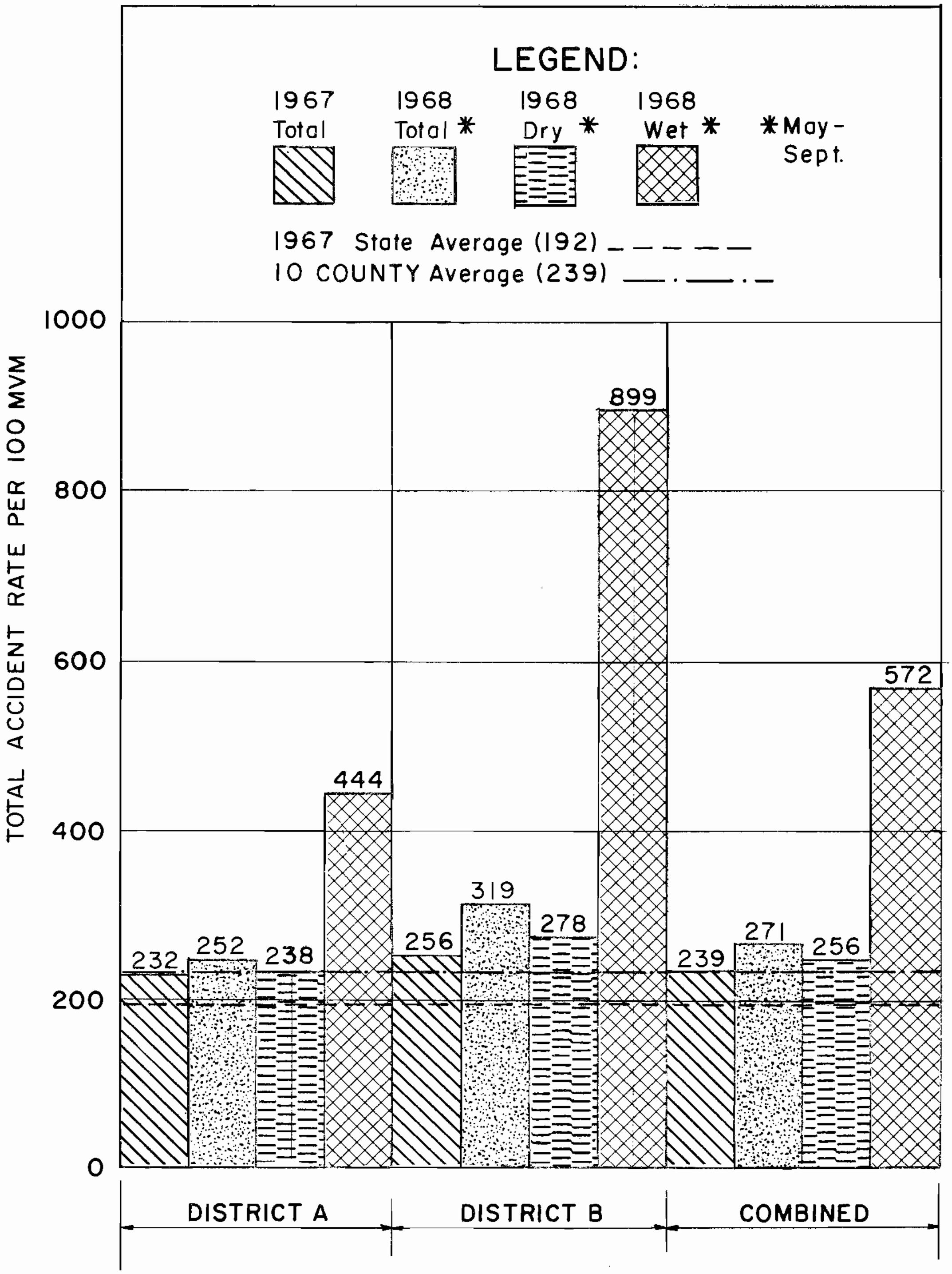
FATAL ACCIDENT RATES PER
100 MILLION VEHICLE MILES

Figure 5



FATAL & INJURY ACCIDENT RATES PER 100 MILLION VEHICLE MILES

Figure 6



TOTAL ACCIDENT RATES

PER 100 MILLION VEHICLE MILES

Figure 7

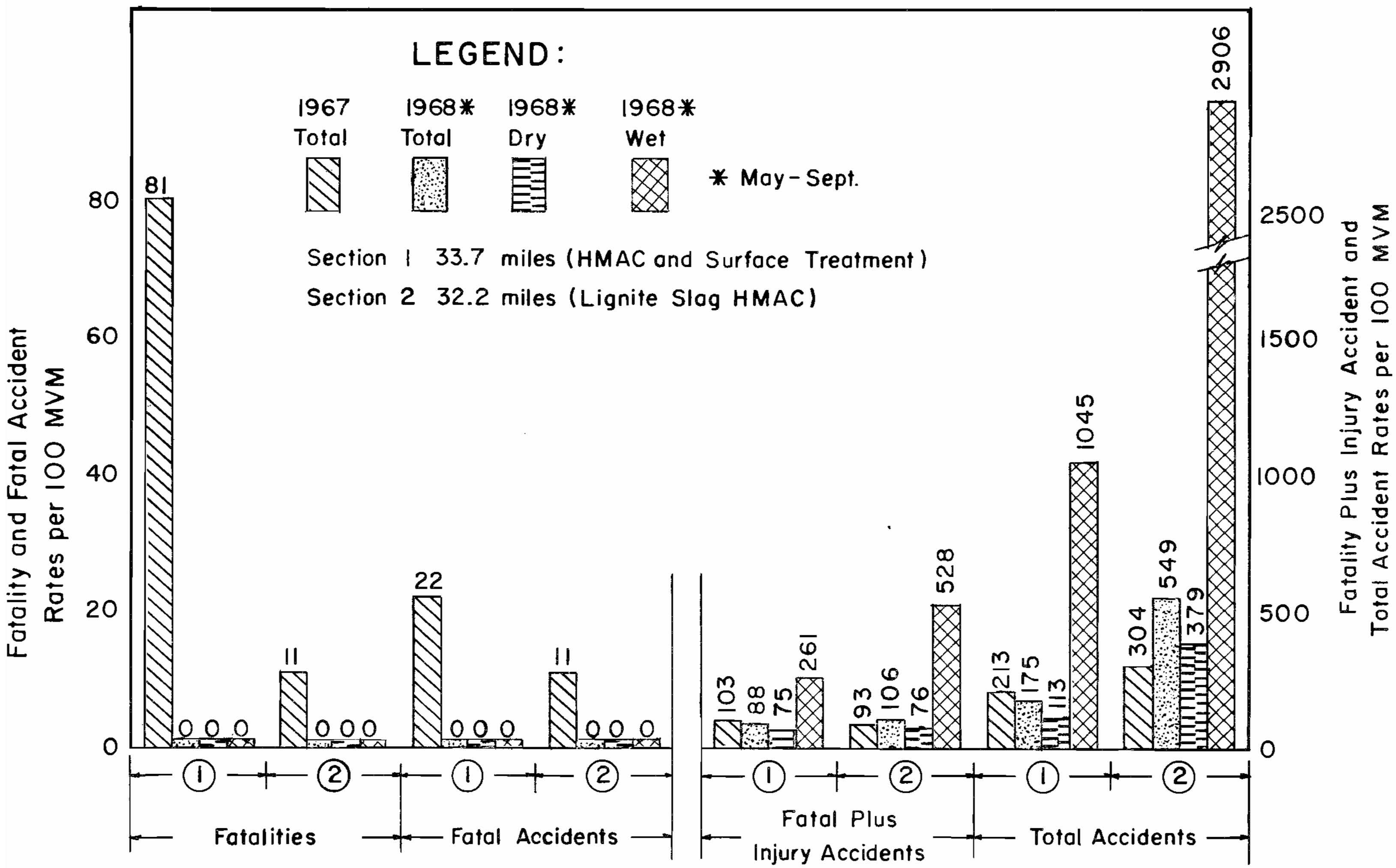
the respective ten county averages was in the wet weather category. District A was above the wet weather averages in the more severe categories of fatality and fatal accident rates (Figures 4 and 5). On the other hand, District B was high in the categories of fatal plus injury and total accident rates (Figures 6 and 7).

By further inspection of the data listed in Table 6, the proportion of wet weather accidents to the total in various categories can be determined. For the 5-month study period, 14.1 percent of the accidents occurred during wet weather. Similarly, wet weather accidents accounted for 25.0, 15.1, and 10.8 percent, respectively, of the fatalities, fatal accidents, and fatal plus injury accidents. This results in a ratio range of about one and one-half to nearly four times the proportion that the wet weather time is of the total time (6.70 percent). Considering total accidents by counties, an individual high of 37.5 percent of the accidents in County number 7 occurred during wet weather.

Another approach involved comparing wet weather rates for two highway sections having similar characteristics but differing considerably in pavement surface type. Two such comparisons were made. One comparison was between sections 1 and 2 on Route A. The wearing course for section 1 was about equally divided between asphaltic concrete and bituminous surface treatment. The wearing course for section 2 was a fine textured asphaltic concrete with lignite slag aggregate. The two sections were thought to be fairly comparable in geometrics and type of traffic. Section 2, however, did have considerably more vehicle-miles of travel. The various rate comparisons for the two sections are shown in Figure 8. The total wet weather accident rates were high on both sections but the rate on section 2 was very high at nearly six times the ten county average of 572 per 100 MVM for the same accident rate category. Both the numbers and rates for the two sections are listed in Table 7.

The second comparison was between a section of Route B and Route C. Both routes were thought to be comparable in function and geometrics. In this case the vehicle-miles of travel were almost identical. Route B had several segments with wearing courses composed of asphaltic concrete and several segments of various grades of bituminous surface treatments. The wearing course for Route C was asphaltic concrete with lignite slag aggregate. The rate comparisons are shown in Figure 9 and the data in Table 7. Here again the total wet weather accident rates were high on both routes but the rate on Route C was somewhat higher at nearly double the ten county average for the same accident rate category.

A still different approach involved analyzing the wet weather accidents from the standpoint of skidding and tire and pavement factors which are known to affect skid resistance. The four categories of accidents described on page 34 were considered in the analysis. Total accident rates for each of



COMPARISON OF ROUTE "A" SECTIONS 1&2

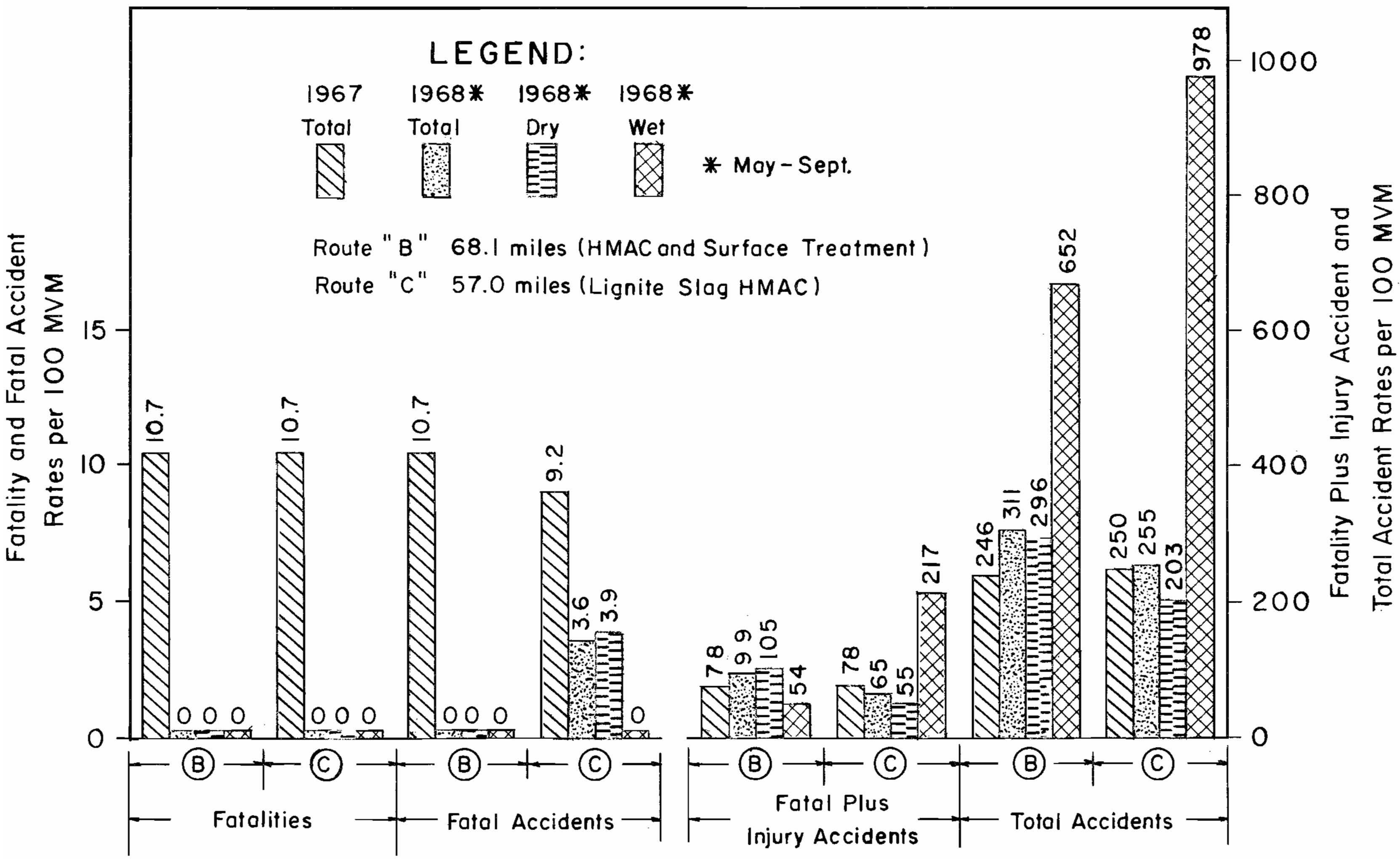
Figure 8

TABLE 7. COMPARISON OF ROUTES AND/OR SECTIONS OF ROUTES

ROUTE A - SECTION 1 VS. SECTION 2
ROUTE B VS. ROUTE C

LEGEND:
1. Total (May-Sept. 1968)
2. Dry Weather (May-Sept. 1968)
3. Wet Weather (May-Sept. 1968)
4. Total (12 months 1967)
(Rates per 100 MVM)

	Section Length Miles	DVM		Fatalities				Accidents: Fatal				Accidents: Fatal + Injury				Accidents: Total			
				1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Route A Sect. 1	33.7	37,341	No.	0	0	0	11	0	0	0	3	5	4	1	14	10	6	4	29
			Rate	0	0	0	80.7	0	0	0	22.0	87	75	261	103	175	113	1045	213
Route A Sect. 2	32.2	73,860	No.	0	0	0	3	0	0	0	3	12	8	4	25	62	40	22	82
			Rate	0	0	0	11.1	0	0	0	11.1	106	76	528	93	549	379	2906	304
Route B	68.1	179,693	No.	0	0	0	7	0	0	0	7	28	27	1	51	88	76	12	161
			Rate	0	0	0	10.7	0	0	0	10.7	99	105	54	78	311	296	651	245
Route C	57.0	179,538	No.	1	1	0	7	1	1	0	6	18	14	4	51	70	52	18	164
			Rate	3.6	3.9	0	10.7	3.6	3.9	0	9.2	65	55	217	78	255	203	978	250



COMPARISON OF ROUTES "B" AND "C"

Figure 9

the four accident categories were determined for each highway control-section (control-sections as designated by the Texas Highway Department) registering wet weather accidents. The accident rates are listed in Appendix A.

It was found that on an individual control-section basis the accident rates varied considerably for each of the four accident categories. A large part of this variation was believed to be due to large differences in the daily vehicle-miles of travel for the various sections. In order to reduce the variation, some grouping together of control-sections was necessary to make the rates more meaningful. This was also a consideration used in selecting counties, highway districts, and long sections of certain routes for accident rate comparisons.

The number of accidents for each of the four accident categories and the respective accident rates for individual counties and highway districts are shown in Table 8. It can be noted that county numbers 7 and 8 were considerably above average in each of the four categories.

Three of the four accident categories for which wet weather accident rates were determined involved some combination of skidding accident classes. Class A, classes A and B combined, and classes A, B, and C combined accounted for 7.3, 8.6, and 11.1 percent, respectively, of the 1280 total accidents recorded during the 5 month period for all weather conditions. Similarly, the three classes of skidding accidents accounted

TABLE 8. WET WEATHER ACCIDENTS (NUMBER OF ACCIDENTS AND RATES per 100 MVM)

	All wet weather accidents		All skidding classes "A","B"&"C"		Skidding classes "A"&"B"		Skidding class "A"	
	No.	Rate	No.	Rate	No.	Rate	No.	Rate
Co. No. 1	11	374	11	374	7	238	6	204
Co. No. 2	10	499	4	200	2	100	1	50
Co. No. 3	6	174	3	87	3	87	2	58
Co. No. 4	4	281	4	281	1	70	1	70
Co. No. 5	50	731	38	556	26	380	23	336
Co. No. 6	20	330	17	280	13	214	9	148
Dist. A	101	444.2	77	338.6	52	228.7	42	184.7
Co. No. 7	36	1746	32	1552	28	1358	28	1358
Co. No. 8	23	1340	14	816	13	758	11	641
Co. No. 9	5	168	4	135	2	67	1	34
Co. No. 10	16	745	15	699	15	699	11	512
Dist. B	80	899.4	65	730.7	58	652.0	51	573.3
Total	181	572.2	142	448.9	110	347.7	93	294.0

Class "A" skidding accidents - generally single car accidents in which no braking was apparent before the vehicle went out of control.

Class "B" skidding accidents - initial braking was involved before the vehicle went out of control.

Class "C" skidding accidents - braking preceeded a collision.

for 51.4, 60.8, and 78.4 percent of the 181 wet weather accidents registered during the 5-month study period.

SKID RESISTANCE

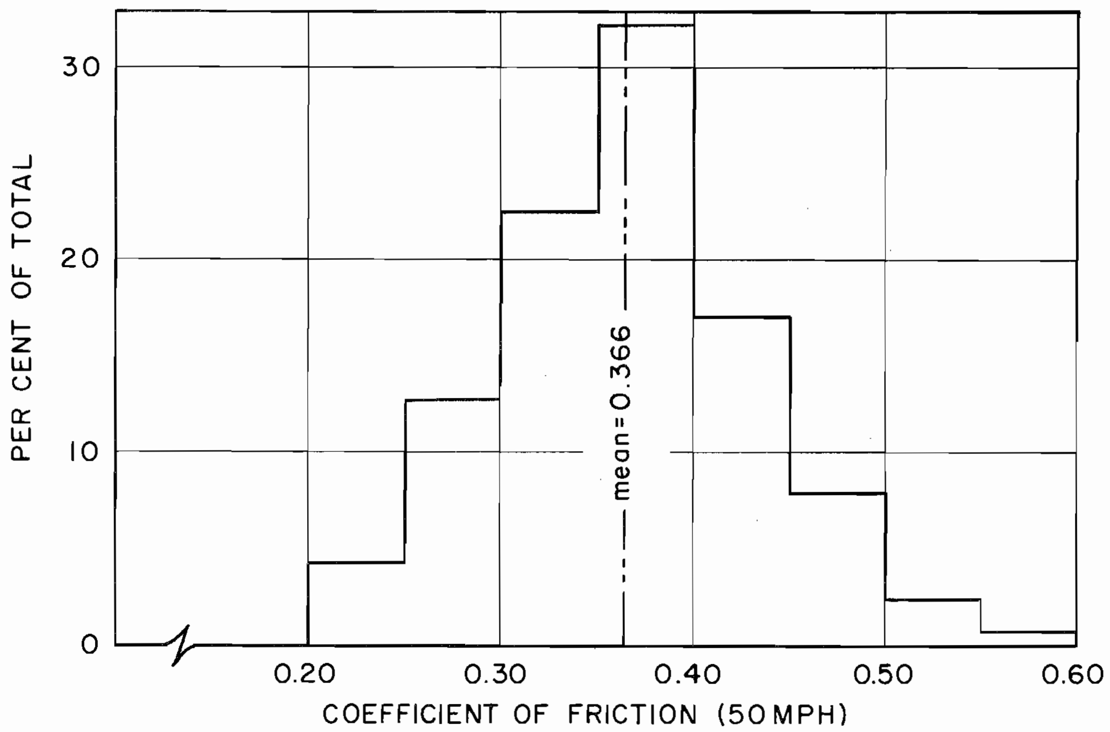
One hundred and eighty-one wet weather accidents were recorded during the five month study period. Skid resistance measurements were made at 164 separate accident locations. The pattern in which the skid measurements were made was described on page 30. Frequency distribution histograms of friction values for the one-mile vicinity averages and the site averages are shown in Figures 10 and 11, respectively. The data are listed in Table 9.

The two distributions were compared statistically with a Students "t" test (Ref 28). This is a statistical test which can be used to compare two samples of data to determine if the sample means come from the same population. The mean ($\bar{x}$) and variance (s^2) of the one-mile vicinity friction values (sample 1) were 0.366 and 4.762×10^{-3}, respectively. The mean and variance of the site friction values (sample 2) were 0.345 and 5.567×10^{-3}, respectively.

It is first necessary to test for homogeneity of variance; i.e. testing the null hypothesis H_o that the two sample variances come from the same population, $H_o: \sigma_1^2 = \sigma_2^2$

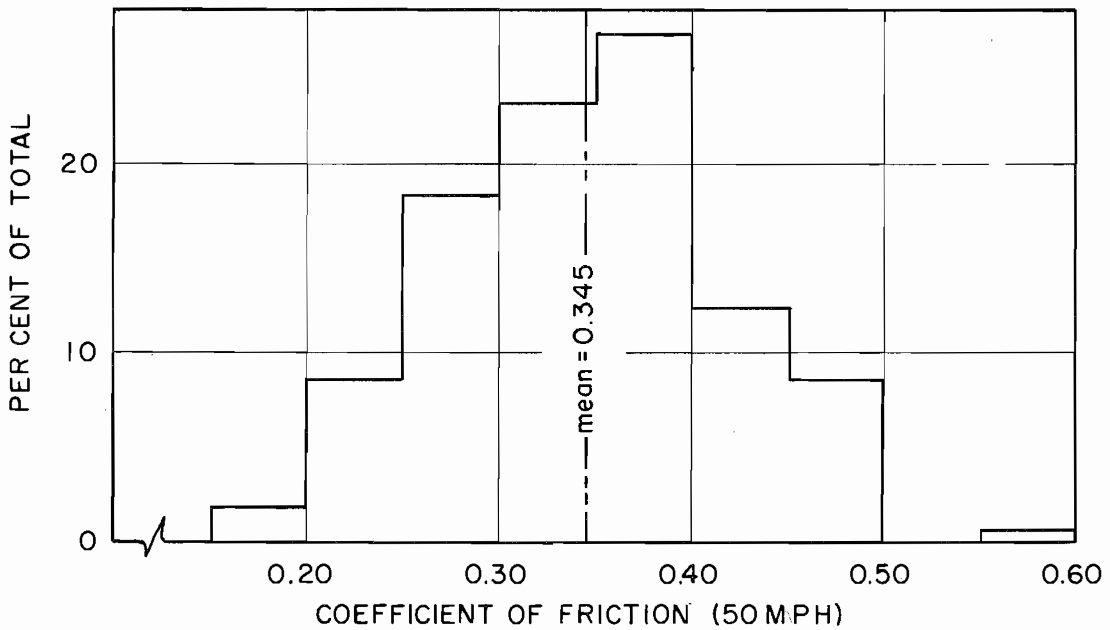
$$F = \frac{s_2^2}{s_1^2} = \frac{5.567 \times 10^{-3}}{4.762 \times 10^{-3}} = 1.17$$

The critical value of F for an α level of 5 percent and 163 degrees of freedom for each sample,



ONE MILE VICINITY AVERAGE FRICTION
WET WEATHER ACCIDENTS

FIGURE 10



SITE AVERAGE FRICTION WET
WEATHER ACCIDENTS

FIGURE 11

TABLE 9. COMPARISON OF COEFFICIENTS OF FRICTION (AVERAGE VALUES FOR ACCIDENT SITES AND ONE-MILE VICINITIES) May - Sept 1968

Coefficient of Friction (50 mph)	ALL WET WEATHER ACCIDENTS				WET WEATHER CLASS "A" SKIDDING ACCIDENTS			
	1 mi. vicinity avg		Site average		1 mi. vicinity avg		Site average	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0.15-0.19	0	0	3	1.8	0	0	1	1.1
0.20-0.24	7	4.3	14	8.5	3	3.4	7	8.0
0.25-0.29	21	12.8	30	18.3	10	11.4	14	15.9
0.30-0.34	37	22.6	38	23.2	19	21.6	21	23.9
0.35-0.39	53	32.3	44	26.9	30	34.1	27	30.7
0.40-0.44	28	17.1	20	12.2	19	21.6	11	12.5
0.45-0.49	13	7.9	14	8.5	6	6.8	6	6.8
0.50-0.54	4	2.4	0	0	1	1.1	0	0
0.55-0.59	1	0.6	1	0.6	0	0	1	1.1
Total	164	100.0*	164	100.0*	88	100.0*	88	100.0*

*Details may not add to totals due to rounding.

$F_{(163)\,(163)\,(0.05)} \cong 1.28$

Therefore, the null hypothesis $H_o: \sigma_1^2 = \sigma_2^2$ is not rejected. Next it is necessary to test the null hypotheses that the two sample means come from the same population, $H_o: \mu_1 = \mu_2$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{0.366 - 0.345}{\sqrt{\frac{1.033 \times 10^{-2}}{164}}} = 2.65$$

The critical value of t for a 5 percent level of significance and 326 degrees of freedom,

$t_{(326)\,(0.05)} \cong 1.96$

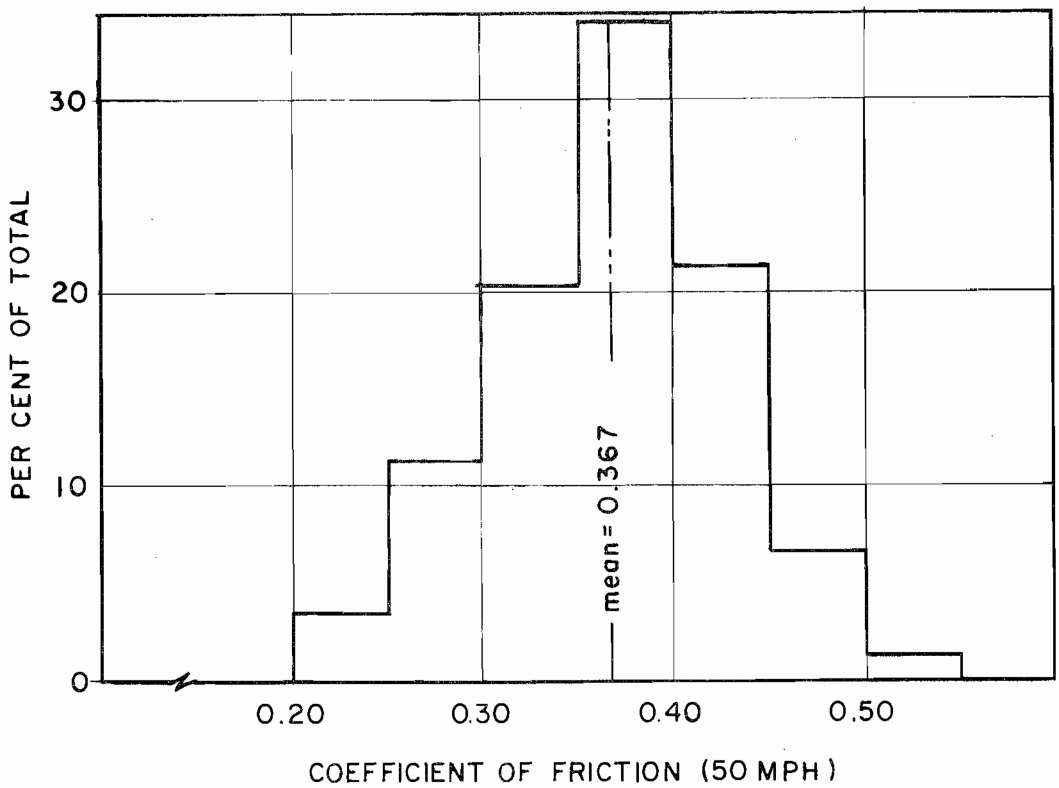
The computed value of t falls in the critical region. Therefore, the null hypothesis $H_o: \mu_1 = \mu_2$ is rejected and it is inferred there is a statistically significant difference between the sample means, i.e., the sample means do not come from the same population or there is a significant difference between samples or data sets.

A further examination was made of the one-mile vicinity and the site friction values for class A skidding accidents (usually single vehicle skidding accidents with no apparent braking), since they were thought to be the more likely linked with skid resistance. Ninety-three of the 181 wet weather accidents were considered to be in this accident class and 88 separate accident locations were represented by friction values. Frequency distribution histograms of friction values for the one-mile vicinity averages and the site averages are shown in Figures 12 and 13, respectively. The data are included in Table 9.

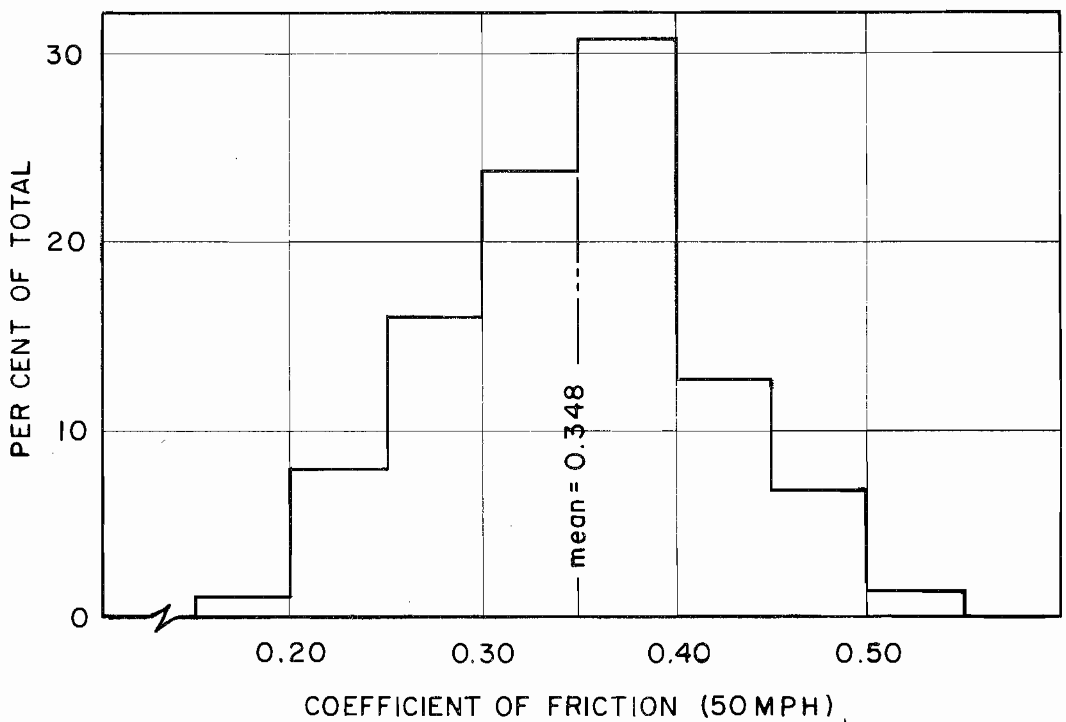
By statistically comparing the one-mile vicinity friction values and the site friction values for class A skidding accidents in the same manner as just described, the computed value of t was found to be 1.86 whereas the critical value of t was approximately 1.96. Therefore, it is inferred there is no significant difference between sample means at a 5 percent level of significance.

In other words, when considering all wet weather accidents, the average friction values at the actual accident sites were significantly lower than the average values representing the vicinities one-half mile in each direction from the accident locations. When considering only class A skidding accidents, however, the difference was not statistically significant. No reason other than chance can be given for one comparison being significant while the other comparison was not, especially since class A skidding accidents were assumed to be the most likely linked with inadequate skid resistance.

Both comparisons, however, involved comparing skid resistance values at the actual accident locations with the vicinity one-half mile in each direction from the accident location. In the comparisons the mean friction values differed



ONE MILE VICINITY AVERAGE FRICTION
WET WEATHER CLASS "A" SKIDDING ACCIDENTS
FIGURE 12



SITE AVERAGE FRICTION WET
WEATHER CLASS "A" SKIDDING ACCIDENTS
FIGURE 13

by only about 0.02. From a practical standpoint it would appear that an average difference of 0.02 in skid resistance could not be the cause of an accident happening at a particular location within the one-mile length of highway. However, even though the accident sites and one-mile vicinities had comparable skid resistance, both could still be either adequate or inadequate. Therefore, it may be more important to compare skid resistance values for wet weather accident locations with skid resistance values for non-accident areas.

The Texas Highway Department has a program whereby skid resistance measurements are made periodically at random locations throughout the state. Eight hundred and thirteen recent tests resulted in a mean of 0.392. By treating the 813 tests as the population of friction values throughout the state, the distribution of the accident site friction values for all wet weather accidents are compared statistically with the state-wide friction values as follows:

μ = 0.392 population mean (state-wide)

$\bar{x}$ = 0.345 sample mean (wet weather accident sites)

Test the null hypothesis H_o: $\bar{x} \geqq \mu$

$$t = \frac{\mu - \bar{x}}{\sqrt{\frac{s^2}{n}}} = \frac{0.392 - 0.345}{\sqrt{\frac{5.567 \times 10^{-3}}{164}}} = 8.07$$

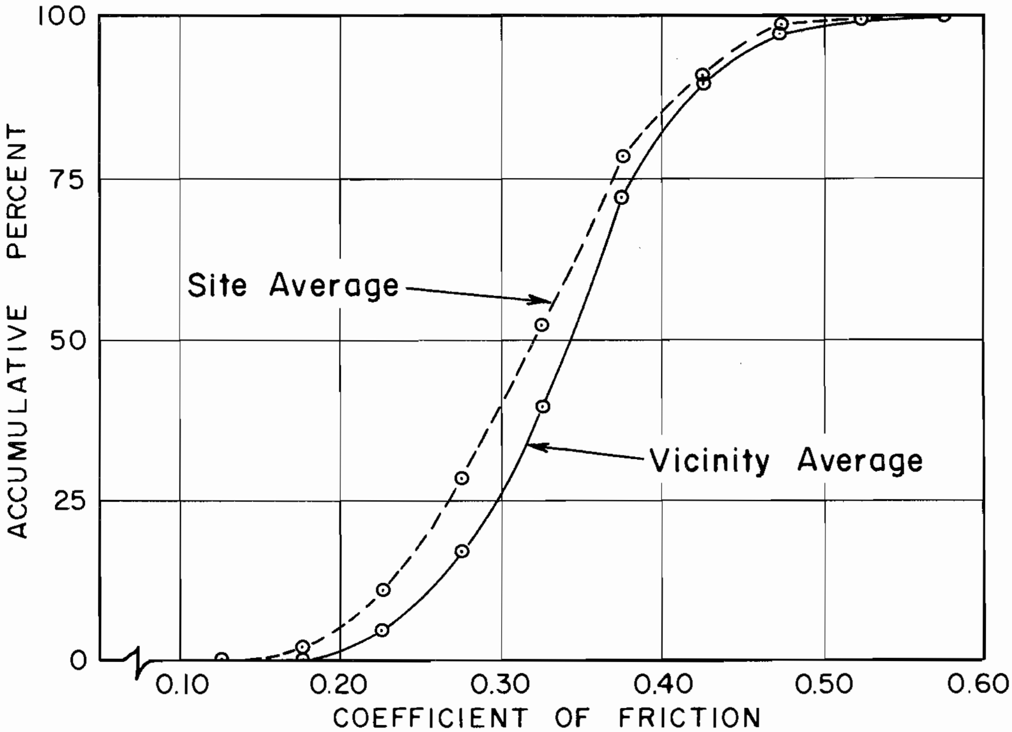
Critical $t_{(163)}$ (0.05) $\cong$ 1.65 (one-sided value)

The computed value of t falls in the critical region. Therefore, the null hypothesis is rejected and it is inferred that the sample mean is significantly less than the population mean.

During 1968, one hundred and ninety skid tests were made in the 10 county study area that were not associated with the wet weather accident study. These tests resulted in a mean friction value of 0.379 which is slightly better than the wet weather accident mean but below the state average.

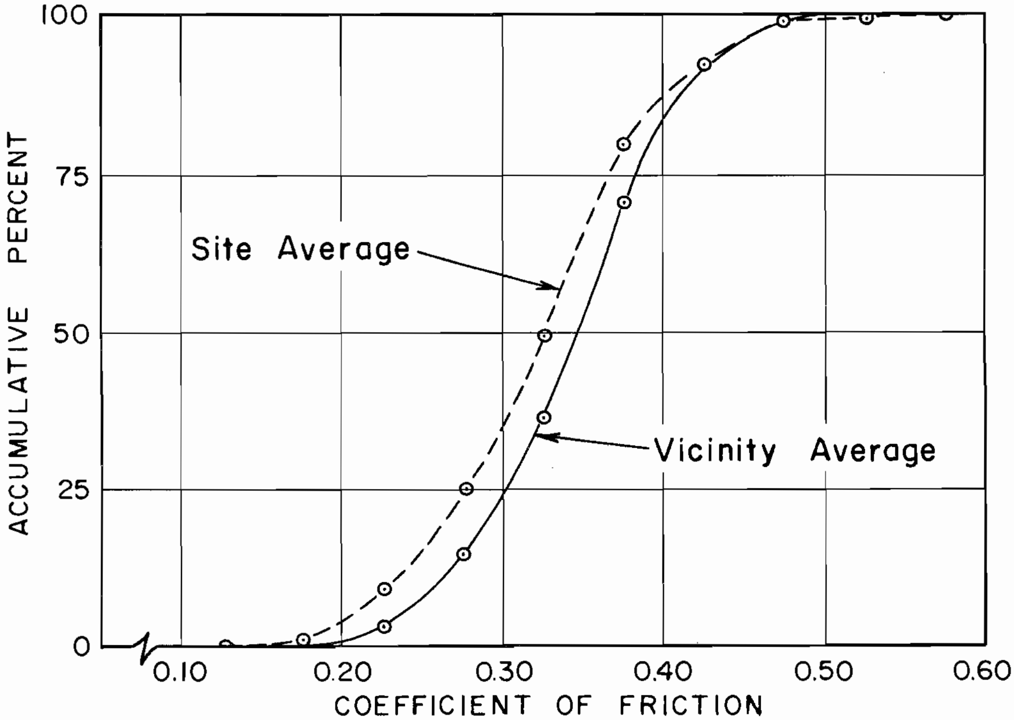
Cumulative frequency distributions of coefficients of friction for all wet weather and class A skidding accidents are shown in Figures 14 and 15, respectively. By inspection of Figure 14 it can be noted that 25 and 40 percent of the wet weather accident vicinities and sites, respectively were at or below a friction value of 0.3. Correspondingly, 7 and 15 percent were at or below a friction value of 0.24. A coefficient of 0.3 (50 mph) is a minimum used by the Texas Highway Department as a guide for recommending pavement surface improvement. A value of 0.24 (50 mph) is considered a minimum for immediate surface improvement (Ref 17). This, in addition to the previous comparison of friction values, indicates that many of the wet weather accident vicinities and to a greater extent the actual accident sites were somewhat lacking in skid resistance.

In the previous comparisons only the measured skid resistance values were considered. The surface texture of the pavement is also an important factor, especially for high speeds and wet conditions. It is possible for a gritty, fine



FRICTION COEFFICIENTS - ALL WET WEATHER ACCIDENTS

FIGURE 14



FRICTION COEFFICIENTS - CLASS "A" SKIDDING ACCIDENTS

FIGURE 15

textured surface to register fairly high friction coefficients and still be susceptible to skidding when wet. This condition would be further aggravated when combined with high operating speeds and treadless tires. Also, it is apparent that hydroplaning is most likely to occur under these circumstances. A brief discussion concerning hydroplaning will be included in a later section on tire factors.

Thirty-five percent of the wet weather accidents involved vehicles skidding while negotiating horizontal curves. If the vehicle skidded sideways, the friction involved would be cornering or side friction whereas the skid-trailer measured the friction coefficients parallel to the direction of movement. Therefore, it was thought the skid resistance on curves warranted further analysis.

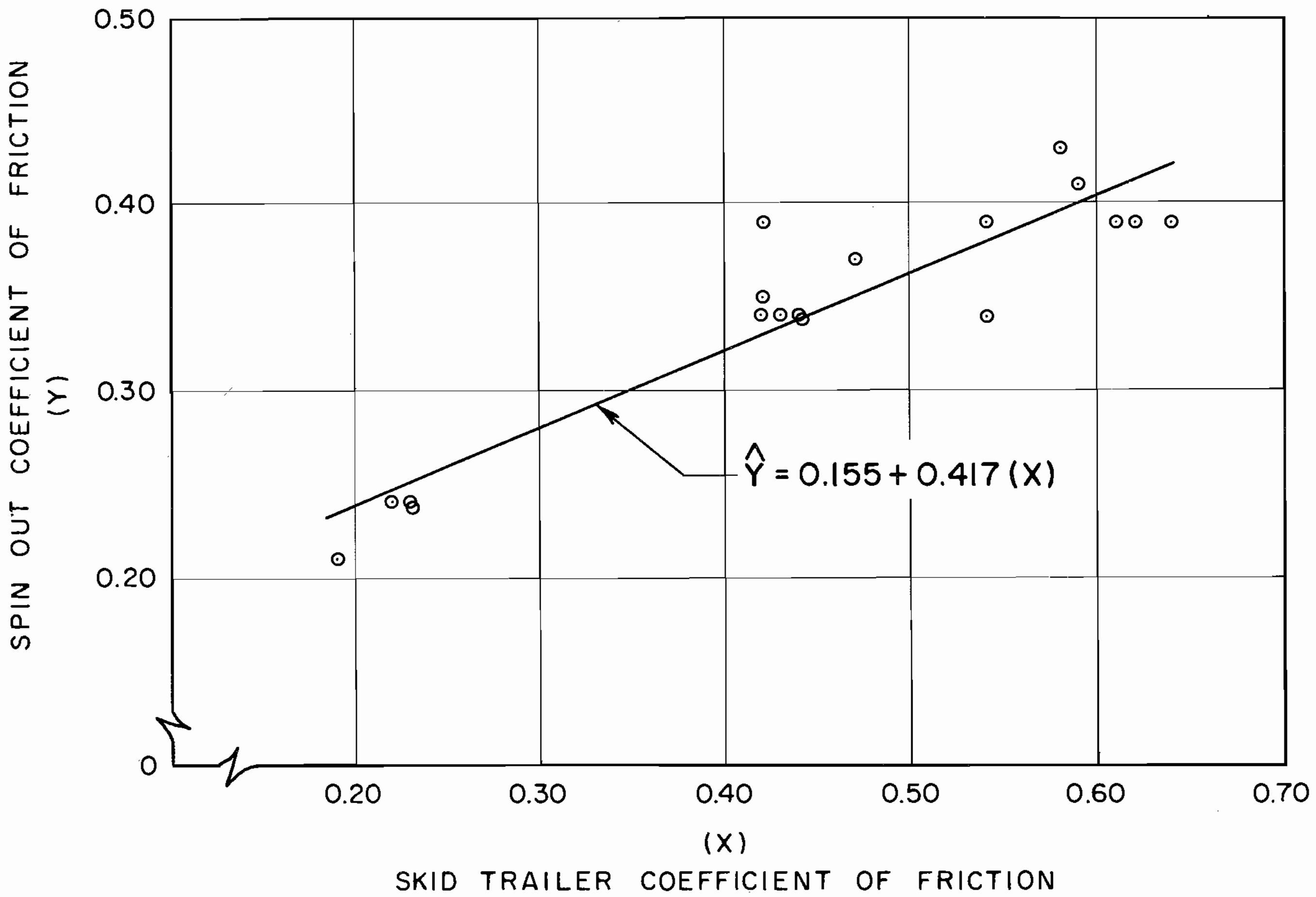
Friction values measured with the skid trailer and the cornering friction values calculated from vehicle spin out tests were correlated so that an estimate could be made of the available cornering friction on the roadway. Cornering friction values were calculated from the relationship $f = \frac{V^2}{14.95R} - e$ using spin out speeds from tests conducted by The Texas Transportation Institute (Ref 22). The spin out tests were done on wet pavement test sections with a known degree of curvature and zero superelevation. Skid trailer measurements were conducted on the same test sections. A linear regression analysis resulted in the prediction equation

$\hat{Y} = 0.155 + 0.417(X)$, for determining the cornering friction from the measured skid trailer value. The correlation coefficient r, was 0.928. A plot of the values is shown in Figure 16.

Two horizontal curves on Route D were selected for investigation. The degree of curvature was determined from design plans and the roadway superelevation was measured at the accident site. The cornering friction developed by the skidding accident vehicle was calculated using the estimated speed recorded in the accident report. The available cornering friction was then determined from the skid-trailer values and compared with the developed cornering friction.

The two curves, numbers 227-4 and 227-31, each recorded only one skidding accident during the 5-month period. The accident vehicle on curve number 227-4 developed 0.02 cornering friction whereas 0.33 was available on the roadway. However, the vehicle was equipped with bald rear tires. On curve number 227-31, the accident vehicle developed 0.10 as compared to 0.32 available cornering friction. In this case a rear tire blew out apparently contributing to the accident. In both cases the skidding vehicle used only a small portion of the available cornering friction.

To further supplement the curve investigation, spot speed studies were conducted to determine how much cornering friction was developed by vehicles negotiating the same curves



CORRELATION OF FRICTION COEFFICIENTS

FIGURE 16

but not skidding. This was done during both dry and wet weather.

It was found that the non-accident vehicles were developing more cornering friction under wet conditions on curve number 227-4 than did the accident vehicle which skidded. The mean vehicle speed developed 0.03 cornering friction with a high of 0.14. Likewise, on curve number 227-31 the average of the non-accident vehicles under wet conditions developed 0.05 cornering friction with a high of 0.12. Therefore, it is evident that something other than lack of adequate skid resistance on the part of the pavement contributed to the skidding accidents.

The spot speed studies were also used to compare running speeds under both dry and wet conditions. The following tabulation shows the average running speeds for the two curves and also one adjacent tangent section:

TABLE 10
Average running speed in mph

Section	Direction of Travel	Dry Conditions	Wet Conditions
Curve No. 227-4	EB	56.7	45.6
Curve No. 227-4	WB	54.7	51.9
Curve No. 227-31	EB	53.0	48.4
Curve No. 227-31	WB	49.3	46.0
Tangent	EB	59.8	60.0
Tangent	WB	68.6	57.8

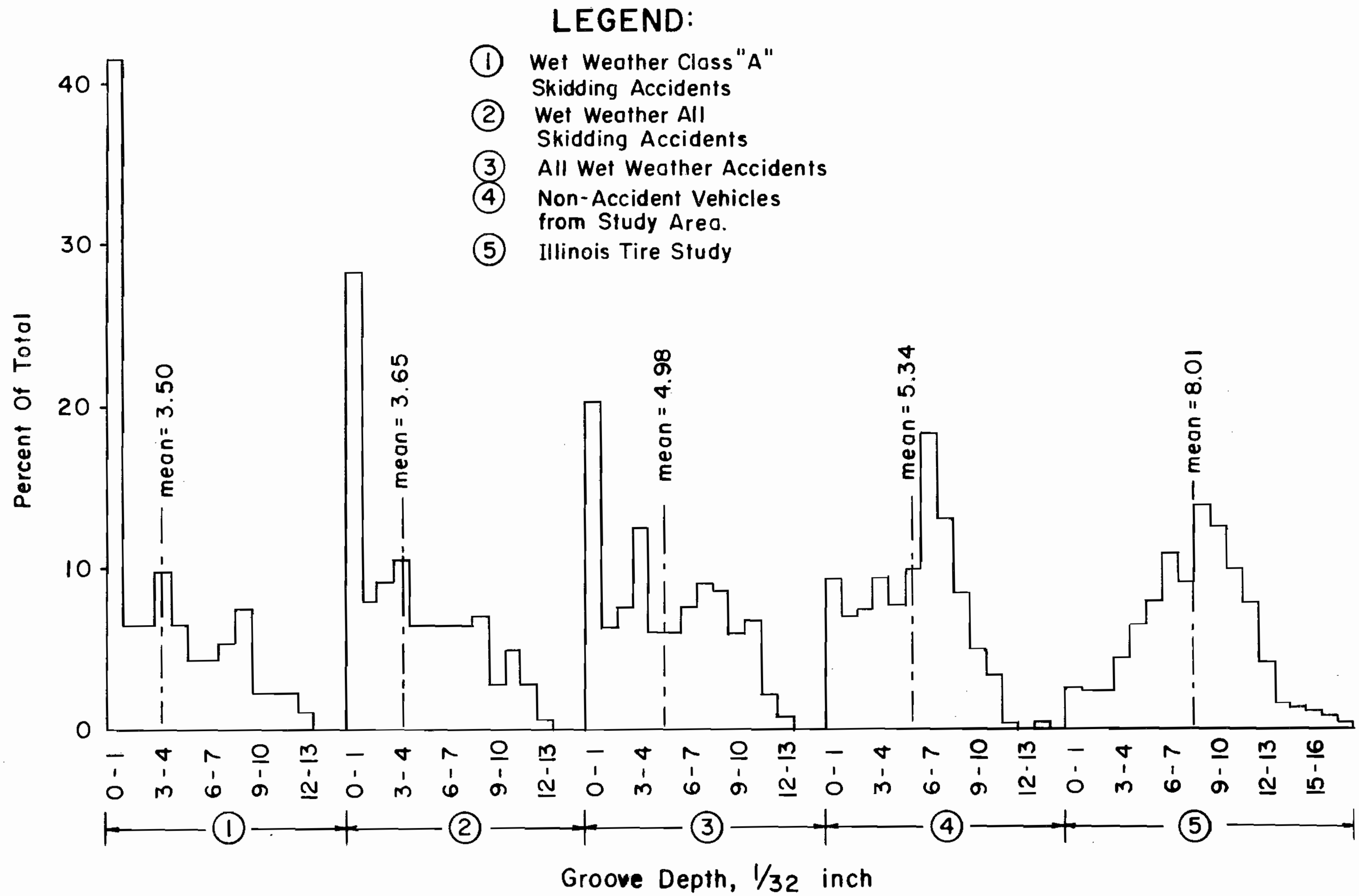
The vertical alignment of the highway was quite rolling and this could have accounted for the variation in speed for different directions of travel.

TIRE FACTORS

The wet weather accident data included tire information such as tread depth, tread pattern, wear condition, pressure, size and manufacturer. Although all of these factors may be important, tread depth was the major consideration in this analysis.

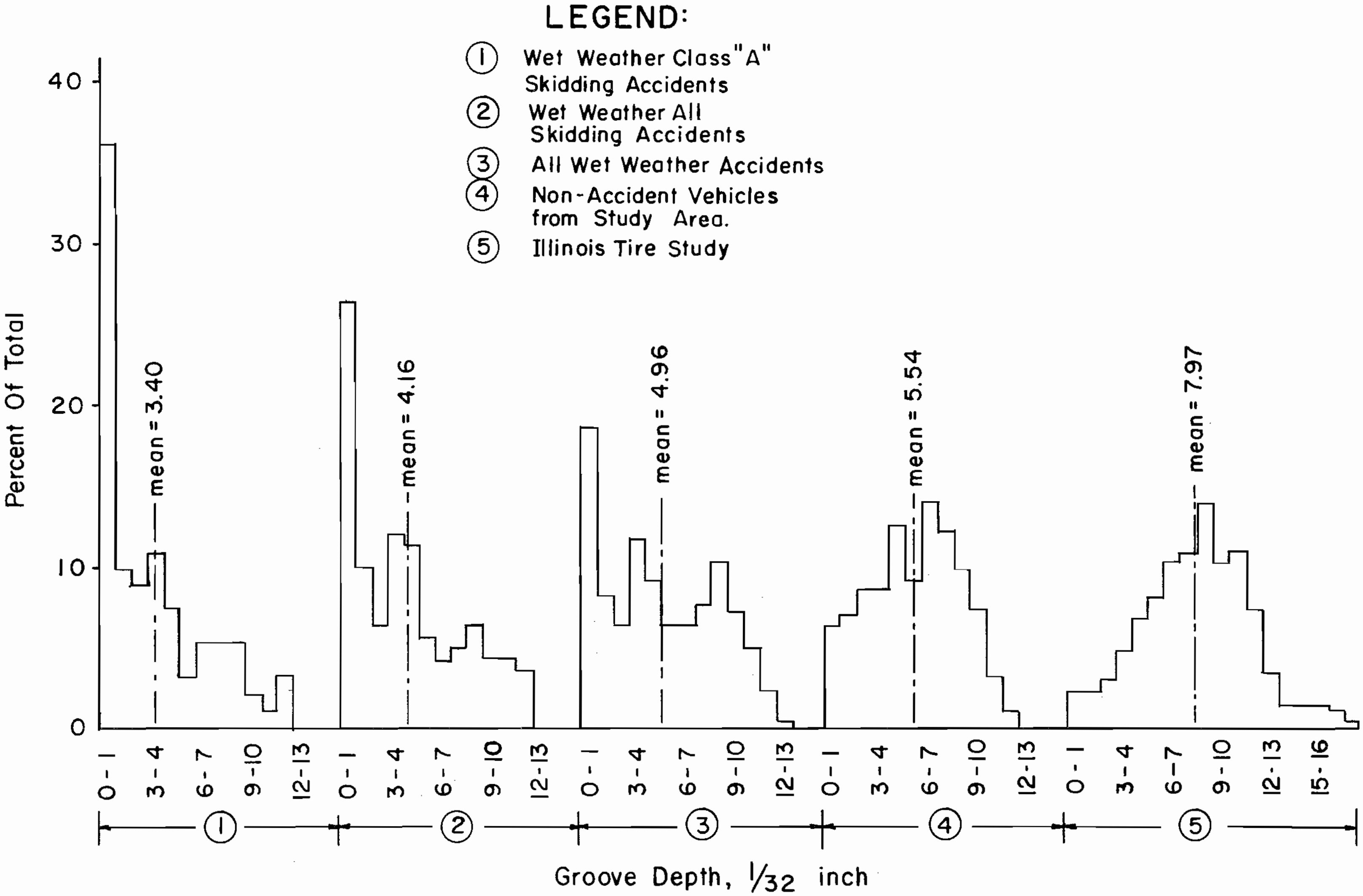
Tread depth measurements in 1/32-inch increments were obtained for each tire on wet weather accident vehicles. Two measurements were made on each tire; one for the minimum tread depth and one for the maximum tread depth. Both measurements were made in the center of the tire, half way between the edges. Occasionally tread depth information was not reported due to the tire being damaged in the accident. The tread depth measurements are included with the accident data summary in Appendix A.

Tread depth distributions for each vehicle tire were determined for three categories of wet weather accidents: total, all classes of skidding (A, B, and C), and class A skidding. The average of the two measurements for each tire was used in determining the tread depth distirbutions for automobiles and pickup trucks involved in accidents. The tread depth distributions are shown in Figures 17 through 20 and the data are listed in Tables 11 through 14.



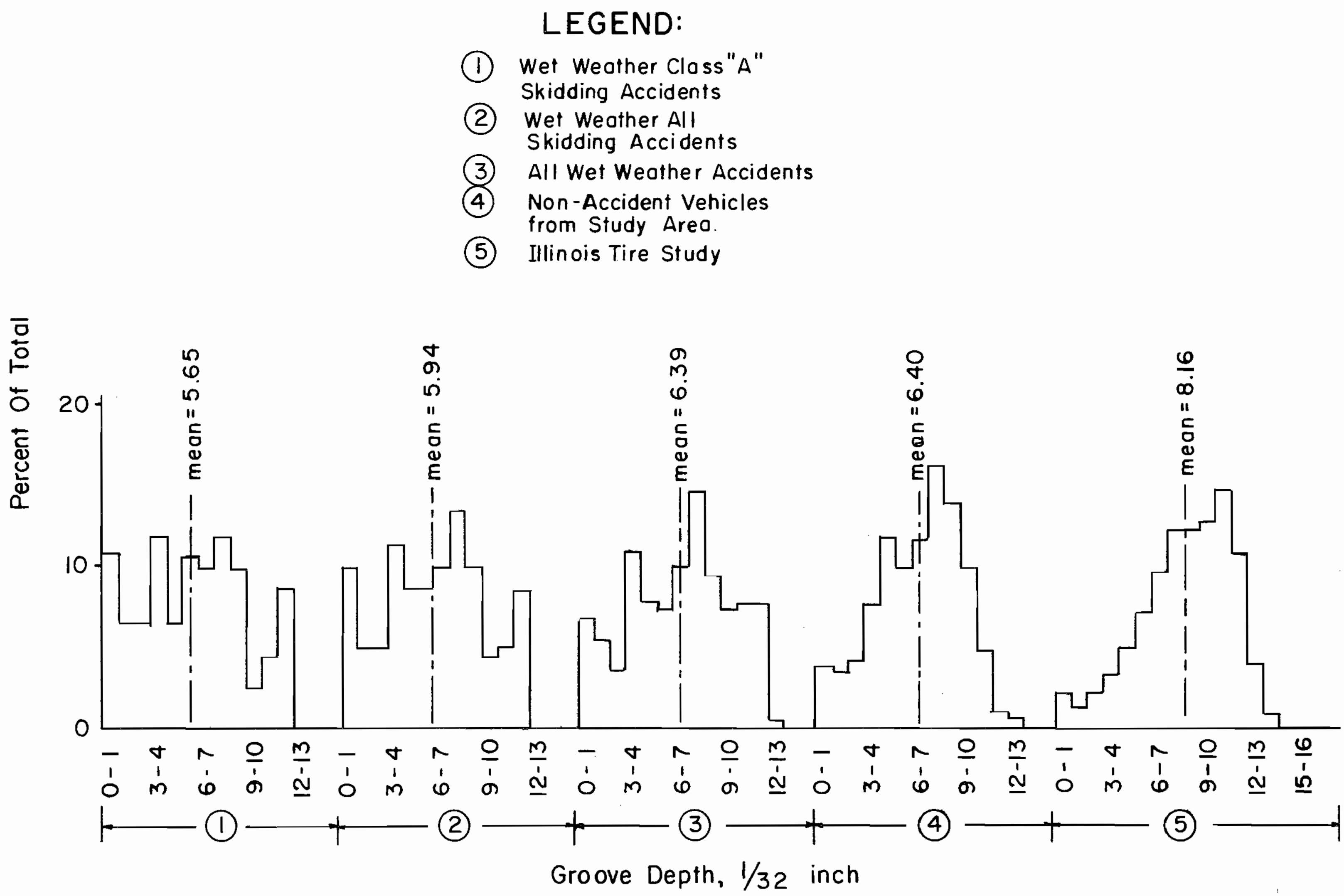
TREAD DEPTH REMAINING ON LEFT REAR TIRES

Figure 17



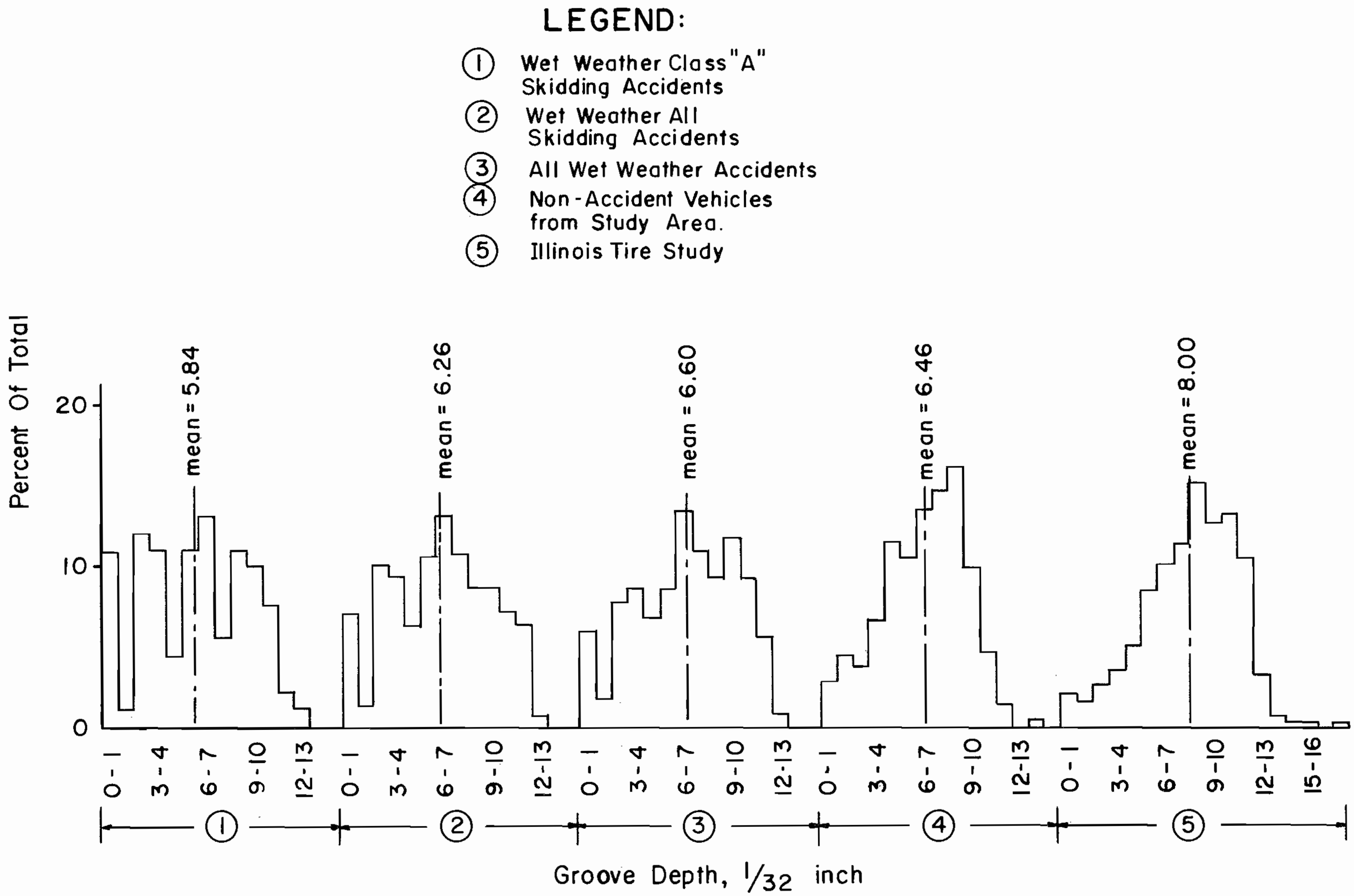
TREAD DEPTH REMAINING ON RIGHT REAR TIRES

Figure 18



TREAD DEPTH REMAINING ON LEFT FRONT TIRES

Figure 19



TREAD DEPTH REMAINING ON RIGHT FRONT TIRES

Figure 20

TABLE 11. TREAD DEPTH REMAINING ON LEFT REAR TIRES

LEGEND: 1 - Wet Weather Accidents - Class "A" skidding
2 - Wet Weather Accidents - Skidding classes "A","B"&"C"
3 - All Wet Weather Accidents (May-Sept. 1968)
4 - Non Accident Vehicles from Study Area
5 - Illinois Tire Study

Tread Depth 1/32"	1		2		3		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
0-1	38	41.4	40	28.4	45	20.4	27	9.5	47	2.7
1-2	6	6.5	11	7.8	14	6.3	20	7.0	44	2.5
2-3	6	6.5	13	9.2	17	7.7	21	7.4	48	2.7
3-4	9	9.8	15	10.6	28	12.7	27	9.5	79	4.5
4-5	6	6.5	9	6.4	13	5.9	22	7.7	111	6.4
5-6	4	4.3	9	6.4	13	5.9	28	9.9	139	8.0
6-7	4	4.3	9	6.4	17	7.7	52	18.3	191	10.9
7-8	5	5.4	9	6.4	20	9.0	37	13.0	159	9.1
8-9	7	7.6	10	7.1	19	8.6	24	8.5	242	13.9
9-10	2	2.2	4	2.8	13	5.9	14	4.9	202	11.6
10-11	2	2.2	7	5.0	15	6.8	10	3.5	171	9.8
11-12	2	2.2	4	2.8	5	2.2	1	0.4	137	7.9
12-13	1	1.1	1	0.7	2	0.9	0	0	74	4.2
13-14	0	0	0	0	0	0	1	0.4	29	1.7
14-15	0	0	0	0	0	0	0	0	27	1.5
15-16	0	0	0	0	0	0	0	0	21	1.2
16-17	0	0	0	0	0	0	0	0	15	0.9
>17	0	0	0	0	0	0	0	0	10	0.5
Total	92	100.0*	141	100.0*	221	100.0*	284	100.0*	1746	100.0*

*Details may not add to totals due to rounding.

TABLE 12. TREAD DEPTH REMAINING ON RIGHT REAR TIRES

LEGEND: 1 - Wet Weather Accidents - Class "A" skidding
2 - Wet Weather Accidents - Skidding classes "A","B"&"C"
3 - All Wet Weather Accidents (May-Sept. 1968)
4 - Non Accident Vehicles from Study Area
5 - Illinois Tire Study

Tread Depth 1/32"	1		2		3		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
0-1	33	36.2	37	26.5	41	18.6	18	6.3	40	2.3
1-2	9	9.9	14	10.0	18	8.2	20	7.0	40	2.3
2-3	8	8.8	9	6.4	14	6.4	25	8.7	54	3.1
3-4	10	11.0	17	12.1	26	11.8	25	8.7	84	4.8
4-5	7	7.7	16	11.4	20	9.1	36	12.6	118	6.8
5-6	3	3.3	8	5.7	14	6.4	26	9.1	143	8.2
6-7	5	5.5	6	4.3	14	6.4	40	14.0	180	10.3
7-8	5	5.5	7	5.0	17	7.7	35	12.2	188	10.8
8-9	5	5.5	9	6.4	23	10.4	28	9.8	242	13.9
9-10	2	2.2	6	4.3	16	7.3	21	7.3	176	10.1
10-11	1	1.1	6	4.3	11	5.0	9	3.2	190	10.9
11-12	3	3.3	5	3.6	5	2.3	3	1.1	128	7.3
12-13	0	0	0	0	1	0.4	0	0	60	3.4
13-14	0	0	0	0	0	0	0	0	23	1.3
14-15	0	0	0	0	0	0	0	0	25	1.4
15-16	0	0	0	0	0	0	0	0	27	1.5
16-17	0	0	0	0	0	0	0	0	21	1.2
>17	0	0	0	0	0	0	0	0	7	0.4
Total	91	100.0*	140	100.0*	220	100.0*	286	100.0*	1746	100.0*

*Details may not add to totals due to rounding.

TABLE 13. TREAD DEPTH REMAINING ON LEFT FRONT TIRES

LEGEND: 1 - Wet Weather Accidents - Class "A" skidding
2 - Wet Weather Accidents - Skidding classes "A","B"&"C"
3 - All Wet Weather Accidents (May-Sept. 1968)
4 - Non Accident Vehicles from Study Area
5 - Illinois Tire Study

Tread Depth 1/32"	1		2		3		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
0-1	10	10.8	14	10.0	15	6.9	11	3.9	38	2.2
1-2	6	6.5	7	5.0	12	5.5	10	3.5	23	1.3
2-3	6	6.5	7	5.0	8	3.7	12	4.2	38	2.2
3-4	11	12.0	16	11.4	24	11.0	22	7.7	59	3.4
4-5	6	6.5	12	8.6	17	7.8	34	11.9	90	5.1
5-6	10	10.8	12	8.6	16	7.3	28	9.8	127	7.3
6-7	9	9.8	14	10.0	22	10.1	34	11.9	172	9.8
7-8	11	12.0	19	13.5	32	14.7	47	16.4	217	12.4
8-9	9	9.8	14	10.0	21	9.6	40	14.0	218	12.5
9-10	2	2.3	6	4.3	16	7.3	29	10.1	225	12.9
10-11	4	4.3	7	5.0	17	7.8	14	4.9	260	14.8
11-12	8	8.7	12	8.6	17	7.8	3	1.0	188	10.8
12-13	0	0	0	0	1	0.5	2	0.7	72	4.1
13-14	0	0	0	0	0	0	0	0	17	1.0
14-15	0	0	0	0	0	0	0	0	1	0.1
15-16	0	0	0	0	0	0	0	0	1	0.1
16-17	0	0	0	0	0	0	0	0	0	0
>17	0	0	0	0	0	0	0	0	0	0
Total	92	100.0*	140	100.0*	218	100.0*	286	100.0*	1746	100.0*

*Details may not add to totals due to rounding.

TABLE 14. TREAD DEPTH REMAINING ON RIGHT FRONT TIRES

LEGEND: 1 - Wet Weather Accidents - Class "A" skidding
2 - Wet Weather Accidents - Skidding classes "A","B"&"C"
3 - All Wet Weather Accidents (May-Sept. 1968)
4 - Non Accident Vehicles from Study Area
5 - Illinois Tire Study

Tread Depth 1/32"	1		2		3		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
0-1	10	10.9	10	7.1	13	5.9	8	2.8	36	2.1
1-2	1	1.1	2	1.4	4	1.8	13	4.6	29	1.7
2-3	11	11.9	14	10.0	17	7.7	11	3.8	46	2.6
3-4	10	10.9	13	9.3	19	8.6	19	6.6	61	3.5
4-5	4	4.3	9	6.4	15	6.8	33	11.5	88	5.0
5-6	10	10.9	15	10.7	19	8.6	30	10.5	147	8.4
6-7	12	13.0	18	13.0	29	13.3	38	13.3	175	10.0
7-8	5	5.4	15	10.7	24	10.9	42	14.7	197	11.3
8-9	10	10.9	12	8.6	20	9.1	46	16.1	263	15.1
9-10	9	9.8	12	8.6	26	11.8	28	9.8	224	12.7
10-11	7	7.6	10	7.1	20	9.1	13	4.6	228	13.1
11-12	2	2.2	9	6.4	12	5.5	4	1.4	180	10.3
12-13	1	1.1	1	0.7	2	0.9	0	0	56	3.2
13-14	0	0	0	0	0	0	1	0.3	12	0.7
14-15	0	0	0	0	0	0	0	0	2	0.1
15-16	0	0	0	0	0	0	0	0	1	0.1
16-17	0	0	0	0	0	0	0	0	0	0
>17	0	0	0	0	0	0	0	0	1	0.1
Total	92	100.0*	140	100.0*	220	100.0*	286	100.0*	1746	100.0*

*Details may not add to totals due to rounding.

A sample of non-accident vehicle tread depths was obtained for comparative purposes. The sample was obtained from four locations throughout the study area. This information, along with data from a tire study (Ref 23) made in Illinois, is included in the aforementioned Figures and Tables.

By inspection of the tread depth distributions, it is readily seen that the percentage of bald tires on wet weather accident vehicles was higher than for non-accident vehicles from the same area. This is especially true of the rear tires. In the tread depth range of 0 to 1/32 of an inch for rear tires, the frequency for wet weather accident vehicles was two to four times higher than for non-accident vehicles.

The difference is even more noticeable when comparing the tread depths of the accident vehicles with the Illinois data. It should be mentioned, however, that the Illinois data were obtained from vehicles operating on a toll road near Chicago. A direct comparison may not be completely valid since the condition of the vehicles and the type of traffic on the toll road could be different from the predominantly rural area included in this study.

Another interesting relationship is apparent from the tread depth distributions. For the rear tires in the tread depth range of 0 to 1/32 of an inch, the frequency for skidding accidents is higher than for overall wet weather accidents.

In fact, for the tread depth range of 0 to 1/32 of an inch, the frequency of occurrence for class A skidding accidents is about double the frequency for all wet weather accidents. Class A skidding accidents were considered to be the most reliable representation of true skidding since no other causes of the accident were apparent. Thus it was assumed that skid resistance, considering both pavement and tire factors, would more likely be the primary factor causing the wet weather accidents in this category.

Average tire tread depths were also determined for all automobiles and pickup trucks without regard for the position of the tire on the vehicle. Distributions for the same five categories as shown in Figures 17 through 20 are listed in Table 15. Four of these categories, along with data (Ref 24) from the Western United States, are graphically illustrated in Figure 21. The Western United States data consist of 45,540 tires sampled from various locations west of the Mississippi River.

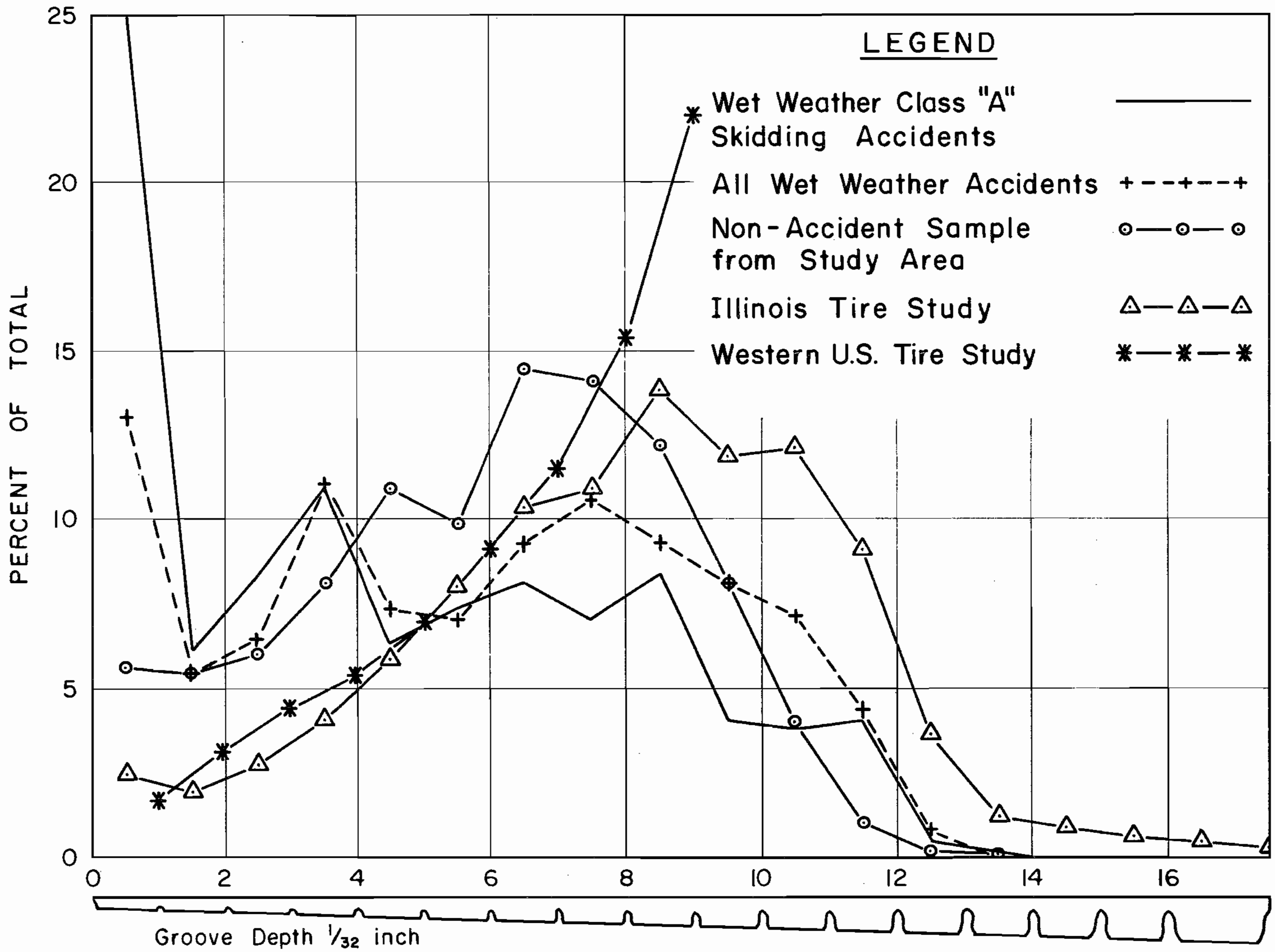
By inspection of the tread depth distributions, it can be seen that the Illinois and Western United States data are quite similar in the tread depth range of 0 to 8/32 of an inch. The distribution representing the non-accident vehicles from the study area is skewed more to the left than either the Illinois or the Western United States distributions. Here again in the tread depth range of 0 to 1/32 of

TABLE 15. AVERAGE TREAD DEPTH REMAINING
(ALL AUTOMOBILE AND PICKUP TRUCK TIRES)

LEGEND: 1. Wet weather class "A" skidding accidents
2. Wet weather - all skidding accidents
3. All wet weather accidents
4. Non-accident vehicles from study area
5. Illinois tire study

Tread Depth 1/32"	1		2		3		4		5	
	No.	%	No.	%	No.	%	No.	%	No.	%
0-1	91	24.8	101	18.0	114	13.0	64	5.6	161	2.3
1-2	22	6.0	34	6.1	48	5.5	63	5.5	136	1.9
2-3	31	8.4	43	7.7	56	6.4	69	6.0	186	2.7
3-4	40	10.9	61	10.9	97	11.0	93	8.1	283	4.0
4-5	23	6.3	46	8.2	65	7.4	125	10.9	407	5.8
5-6	27	7.4	44	7.8	62	7.0	112	9.8	556	8.0
6-7	30	8.2	47	8.4	82	9.3	164	14.4	718	10.3
7-8	26	7.1	50	8.9	93	10.6	161	14.1	761	10.9
8-9	31	8.4	45	8.0	83	9.4	138	12.1	965	13.8
9-10	15	4.1	28	5.0	71	8.1	92	8.1	827	11.8
10-11	14	3.8	30	5.3	63	7.2	46	4.0	849	12.2
11-12	15	4.1	30	5.3	39	4.4	11	1.0	633	9.1
12-13	2	0.5	2	0.4	6	0.7	2	0.2	262	3.7
13-14	0	0.0	0	0.0	0	0.0	2	0.2	81	1.2
14-15	0	0.0	0	0.0	0	0.0	0	0.0	55	0.8
15-16	0	0.0	0	0.0	0	0.0	0	0.0	50	0.7
16-17	0	0.0	0	0.0	0	0.0	0	0.0	36	0.5
17	0	0.0	0	0.0	0	0.0	0	0.0	18	0.3
Total	367	100.0*	561	100.0*	879	100.0	1142	100.0*	6984	100.0*

*Details may not add to totals due to rounding.



AVERAGE TREAD DEPTH REMAINING - ALL TIRES

FIGURE 21

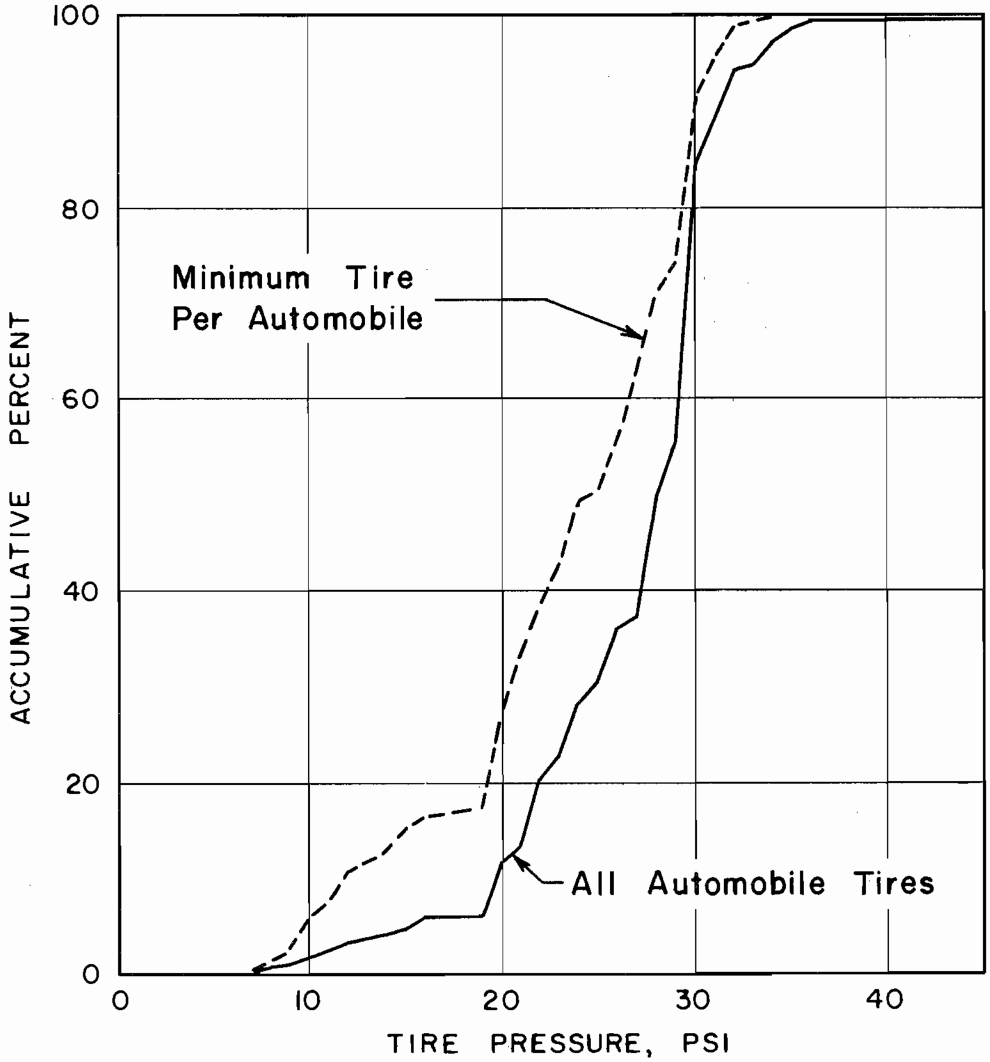
an inch, the frequency is higher for wet weather accidents and especially class A skidding accidents than for any of the other data.

Skid resistance is affected by tire inflation pressure. Wet conditions accentuate this effect since it is known that low inflation pressures make hydroplaning possible at lower speeds providing the depth of the water layer is constant (Ref 12). Although inflation pressure was not a major consideration in the overall analysis, skid resistance was felt to be an important factor influencing class A skidding accidents; therefore, inflation pressures were investigated for this accident category.

Inflation pressures for all automobile tires and for the minimum tire pressure per automobile are listed in Table 16. The cumulative-frequency distributions are illustrated in Figure 22. The tires were assumed to be "cold" when pressure measurements were made. Little was known as to the proper inflation pressure since this depends on the tire load and information of this type was not available. It is noted, however, that 28 and 50 percent, respectively, of all tires and the minimum tire pressure per vehicle were at or below 24 psi which would normally be a minimum operating pressure. Also, the pressures did range as low as 8 psi. With pressures ranging as low as 8 psi there is reason to suspect that some tires could have lost pressure resulting from damage during the accident.

TABLE 16. AUTOMOBILE TIRE INFLATION PRESSURE
CLASS "A" SKIDDING ACCIDENTS

Tire pressure (psi)	All automobile tires		Minimum tire pressure per automobile	
	Number	Cumulative percent	Number	Cumulative percent
8	1	0.3	1	1.1
9	1	0.6	1	2.2
10	3	1.5	3	5.4
11	2	2.1	2	7.5
12	3	3.0	3	10.8
13	2	3.6	1	11.8
14	1	3.9	1	12.9
15	2	4.5	2	15.1
16	3	5.5	1	16.2
17	0	5.5	0	16.2
18	1	5.8	0	16.2
19	1	6.1	1	17.2
20	18	11.5	9	26.9
21	7	13.7	6	33.4
22	22	20.4	5	38.7
23	8	22.8	4	43.0
24	18	28.3	6	49.5
25	8	30.8	1	50.6
26	18	36.2	5	56.0
27	4	37.5	0	56.0
28	40	49.7	14	71.0
29	19	55.5	3	74.2
30	95	84.4	16	91.4
31	16	89.3	4	95.7
32	17	94.5	3	99.0
33	2	95.1	0	99.0
34	8	97.5	1	100.0
35	4	98.7	0	100.0
36	2	99.4	0	100.0
37	0	99.4	0	100.0
38	1	99.7	0	100.0
39	0	99.7	0	100.0
40	0	99.7	0	100.0
41	0	99.7	0	100.0
42	0	99.7	0	100.0
43	0	99.7	0	100.0
44	0	99.7	0	100.0
45	1	100.0	0	100.0
Total	328		93	



CUMULATIVE - FREQUENCY DISTRIBUTION
TIRE INFLATION PRESSURE,
CLASS "A" SKIDDING ACCIDENTS

FIGURE 22

Hydroplaning is thought by many to be a major contributor to wet weather skidding accidents. Hydroplaning simply means the vehicle tire actually skis on a film of water. The likelihood of this happening is greater when the pavement has a fine textured surface, the vehicle tires are treadless, the inflation pressure is low, and the vehicle is traveling at high speed.

Each wet weather accident report was reviewed with this possibility in mind. If, according to the report, the vehicle went out of control for no apparent reason, hydroplaning was suspected as contributing to the accident. Forty-two of the 181 wet weather accidents or 23 percent were suspected of hydroplaning. A few others could have been included but driving while intoxicated was thought possibly to have been a contributing cause of the accident. Thirty-six of the 42 or 86 percent of the hydroplaning suspects were included in the class A skidding accident category. In the other six accidents, braking was possibly involved in the vehicle going out of control and thus the accident was classified in one of the other skidding accident categories.

RELATIONSHIP OF SKID RESISTANCE AND TREAD DEPTH TO SKIDDING ACCIDENT RATES

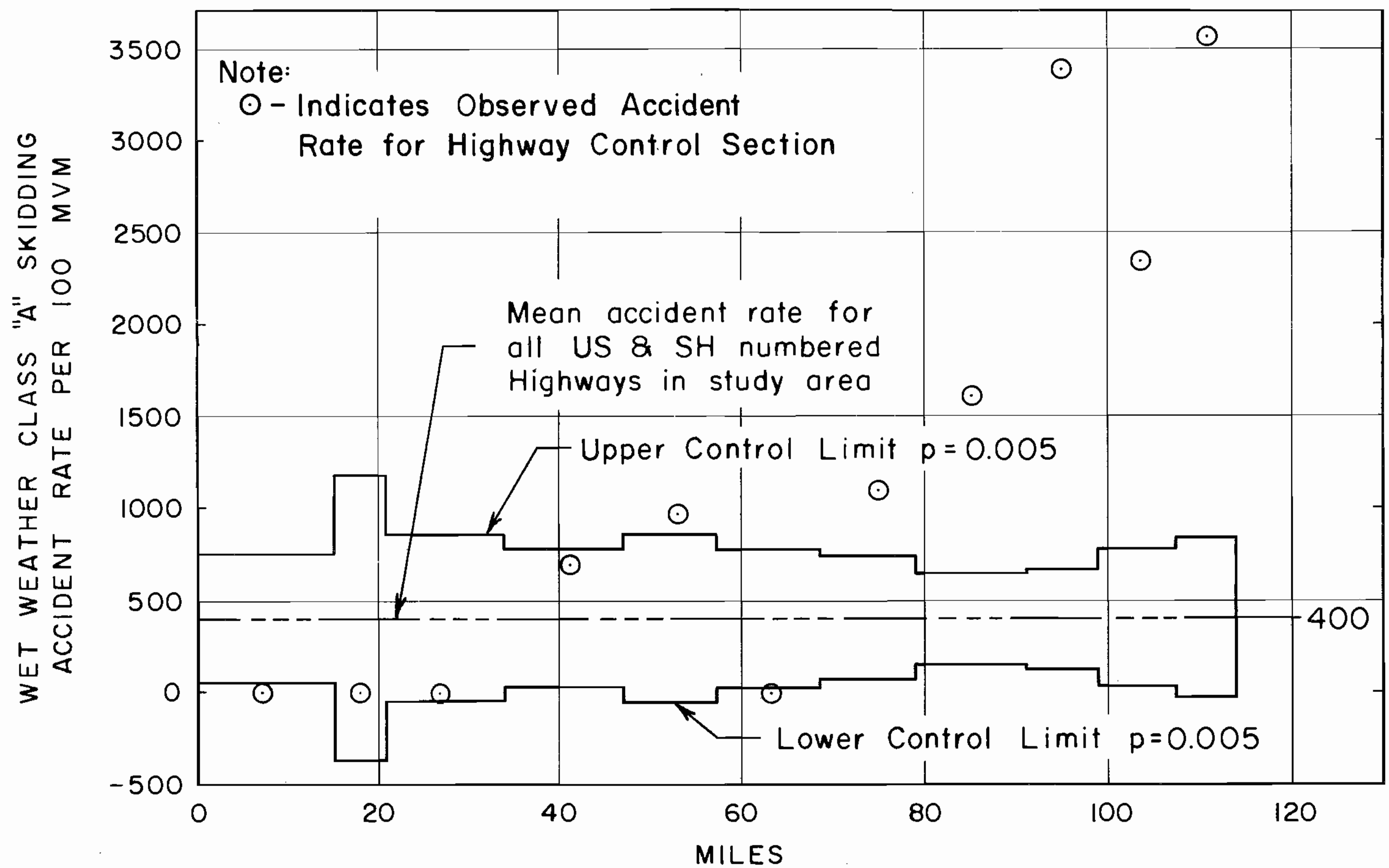
Wet weather accident rates for the four accident categories described on page 34 were determined for each of the 80 control-sections registering wet weather accidents.

Average skid resistance values for each of the accident sites and the tire tread depth per automobile (minimum depth for a single tire, average depth for the rear tires, and average depth for all tires) were also determined.

The accident rates by highway control-sections were plotted versus the respective friction values and tread depths. The scatter of points was such that no meaningful relationship was apparent. The accident rates for individual control-sections did vary considerably which was believed to be partly due to the large variation in vehicle-miles of travel for the various control-sections. The scatter of points was reduced by combining control-sections into longer highway segments with more comparable vehicle-miles of travel. However, a meaningful relationship still did not appear to exist. For this reason, the graphical representation of these analyses are not included in this report. Some relationship may develop with more data. The basic data by control-section, however, are listed in Appendix A.

Another approach, involving a statistical technique, was used to investigate the relationship of skid resistance and tread depth on wet weather accident rates. For this analysis, all US and state numbered highways were grouped together. A total of 96 control-sections having a combined length of 843.9 miles were included. Average wet weather accident rates were determined for each of the four accident categories previously described. Using the control limit technique described on page 39, upper and lower statistical control limits were established for each of the four accident categories for all 96 sections. The observed accident rates are listed in Appendix A and the computed statistical control limits are listed in Appendix B. The overall mean class A skidding accident rate, statistical control limits, and the observed rates for 11 highway control-sections (114.1 miles) on Route A are graphically illustrated in Figure 23. Similar illustrations could be prepared for other highway control-sections from the data listed in Appendices A and B.

The computed statistical control limits, in effect, establish a band or range within which an observed accident rate could be expected to vary from the average due to chance alone. In other words, if the observed rates fall above the upper control limit or below the lower control limit, those sections should be investigated to determine what is unusual about them. Along this line, tread depth and skid resistance values were analyzed for all class A skidding accidents contributing to the observed rates falling above the upper statistical control limit. Most of the sections that fell below the lower control limit had zero accident rates and thus not enough data were available for comparison with sections having observed rates above the upper control limit. Therefore, the tread depth and skid resistance data for the control-sections with observed rates above the upper control limits were compared with all of the tread depth and skid resistance data for the class A skidding accident category.



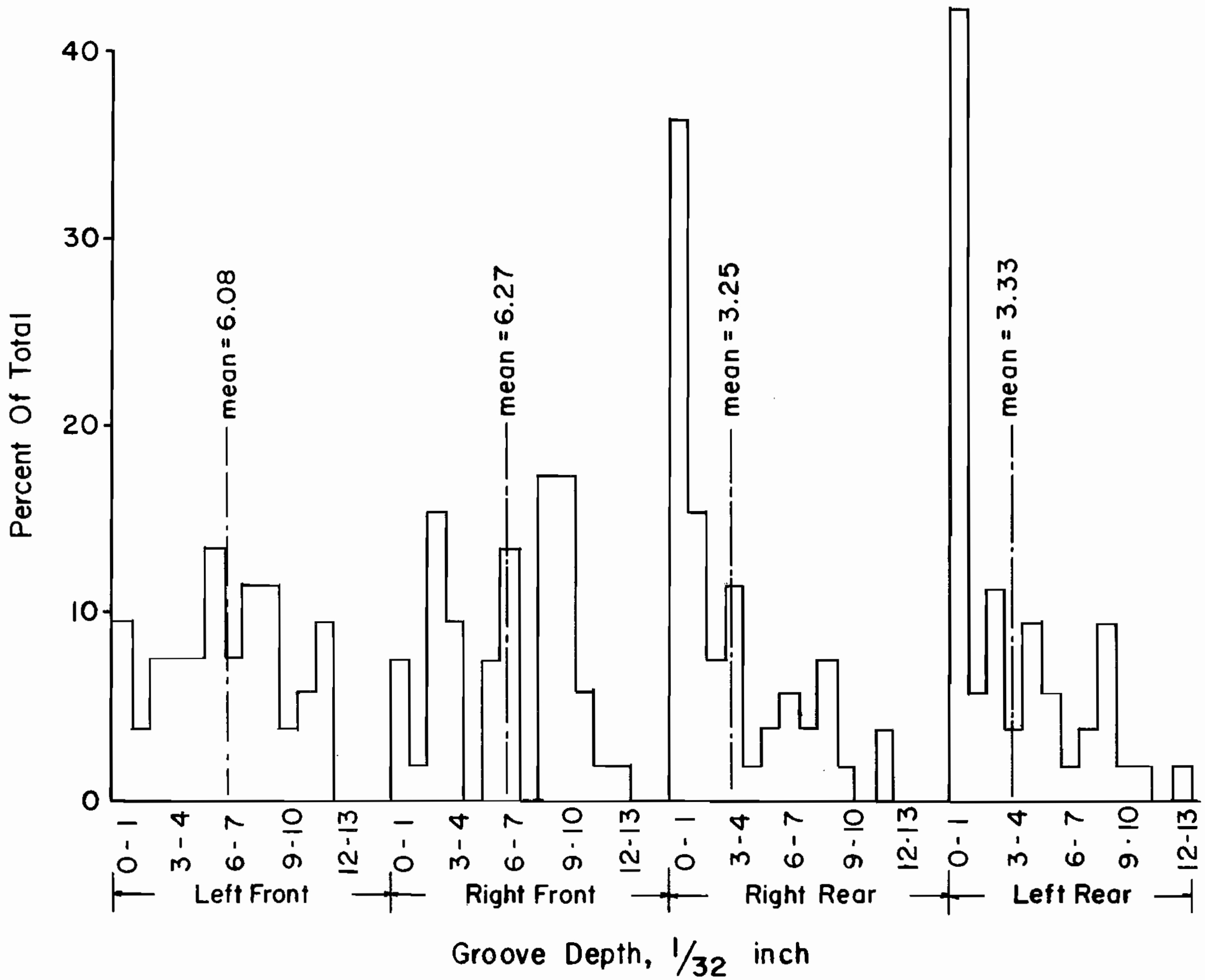
CONTROL LIMITS AND OBSERVED ACCIDENT RATES BY HIGHWAY CONTROL SECTION FOR ROUTE "A"

FIGURE 23

The tread depth distributions and data are shown in Figure 24 and Table 17, respectively. Correspondingly, the skid resistance values are shown in Figure 25 and Table 18. These distributions compare quite well with those shown previously for all class A skidding accidents (Figures 13 and 17 through 20). For the sections with observed rates above the upper limit, the tread depth means for the rear tires were slightly less than, and the means for the front tires were slightly more than, those for all class A skidding accidents. The mean coefficient of friction for the sections with rates above the upper limit was somewhat higher than for all class A skidding accidents, 0.370 to 0.348.

A statistical control limit analysis was also made by pavement surface type. The US and state numbered highways were divided into three broad categories of wearing surface: (1) bituminous surface treatment, (2) asphaltic concrete containing lignite slag aggregate, and (3) other types of asphaltic concrete. The observed rates are listed in Appendix A and the computed statistical control limits are listed in Appendix B.

The observed accident rates in all four accident categories were either within the statistical control limit band or below the lower limit except for those sections with lignite slag asphaltic concrete. In fact, in each of the four accident categories, the observed rates for lignite slag sections were approximately double the respective overall averages



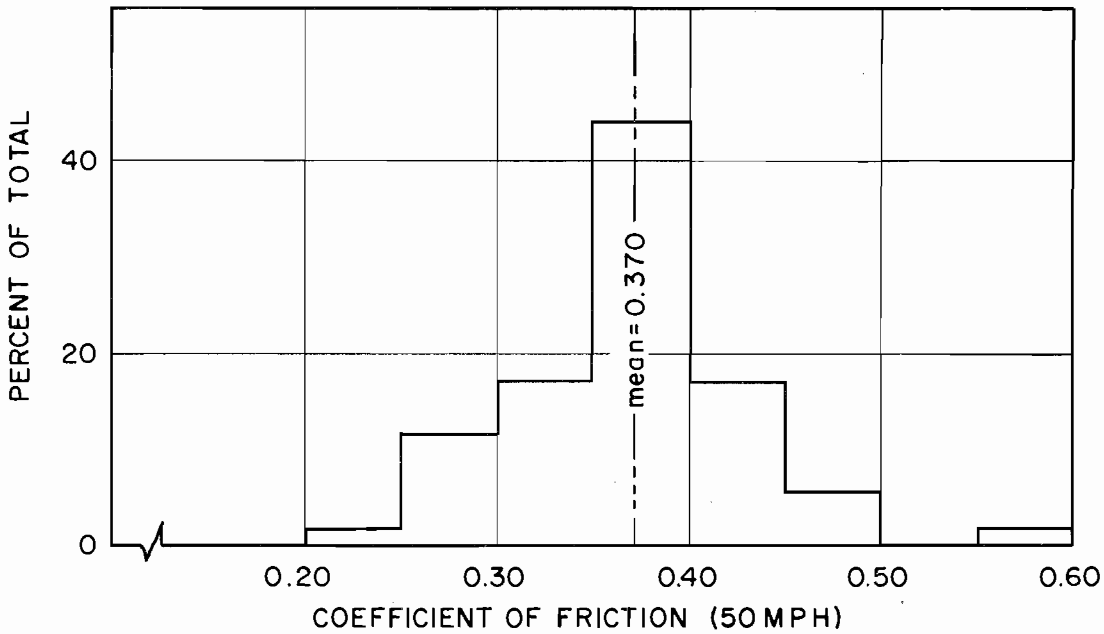
TREAD DEPTH REMAINING - CLASS "A" SKIDDING ACCIDENTS FOR SECTIONS WITH RATE ABOVE UPPER CONTROL LIMIT

Figure 24

TABLE 17. TREAD DEPTH REMAINING - CLASS "A" SKIDDING ACCIDENTS FOR SECTIONS WITH ACCIDENT RATES ABOVE UPPER STATISTICAL CONTROL LIMIT

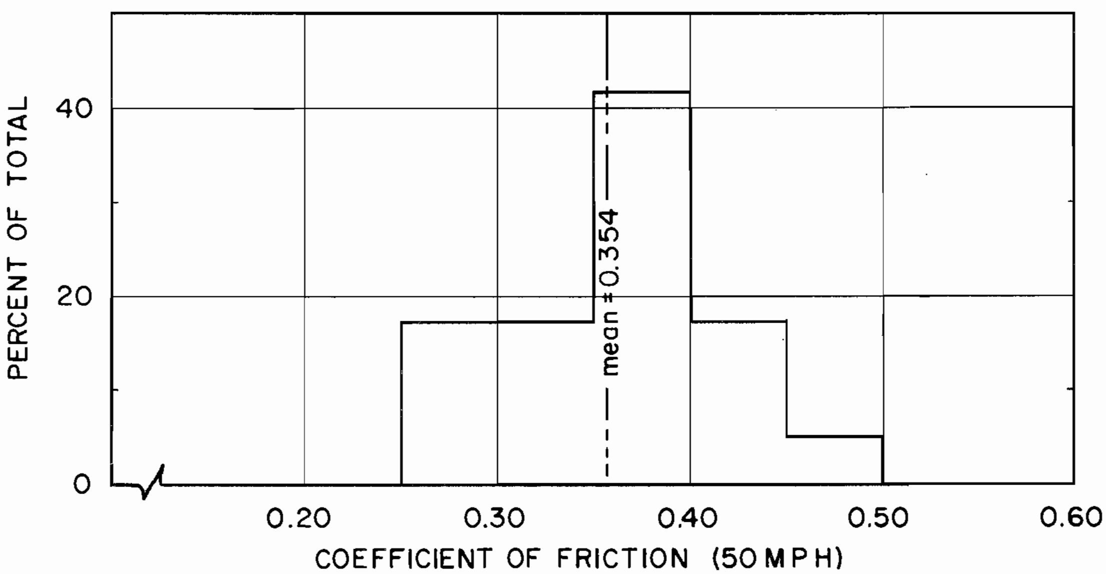
Tread Depth 1/32"	Left Front		Right Front		Right Rear		Left Rear	
	No.	%	No.	%	No.	%	No.	%
0-1	5	9.6	4	7.7	19	36.5	22	42.3
1-2	2	3.8	1	1.9	8	15.4	3	5.8
2-3	4	7.7	8	15.4	4	7.7	6	11.5
3-4	4	7.7	5	9.6	6	11.5	2	3.9
4-5	4	7.7	0	0	1	1.9	5	9.6
5-6	7	13.5	4	7.7	2	3.9	3	5.8
6-7	4	7.7	7	13.5	3	5.8	1	1.9
7-8	6	11.5	0	0	2	3.9	2	3.9
8-9	6	11.5	9	17.3	4	7.7	5	9.6
9-10	2	3.9	9	17.3	1	1.9	1	1.9
10-11	3	5.8	3	5.8	0	0	1	1.9
11-12	5	9.6	1	1.9	2	3.8	0	0
12-13	0	0	1	1.9	0	0	1	1.9
Total	52	100.0*	52	100.0*	52	100.0*	52	100.0*

*Details may not add to totals due to rounding.



AVERAGE FRICTION AT CLASS "A" SKIDDING ACCIDENT SITES FOR SECTIONS WITH RATES ABOVE UPPER CONTROL LIMIT

FIGURE 25



AVERAGE FRICTION AT CLASS "A" SKIDDING ACCIDENT SITES FOR SECTIONS WITH LIGNITE SLAG WEARING COURSE

FIGURE 26

TABLE 18. AVERAGE COEFFICIENTS OF FRICTION AT ACCIDENT SITES - CLASS "A" SKIDDING ACCIDENTS

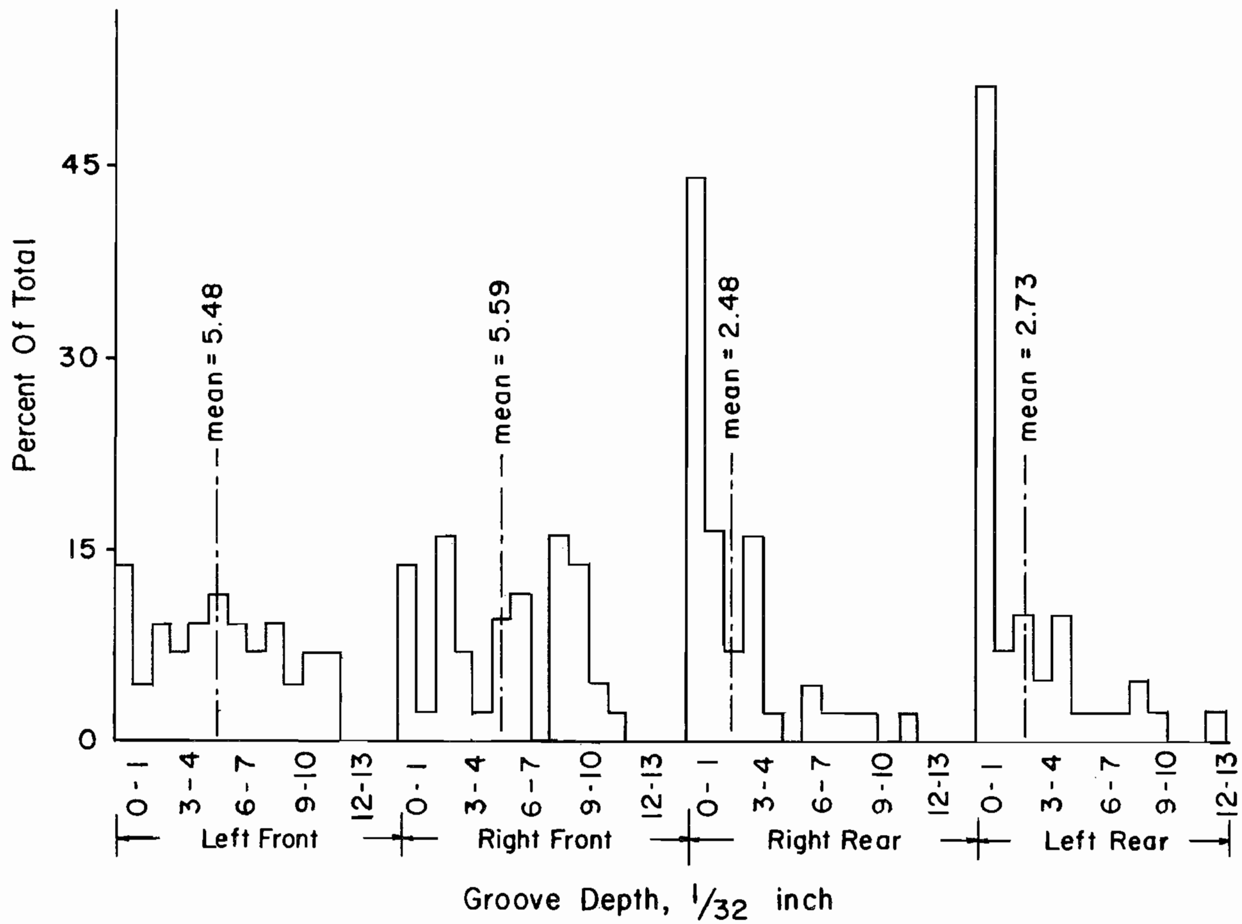
Coefficient of friction (50 mph)	Sections with accident rates above upper statistical control limit		Sections with predominant wearing course composed of lignite slag	
	Number	Percent	Number	Percent
0.20-0.24	1	1.9	0	0
0.25-0.29	6	11.6	7	17.5
0.30-0.34	9	17.3	7	17.5
0.35-0.39	23	44.2	17	42.5
0.40-0.44	9	17.3	7	17.5
0.45-0.49	3	5.8	2	5.0
0.50-0.54	0	0	0	0
0.55-0.59	1	1.9	0	0
Total	52	100.0	40	100.0

for the entire 844 miles of highways. On the other hand, the rates for the other two surface types were below the average in each of the four accident categories.

Since lignite slag asphaltic concrete was the only surface type with observed accident rates above the upper control limits, tread depth distributions were determined for class A skidding accidents occurring on sections with lignite slag asphaltic concrete. The distributions are shown in Figure 27 and Table 19. Upon inspection it can be seen that the mean tread depth for each tire is considerably below the overall mean for class A skidding accidents (Figures 17 through 20). In fact, the mean of each of the rear tires is approximately 1/32 of an inch less than the overall mean for rear tires in the same accident category.

The distribution of accident site coefficients of friction for class A skidding accidents occurring on lignite slag sections is shown in Figure 26 and Table 18. The mean value is slightly above the overall mean for class A skidding accidents, 0.354 to 0.348. This is not too surprising because lignite slag asphaltic concrete surfaces, although fine textured, are generally abrasive or gritty.

Skid resistance values can be fairly high on fine textured, gritty surfaces such as lignite slag asphaltic concrete. However, the combination of water, high speed, and lack of tire tread causes a reduction in the effective skid resistance. Also, under this combination of conditions, hydroplaning would be more likely.



TREAD DEPTH REMAINING - CLASS "A" SKIDDING ACCIDENTS FOR SECTIONS WITH LIGNITE SLAG WEARING COURSE

Figure 27

TABLE 19. TREAD DEPTH REMAINING - CLASS "A" SKIDDING ACCIDENTS FOR SECTIONS WITH PREDOMINANT WEARING COURSE COMPOSED OF LIGNITE SLAG

Tread Depth 1/32"	Left Front		Right Front		Right Rear		Left Rear	
	No.	%	No.	%	No.	%	No.	%
0-1	6	14.0	6	14.0	19	44.2	22	51.2
1-2	2	4.6	1	2.3	7	16.3	3	7.0
2-3	4	9.3	7	16.3	3	7.0	4	9.3
3-4	3	7.0	3	7.0	7	16.3	2	4.6
4-5	4	9.3	1	2.3	1	2.3	4	9.3
5-6	5	11.6	4	9.3	0	0	1	2.3
6-7	4	9.3	5	11.6	2	4.6	1	2.3
7-8	3	7.0	0	0	1	2.3	1	2.3
8-9	4	9.3	7	16.3	1	2.3	3	7.0
9-10	2	4.6	6	14.0	1	2.3	1	2.3
10-11	3	7.0	2	4.6	0	0	0	0
11-12	3	7.0	1	2.3	1	2.3	0	0
12-13	0	0	0	0	0	0	1	2.3
Total	43	100.0*	43	100.0*	43	100.0*	43	100.0*

*Details may not add to totals due to rounding.

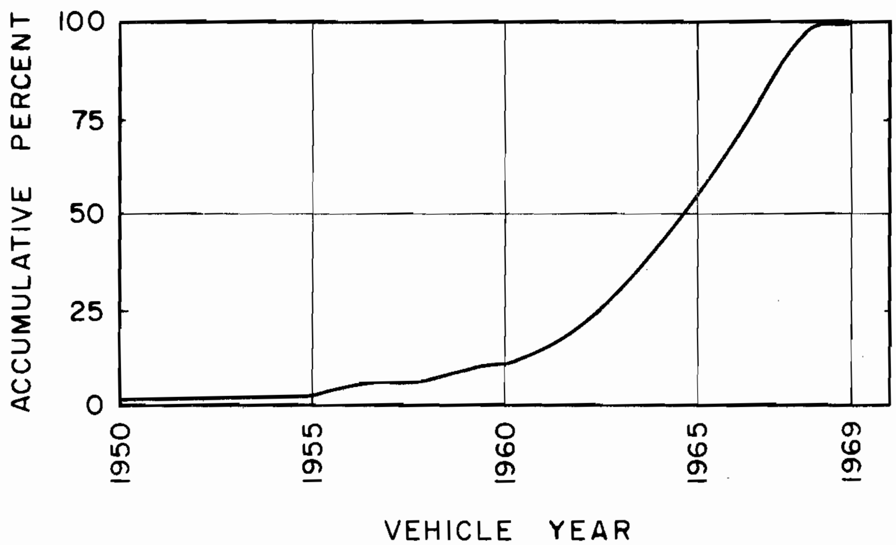
It was previously mentioned that hydroplaning was suspected in 42 of the 181 wet weather accidents. Thirty-one of these occurred on the 834 miles of US and state numbered highways. Five of the 31, or 16 percent occurred on "other asphaltic concrete" pavements whereas this pavement category constituted 20 percent of the 834 miles and carried 31 percent of the daily vehicle-miles of travel. Three of the 31 or 10 percent occurred on sections with bituminous surface treatment wearing courses which accounted for 55 percent of the mileage and 43 percent of the vehicle-miles of travel. Lignite slag asphaltic concrete surfaces registered 23 of the 31 or 74 percent of the accidents suspected of hydroplaning. Lignite slag surfaces accounted for 25 percent of the mileage and 26 percent of the 1,852,094 daily vehicle-miles of travel considered.

MISCELLANEOUS

Thirty-nine percent of the accident vehicles had power steering and thirty-six percent had power brakes. This did not include vehicles which were involved in accidents while stopped. The percentage having power steering was somewhat below the national statistics for factory equipped vehicles. From 48 to 75 percent of 1963 through 1967 vehicles were equipped with power steering at the factory (Ref 1). Correspondingly, 27 to 39 percent were factory equipped with power brakes (Ref 1).

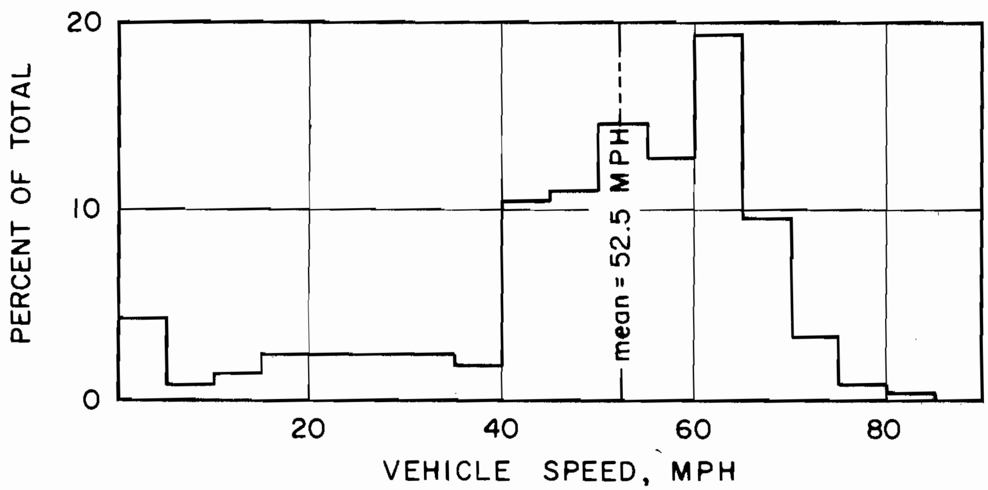
Male drivers accounted for 74 percent of the wet weather accidents. No information was available concerning driver age. Sixty-nine percent of the wet weather accident vehicles were 1966 models or older. The cumulative-frequency distribution of accident vehicles by model year is shown in Figure 28. The speed distribution for all accident vehicles is shown in Figure 29. The mean accident speed (based on the estimated speed reported) was 52.5 mph. This seems quite high since it includes several vehicles which were involved in accidents while stopped.

The frequency of wet weather accidents was highest between 4 and 6 p.m. as indicated in Figure 30. Of course the traffic volumes were also likely to be highest during these hours even though the study area was primarily rural in nature. The rainfall distribution was quite uniform on an hourly basis for the five month period as shown in Figure 30. Figure 31 shows the frequency of wet weather accidents and wet time for each of the five months included in the study period. The percentage of accidents and wet time by months are in comparable proportions except for August and September. Only 2 percent of the wet time was registered in August whereas 10 percent of the wet weather accidents occurred during that month. During September 33 percent of the wet time and 19 percent of the accidents were recorded.



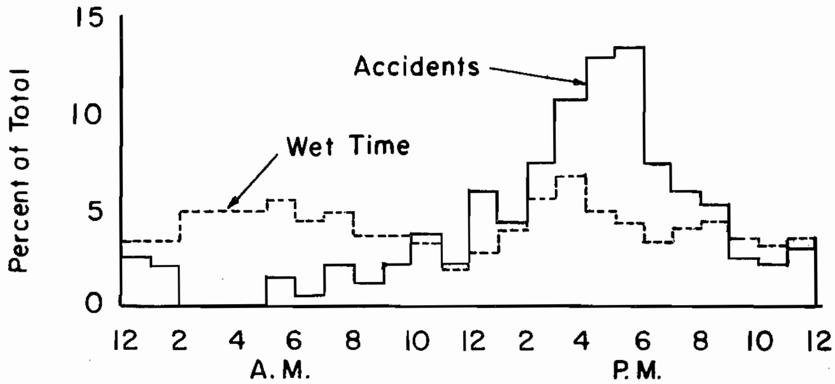
DISTRIBUTION OF ACCIDENT VEHICLES BY YEAR

FIGURE 28



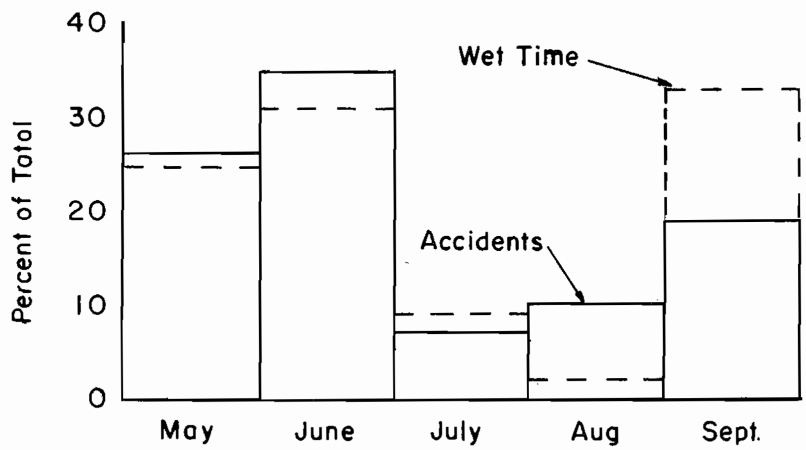
SPEED DISTRIBUTION FOR ALL ACCIDENT VEHICLES

FIGURE 29



DISTRIBUTION OF WET WEATHER ACCIDENTS AND WET TIME BY HOUR OF THE DAY

Figure 30



DISTRIBUTION OF WET WEATHER ACCIDENTS AND WET TIME BY MONTHS

Figure 31

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Considering all of the accidents recorded within the study area for the 5-month study period in 1968 (May-September), the various rates were quite comparable to those experienced for the same area during 1967. However, for the 5-month study period, rates on the basis of wet weather were much higher. Fatality, fatal accident, fatal plus injury accident, and total accident rates during wet weather were approximately 4, 2, 1½, and 2 times greater than the respective rates for all weather conditions combined. The same ratios can also be expressed in another way. Approximately 25, 15, 11 and 14 percent of the fatalities, fatal accidents, fatal plus injury accidents, and total accidents, respectively, occurred under wet weather conditions; whereas the pavement was estimated to be wet only 6.7 percent of the time. These relative comparisons are thought to show some indication as to the influence of wet conditions on traffic accidents.

Statistically the skid resistance values representing the actual sites of the wet weather accidents were significantly lower than the values representing the vicinities approximately one-half mile in each direction from the accident sites. This showed up with only 0.02 difference in the mean values. Providing that inadequate skid resistance was the primary cause of the average wet weather accident, one question becomes readily apparent. Was this slight difference in the mean skid resistance values enough to influence where the average accident actually took place? From a practical standpoint, it would appear that the effects of 0.02 difference in the mean skid resistance values would be very difficult to realize as far as causing the accident to happen at a particular location. It appears that many factors other than skid resistance are also involved.

This is not intended to imply, however, that skid resistance values for the wet weather accident locations should not be a matter for concern. Approximately 25 and 40 percent of the wet weather accident vicinities and sites, respectively, were at or below 0.3 and are therefore in the category where surface improvement should be considered (Ref 17). Likewise, approximately 7 and 15 percent were at or below 0.24 and thus in the category where immediate surface improvement is recommended (Ref 17). Both of these minimums are based on skid test speeds of 50 mph.

Overall, it is quite apparent that the vehicles involved in wet weather accidents, and to a greater extent those involved in the various classes of skidding accidents, were very deficient in tire tread depth. The deficiency is most pronounced for rear tires. This is the case when comparing accident vehicles with non-accident vehicles from the same area. It is even more noticeable when comparing tread depths for wet weather accident vehicles with tread depth data obtained from other parts of the United States. For rear tires in the tread depth range of 0 to 1/32 of an inch, the frequency for skidding accident vehicles in which no braking was apparent (class A) was approximately four to five times higher than for non-accident vehicles from the same area. The ratio dropped to about three and four when considering a tread depth range of 0 to 2/32 of an inch.

Statistical control limits were determined for all highway control-sections on US and state numbered highways. This was done for four categories of wet weather accidents (all wet weather, skidding class A, skidding class A and B combined, and skidding classes A, B, and C combined). Tire tread and skid resistance for all skidding accidents in the class A category, which were associated with sections with observed accident rates falling above the upper statistical control limit, were analyzed separately. The tread depth and skid resistance data for those sections with class A skidding accident rates above the upper limit were quite comparable to the corresponding data for all highway control-sections. Therefore, it does not appear that lack of tread or skid resistance alone were the major reasons for the observed accident rates being above the upper control limit. It is recognized however, that factors other than skid resistance and tread depth could have contributed to the excessively high rates, but they were not included in the analysis.

Statistical control limits were also determined for three broad categories of surface type: (1) bituminous surface treatment, (2) asphaltic concrete containing lignite slag aggregate, and (3) other types of asphaltic concrete. The observed rates for all four wet weather accident categories were above the upper control limits for the sections with lignite slag asphaltic concrete wearing surfaces. Friction values for lignite slag sections in the class A skidding accident category were slightly higher than for all highway control-sections in the same accident category. The mean friction value for class A skidding accident sites on lignite slag sections was 0.354 as compared to a mean of 0.348 for all class A skidding accident sites. Similar comparisons of tire tread depths for class A skidding accidents indicated a considerable difference, especially for rear tires. The mean tread depth for rear tires was approximately 1/32 of an inch less than the overall mean for rear tires in the same accident category.

Hydroplaning was suspected in 23 percent of all wet weather accidents. Eighty-six percent of the suspects were in the class A skidding accident category. Thirty-one of the suspects occurred on US and state numbered highways. Twenty-three or 74 percent of the 31 took place on sections with lignite slag asphaltic concrete surfaces.

Accident causes are recognized to be complex and many factors could be involved. However, tread depth and skid resistance were the main factors considered in analyzing the wet weather accident data. Under wet conditions surface texture and tread depth are very important to skid resistance. Surface texture measurements were not available for analysis but some assumptions were made in this regard. This was the underlying reason for dividing surface type into three categories. Lignite slag asphaltic concrete is generally recognized to have a very fine, gritty or abrasive, texture. On the other hand, bituminous surface treatments are likely to have a coarse texture and "other asphaltic concrete" surfaces are likely to have textures somewhere in between the other two. Of course the texture of the latter two surface types could vary considerably depending on their condition. In general, however, it seems to be a fairly safe assumption that lignite slag surfaces would have the finest texture of the three surface types.

This leads to the tentative conclusion that surface texture, as well as tire tread depth, are very important factors in wet weather accidents. At any rate many of the results seem to indicate this. Lignite slag sections overall registered very high in total wet weather accident rates, wet weather skidding accident rates, and accidents suspected of hydroplaning. Also, vehicles involved in class A skidding accidents on US and state numbered highways with lignite slag asphaltic concrete wearing surfaces had less tire tread, especially on rear tires, than did those vehicles involved in accidents of the same class on all highway control-sections. This tends to combine fine textured surfaces and treadless tires which according to much of the theory regarding skid resistance, is a poor combination under wet conditions.

Overall it is thought that tread depth, and in some instances skid resistance, were deficient. Improvements in both areas are therefore needed:

1. Surface improvements should be initiated at least at all wet weather accident locations registering skid resistance values below the current recommended minimum.
2. Drivers should be made aware of the effect that tire tread depth has on skid resistance under wet conditions. Inclusion of tires in vehicle inspection procedures should help in this respect. Also, serious consideration should be given to establishing a minimum legal tread depth.

The following suggestions are made regarding further research of the tire-pavement factors associated with traffic accidents occurring under wet conditions:

1. Surface texture measurements should be made and analyzed in conjunction with skid resistance and tire factors. This could lead to more definite conclusions as to the effects of surface texture on wet weather accidents.

2. After more accident data become available, the relationship of skidding accident rates to skid resistance, surface texture, and tire tread depth should be further investigated.

3. Inasmuch as only a small difference has been found between skid resistance values at the actual accident site and the vicinities one-half mile in each direction from the sites, consideration should be given to reducing the number of skid tests for future accident investigations. It appears that three skid tests made in close proximity to the actual site of the accident would provide adequate information on skid resistance.

4. It may be worthwhile to examine pavement drainage properties at accident sites where hydroplaning was suspected. The crown or cross-slope of the pavement, possible rutting of the surface, and possible drainage restrictions of the roadway shoulder should be examined.

5. High frequency accident locations should be investigated for possible improvements in geometrics, delineation, signing, and pavement markings.

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APPENDIX A

WET WEATHER ACCIDENT RATES, SKID RESISTANCE, AND TIRE TREAD DEPTH

APPENDIX A - WET WEATHER ACCIDENT RATES, SKID RESISTANCE, AND TIRE TREAD DEPTH

LEGEND: * indicates vehicle which skidded in multiple vehicle accident
S indicates single vehicle accident (Veh. No.)
O indicates non-skidding accident (Acc. Class)
NA indicates data not available
T indicates truck (tire data not used in analysis)

Hwy. Cont. Sect.	Wet Weather Accident Rates per 100 MVM: Total Wet Weather	Skidding Classes A,B,&C	Skidding Classes A&B	Skidding Class A	Acc. No.	Coefficient of Friction: Site Average	1-mile Vicinity Average	Acc. Class	Veh. No.	Tread Depth-Average of Two Measurements per Tire: LF	RF	LR	RR
114-6	493	493	0	0	G1-5	0.47	0.47	C	*2	2.5	3.5	10.0	11.0
									1	NA	NA	NA	NA
265-5	447	447	224	224	G1-6	0.28	0.29	C	*2	4.0	2.0	3.5	4.0
									1	NA	NA	NA	NA
					G1-8	0.32	0.36	A	*2	8.0	8.0	8.0	8.0
									1	8.0	8.0	6.0	8.0
265-6	3033	3033	2275	2275	G1-1	0.23	0.27	A	S	12.0	11.0	4.5	8.5
					G1-3	0.23	0.25	C	*1	7.5	9.0	2.0	3.0
									2	NA	NA	NA	NA
					G1-4	0.27	0.26	A	*1	6.0	10.0	5.5	9.0
									2	NA	NA	NA	NA
					G1-7	0.37	0.35	A	*2	8.5	10.0	6.0	5.5
									1	7.0	6.5	10.0	4.0
321-3	1727	1727	1727	1727	G1-11	0.39	0.37	A	S	8.0	7.0	7.5	6.0
322-1	680	680	0	0	G1-9	0.32	0.33	C	*1	5.5	11.5	5.0	5.5
									2	3.5	4.5	8.5	7.5
472-1	696	696	696	696	G1-2	0.27	0.32	A	S	11.5	11.0	4.5	12.0
571-1	22428	22428	22428	0	G1-10	0.37	0.39	B	S	10.0	11.5	0.5	2.5

49-9	737	737	737	737	B2-34	0.34	0.35	A	S	0.5	1.0	0.5	1.5
50-1	812	812	812	812	B2-33	0.37	0.39	A	S	11.0	11.0	0.0	0.0
50-2	1351	965	965	965	B2-5	0.38	0.39	O	S	2.0	10.5	6.0	0.5
					B2-10	0.39	0.41	A	S	8.0	9.0	0.0	1.0
					B2-11	0.38	0.41	A	S	10.5	11.5	0.0	0.0
					B2-14	0.40	0.39	A	S	5.0	6.0	3.5	4.5
					B2-28	0.43	0.43	O	S	10.0	10.0	10.0	10.0
					B2-31	0.39	0.39	A	S	5.5	2.5	0.0	0.0
					B2-35	0.36	0.36	A	S	10.0	10.0	6.5	6.0
116-4	4522	3768	3392	3392	B2-3	0.36	0.37	O	S	T	T	T	T
					B2-7	0.34	0.35	A	S	3.0	6.0	2.0	0.0
					B2-12	0.36	0.37	A	S	4.0	3.0	0.0	9.0
					B2-13	0.36	0.37	A	S	7.5	7.0	1.5	2.5
					B2-16	0.29	0.32	O	S	T	T	T	T
					B2-17	0.31	0.32	C	*1	11.0	11.0	11.0	11.0
									2	NA	NA	NA	NA
					B2-20	0.31	0.32	A	S	10.0	10.0	1.0	0.0
					B2-21	0.40	0.44	A	S	8.5	8.5	8.5	8.5
					B2-22	0.29	0.32	A	S	0.0	0.0	0.0	2.5
					B2-25	0.34	0.37	A	S	7.0	6.0	3.5	3.0
					B2-26	0.31	0.32	A	S	5.5	4.0	4.0	3.5
					B2-29	0.38	0.37	A	S	9.0	9.0	0.0	0.0
117-1	2935	2935	2348	2348	B2-6	0.38	0.39	A	S	5.0	7.0	2.5	2.5
					B2-18	NA	NA	A	S	6.0	3.0	0.0	0.0
					B2-23	0.36	0.38	A	S	9.0	8.5	1.5	8.0
					B2-27	0.35	0.35	A	S	0.5	2.5	0.0	0.0
					B2-32	0.37	0.37	C	*1	5.5	6.0	0.5	1.5
									2	7.0	7.0	5.0	4.5
									3	8.0	8.0	3.0	3.0
117-2	4483	4483	3587	3587	B2-1	0.40	0.41	A	S	3.5	2.5	0.0	0.5
					B2-4	0.40	0.41	A	S	0.0	0.0	0.0	0.0
					B2-9	0.39	0.40	C	*1	0.0	7.5	0.0	0.0
									2	11.0	11.0	11.0	11.0
					B2-19	0.38	0.39	A	S	7.5	7.0	7.0	7.0
					B2-24	0.36	0.36	A	S	11.5	11.0	2.0	4.5
212-3	1571	1571	1571	1571	B2-36	0.29	0.29	A	S	9.0	9.0	9.0	8.5

506-1	2580	2580	2580	2580	B2-8	0.40	0.40	A	S	4.0	4.0	0.5	0.0
					B2-15	0.34	0.41	A	S	6.0	4.0	0.0	0.0
					B2-30	0.33	0.33	A	S	3.5	9.0	0.0	0.0
1560-2	7811	7811	0	0	B2-2	0.33	0.36	C	1	NA	NA	NA	NA
									*2	7.0	7.0	4.0	4.0
116-2	1095	1095	1095	1095	B3-1	0.41	0.42	A	S	11.5	10.0	3.5	0.5
					B3-13	0.39	0.38	A	S	0.0	9.5	7.5	1.5
116-3	2590	1942	1619	1619	B3-5	0.45	0.41	O	1	11.0	11.0	11.0	11.0
									2	T	T	T	T
					B3-6	0.39	0.41	O	S	11.0	10.5	3.0	3.5
					B3-9	0.39	0.41	A	S	11.5	10.0	11.5	12.5
					B3-14	0.46	0.47	C	1	10.0	10.0	9.0	9.5
									*2	9.0	10.0	10.0	9.5
					B3-20	0.43	0.46	A	1	8.0	8.5	8.0	8.0
									*2	3.5	2.5	2.0	1.0
					B3-21	0.34	0.38	A	S	3.0	3.5	3.0	3.5
					B3-22	0.58	0.48	A	S	6.0	2.0	0.0	9.0
					B3-23	0.58	0.48	A	S	5.0	6.0	4.0	4.5
186-2	1237	824	824	412	B3-3	0.29	0.30	A	1	8.5	10.0	7.5	8.0
									*2	2.0	5.0	4.0	0.0
					B3-7	0.37	0.36	B	*1	4.0	5.0	5.0	3.0
									2	NA	NA	NA	NA
					B3-18	0.36	0.35	O	S	9.5	10.0	9.5	1.5
186-3	965	241	241	0	B3-11	0.30	0.32	B	S	1.0	2.5	2.0	2.5
					B3-15	NA	NA	O	S	4.0	11.5	3.0	3.0
					B3-16	NA	NA	O	1	10.0	10.0	9.5	9.0
									2	6.0	7.5	6.5	7.0
									3	10.0	11.0	9.5	10.0
					B3-17	0.35	0.34	O	S	6.5	10.0	3.0	0.5
186-4	3816	1908	1908	1908	B3-2	0.36	0.38	O	S	5.5	6.0	8.5	4.5
					B3-4	0.38	0.38	A	S	1.5	0.0	4.5	5.0
457-1	1218	1218	1218	1218	B3-10	0.31	0.34	A	S	8.0	6.0	5.5	6.0
506-2	3179	0	0	0	B3-19	NA	NA	O	1	8.0	6.5	7.0	7.5
									2	8.5	8.5	8.0	8.0

648-3	1372	686	686	686	B3-8	0.43	0.39	O	S	1.5	1.0	4.5	11.0
					B3-12	NA	NA	A	S	3.5	4.0	3.5	3.0
29-3	818	409	409	205	G4-3	0.25	0.27	A	S	3.5	3.0	0.0	0.0
					G4-4	0.33	0.30	B	S	6.0	4.5	5.0	5.0
					G4-7	0.25	0.30	O	1	2.0	4.0	4.0	3.5
									2	11.0	9.0	9.0	10.5
					G4-8	0.25	0.30	O	1	12.0	8.0	9.0	8.0
									2	7.0	7.0	7.0	7.0
									3	T	T	T	T
152-2	809	405	0	0	G4-5	0.29	0.31	C	1	9.0	9.0	6.0	2.0
									*2	8.0	4.5	4.0	9.0
					G4-9	0.36	0.37	O	1	7.0	7.0	4.0	4.0
									2	2.0	4.0	7.0	1.0
152-3	308	0	0	0	G4-6	0.17	0.21	O	1	7.0	7.0	1.0	4.0
									2	5.0	5.0	2.0	4.0
					G4-2	0.19	0.21	O	S	10.0	10.0	10.0	10.0
286-2	601	0	0	0	G4-1	0.34	0.33	O	S	10.5	9.5	5.5	7.0
384-1	784	784	0	0	G4-10	0.21	0.26	C	*1	9.0	7.5	11.0	7.5
									2	10.0	7.0	8.0	8.5
16-2	111	56	56	56	A5-3	0.49	0.49	A	1	6.0	5.0	10.0	10.0
									*2	0.0	0.0	0.0	0.0
					A5-6	0.43	0.39	O	1	5.0	4.5	8.5	8.5
									2	8.0	8.0	8.0	8.0
16-16	3436	0	0	0	A5-2	0.29	0.50	O	S	NA	NA	NA	NA
366-1	798	0	0	0	A5-5	0.33	0.36	O	S	8.0	8.0	9.0	8.0
1754-2	12500	12500	12500	6250	A5-1	0.48	0.49	A	S	6.0	8.0	4.0	4.0
					A5-4	NA	NA	B	S	1.0	6.0	11.0	11.0
114-7	234	234	0	0	B6-4	0.41	0.43	C	1	4.5	9.0	4.5	7.0
									*2	4.0	9.5	6.0	6.5
116-1	1462	1462	0	0	B6-1	0.30	0.32	C	1	10.5	4.0	7.5	4.0
									2	11.0	11.0	11.0	11.0
									*3	8.0	8.0	8.0	5.5

					B6-2	0.30	0.32	C	1 *2	7.0 7.5	7.0 8.0	8.0 4.0	8.0 8.0
473-2	979	979	979	979	B6-3	0.38	0.37	A	S	7.5	6.5	2.5	1.5
185-4	342	342	342	342	B7-1	0.29	0.31	A	S	0.0	0.0	0.0	0.0
204-8	1018	509	0	0	B7-4 B7-5	0.21 0.24	0.23 0.25	O C	S *1 2	12.0 11.0 T	11.0 10.5 T	0.0 6.5 T	11.0 6.5 T
210-1	1082	1082	1082	0	B7-3	0.36	0.31	B	S	6.5	6.0	4.5	4.0
211-1	883	883	0	0	B7-2	0.47	0.49	C	1 *2	11.0 8.0	11.0 6.0	9.0 5.0	9.0 5.0
49-6	485	242	242	242	B8-3 B8-8	NA 0.28	NA 0.28	O A	S S	3.5 2.5	2.5 0.5	3.5 1.0	3.5 0.0
49-7	1034	1034	1034	1034	B8-9 B8-13	0.39 0.39	0.40 0.39	A A	1 *2 1 *2	NA 3.0 NA 7.0	NA 2.5 NA 9.5	NA 0.5 NA 1.0	NA 0.5 NA 0.0
49-8	1093	1093	1093	875	B8-1 B8-2 B8-5 B8-15 B8-16	0.31 0.28 0.26 0.29 0.27	0.31 0.29 0.29 0.30 0.32	A B A A A	S *1 2 S S *1 2	NA 9.5 NA 5.0 6.5 5.5 NA	NA 8.0 NA 7.0 6.5 4.0 NA	NA 10.0 NA 2.0 0.0 4.0 NA	NA 7.5 NA 0.0 0.0 0.0 NA
205-1	1174	1174	1174	1174	B8-6 B8-7	0.45 0.41	0.46 0.44	A A	S S	6.5 8.5	9.0 8.5	10.0 2.5	10.0 1.0
205-2	759	759	759	380	B8-10 B8-11	0.45 0.47	0.46 0.50	A B	S S	10.5 12.0	10.0 12.0	1.5 5.0	2.0 4.0
262-3	1557	1557	1557	1557	B8-14	0.32	0.36	A	S	0.0	2.5	7.0	4.5
540-1	1677	1677	1677	0	B8-4	0.31	0.39	B	S	12.0	12.0	4.5	2.0
648-1	1343	1343	1343	0	B8-12	0.28	0.30	B	S	1.5	4.0	2.0	2.0

15-11	1034	1034	1034	0	A9-1	0.30	0.30	B	*1	8.0	8.0	4.5	7.0
									2	NA	NA	NA	NA
15-13	200	200	0	0	A9-42	0.47	0.45	C	1	7.0	6.0	4.0	4.0
									*2	0.5	3.0	4.0	0.0
16-1	1251	750	250	250	A9-23	0.40	0.40	O	1	8.5	9.0	3.5	5.5
									2	8.0	8.0	7.0	7.0
					A9-30	0.36	0.37	A	S	7.0	7.0	7.0	7.0
					A9-32	0.34	0.36	O	S	9.0	5.5	1.5	2.0
					A9-37	0.39	0.45	C	1	11.5	11.0	7.0	8.5
									*2	11.0	11.0	10.5	11.0
					A9-49	0.32	0.46	C	1	12.0	11.5	10.5	10.5
									*2	5.0	8.0	10.0	9.0
113-8	1158	1158	1158	1158	A9-21	0.33	0.32	A	S	8.0	8.5	9.0	8.0
					A9-39	0.38	0.39	A	S	3.0	3.5	1.5	5.0
					A9-45	0.34	0.35	A	S	11.5	12.5	0.0	0.0
113-9	626	313	0	0	A9-15	0.32	0.33	C	*1	NA	6.5	2.0	6.0
									2	8.0	10.0	9.0	9.0
					A9-47	0.33	0.33	O	S	10.0	10.0	10.0	10.0
114-2	221	0	0	0	A9-7	0.36	0.37	O	1	3.5	3.0	1.5	2.5
									2	2.0	4.0	0.0	4.0
114-3	750	375	0	0	A9-2	0.29	0.29	O	1	NA	5.0	6.0	4.0
									2	NA	1.5	3.5	7.0
					A9-3	0.29	0.29	C	1	NA	NA	NA	NA
									*2	8.0	NA	5.5	7.0
151-6	612	408	408	408	A9-13	0.29	0.33	O	S	T	T	T	T
					A9-25	0.32	0.34	A	S	6.5	6.5	2.5	7.5
					A9-46	0.32	0.34	A	S	8.0	6.0	5.0	7.0
151-9	995	796	597	597	A9-11	0.28	0.30	A	S	7.5	7.0	0.5	0.5
					A9-12	NA	NA	NA	NA	NA	NA	NA	NA
					A9-19	0.30	0.28	A	S	7.0	8.0	9.0	7.0
					A9-38	0.25	0.26	C	*1	5.5	4.5	4.5	6.5
									2	8.5	8.5	8.5	8.5
					A9-43	0.22	0.25	A	S	9.0	8.0	8.0	9.0

152-1	904	904	452	452	A9-6	0.23	0.23	A	S	2.5	5.0	1.0	1.0
					A9-35	0.29	0.29	C	*1	9.0	11.5	11.0	11.0
									2	4.0	1.5	2.0	1.0
					A9-40	0.26	0.24	C	1	4.0	4.0	3.0	3.0
									*2	8.0	8.0	9.0	9.0
					A9-50	0.29	0.29	A	S	9.0	0.0	1.0	0.0
265-2	744	744	372	372	A9-27	0.41	0.38	C	1	0.5	6.0	0.5	2.0
									*2	10.0	10.0	9.0	9.0
					A9-29	0.35	0.41	A	S	3.5	3.0	2.5	3.5
321-2	7616	7616	7616	7616	A9-52	0.48	0.41	A	S	12.0	11.0	11.5	11.0
683-2	1059	1059	1059	1059	A9-9	0.20	0.23	A	S	6.0	5.0	5.0	1.5
					A9-26	0.22	0.21	A	S	8.5	7.0	3.0	4.0
700-3	1932	1380	828	828	A9-4	0.42	0.43	A	S	2.0	4.0	0.0	0.0
					A9-18	0.43	0.43	A	S	5.0	9.0	9.0	0.0
					A9-31	0.40	0.37	O	S	10.5	11.0	6.5	11.0
					A9-33	0.49	0.50	O	S	9.0	9.0	9.0	9.0
					A9-34	0.49	0.50	C	1	10.0	10.0	10.0	10.0
									*2	9.0	9.0	9.0	10.0
									3	12.0	12.0	11.0	12.0
									4	13.0	13.0	13.0	13.0
					A9-36	0.41	0.42	C	*1	5.0	6.5	6.0	6.0
									2	10.0	10.0	10.0	10.0
					A9-48	0.36	0.35	A	S	3.5	1.0	0.0	2.5
757-2	4213	4213	4213	4213	A9-17	0.48	0.52	A	S	5.0	11.0	11.0	11.0
					A9-51	0.32	0.35	A	S	0.0	5.5	NA	3.5
1186-1	1165	1165	582	0	A9-14	0.25	0.44	C	*1	8.0	8.0	8.0	8.0
									2	4.0	1.0	4.0	4.0
					A9-24	0.24	0.29	B	1	NA	NA	NA	NA
									*2	12.0	12.0	12.0	12.0
									3	NA	NA	NA	NA
1378-1	1291	1291	1291	0	A9-20	0.29	0.32	B	S	5.0	8.0	1.0	2.5
1902-1	1775	1775	1775	1775	A9-10	0.32	0.33	A	S	4.0	4.0	4.0	4.0
2100-1	1856	619	619	619	A9-5	NA	NA	NA	NA	NA	NA	NA	NA
					A9-22	NA	NA	O	1	3.5	2.0	5.5	0.0
									2	4.5	5.0	8.5	7.5

					A9-41	0.35	0.41	A	S	12.0	1.0	1.0	1.0
2102-1	1237	619	619	619	A9-16	0.38	0.45	A	1	5.0	4.0	3.5	3.5
									*2	6.5	8.0	7.0	4.0
					A9-28	0.36	0.38	O	S	10.5	10.0	8.0	9.5
15-8	80	0	0	0	G10-2	0.40	0.40	O	S	9.0	10.0	9.0	7.0
15-9	570	488	407	244	G10-14	NA	NA	O	S	3.0	4.0	9.0	6.0
					G10-15	0.21	0.32	A	S	2.0	6.0	1.5	0.0
					G10-16	0.21	0.32	A	S	2.0	4.0	3.0	2.0
					G10-17	0.23	0.26	C	1	8.0	7.0	7.5	6.0
									*2	4.5	6.0	9.0	6.0
					G10-18	0.32	0.36	B	1	NA	NA	NA	NA
									*2	7.0	3.0	2.0	3.0
					G10-19	0.29	0.37	B	S	5.0	7.0	3.0	3.0
					G10-20	0.30	0.34	A	S	4.0	6.0	4.5	4.0
151-4	504	504	0	0	G10-6	0.32	0.33	C	*1	7.0	5.0	4.0	5.0
									2	6.0	7.0	7.0	5.0
151-5	657	438	219	219	G10-1	0.35	0.37	C	1	NA	NA	NA	NA
									*2	11.5	12.0	12.0	12.0
					G10-8	0.49	0.55	O	1	8.0	8.0	8.0	6.0
									2	8.0	8.0	6.0	7.0
					G10-9	0.31	0.37	A	S	0.5	7.0	0.0	0.5
204-1	482	482	482	482	G10-10	0.22	0.30	A	S	2.0	3.0	8.0	8.0
204-2	803	803	803	803	G10-13	0.38	0.40	A	S	5.0	5.0	0.0	0.0
273-4	578	578	578	578	G10-11	0.29	0.43	A	S	7.0	12.0	12.0	12.0
320-3	318	318	318	318	G10-12	0.19	0.29	A	S	7.5	6.0	4.5	0.5
337-2	634	634	634	634	G10-21	0.42	0.44	A	S	11.0	11.0	10.0	10.0
440-2	980	980	980	0	G10-7	0.33	0.36	B	1	8.0	7.0	5.0	5.0
									*2	4.0	4.0	4.0	4.0
836-1	2368	2368	2368	0	G10-5	0.27	0.39	B	S	10.0	7.0	5.5	2.0
1378-2	4871	4871	0	0	G10-3	0.24	0.25	C	1	NA	NA	NA	NA
									*2	7.0	7.0	6.0	3.5

APPENDIX B

COMPUTED STATISTICAL CONTROL LIMITS BY HIGHWAY CONTROL-SECTION (ALL US AND STATE NUMBERED HIGHWAYS IN TEN COUNTY STUDY AREA)

APPENDIX B - COMPUTED STATISTICAL CONTROL LIMITS BY HIGHWAY CONTROL-SECTION (ALL US AND STATE NUMBERED HIGHWAYS IN TEN COUNTY STUDY AREA)

Legend: Four categories of wet weather accidents (mean accident rates are based on 843.9 miles of highways - rates per 100 MVM)

	Mean Accident Rates
1 - All wet weather accidents	700.6
2 - All skidding accidents, classes "A", "B", and "C"	553.1
3 - Skidding accidents, classes "A" and "B"	431.9
4 - Class "A" skidding accidents	400.3

Hwy. Cont. Sect.	Upper Statistical Control limits				Lower Statistical Control limits			
	1	2	3	4	1	2	3	4
471-2	1151	956	790	746	250	151	74	55
471-4	1711	1461	1245	1187	-310	-355	-381	-386
471-5	1290	1080	902	854	111	26	-38	-53
472-1	1189	990	821	775	212	116	43	25
473-2	1285	1076	898	850	116	30	-34	-50
116-1	1202	1001	831	785	199	105	33	15
116-2	1132	938	774	731	269	168	89	70
116-3	1029	846	692	651	372	260	172	149
116-4	1056	870	713	672	345	236	150	129
117-1	1148	953	787	743	253	153	76	57
117-2	1259	1053	877	830	142	53	-13	-29
204-1	1104	914	752	709	297	193	111	91
204-2	1228	1024	852	805	173	82	12	-5
204-3	1172	974	807	762	229	132	57	39

204-4	1029	846	692	651	373	260	172	150
204-5	1208	1007	836	790	193	99	28	10
204-6	982	804	654	615	420	302	209	186
204-7	1226	1023	850	804	175	83	14	-3
204-8	1116	924	762	718	285	182	102	82
204-9	1312	1101	920	872	89	5	-56	-71
205-1	1148	953	787	743	253	153	76	57
205-2	1057	871	715	673	344	235	149	128
50-2	952	777	631	592	449	329	233	208
50-1	1231	1027	854	808	170	79	10	-7
49-9	1204	1003	833	787	197	103	31	13
49-8	969	792	644	605	432	314	220	196
49-7	1119	927	764	721	282	179	99	80
49-6	983	805	656	616	418	301	208	184
186-2	1073	885	727	685	328	221	137	116
186-3	983	805	655	616	418	301	209	185
186-4	1535	1302	1101	1047	-134	-196	-237	-246
185-2	1141	947	782	738	260	159	82	62
185-3	1132	939	775	731	269	168	89	70
185-4	1038	855	700	658	363	252	164	142
186-1	1197	997	827	782	204	109	37	19
152-3	1021	839	685	645	380	267	178	156
152-2	1069	882	724	682	332	224	140	118
152-1	973	796	648	608	428	310	216	192
151-9	956	781	634	595	445	325	230	205
151-6	959	784	637	598	442	322	227	203

151-4	1114	922	760	717	287	184	104	84
151-5	969	792	644	605	432	314	220	196
273-4	1144	949	784	740	257	157	79	60
700-3	1003	823	671	631	398	283	192	169
265-1	1015	834	681	641	386	272	182	160
265-2	1053	868	712	670	348	238	152	130
265-3	1005	825	673	633	396	281	191	168
265-4	1018	836	683	643	383	270	181	158
265-5	972	795	647	607	429	311	217	193
265-6	1212	1010	839	793	189	96	25	8
323-1	1675	1428	1215	1157	-273	-322	-351	-357
322-1	1184	985	816	771	217	121	48	29
321-3	1492	1262	1065	1012	-91	-156	-202	-212
321-2	2496	2177	1896	1820	-1095	-1070	-1032	-1019
321-7	5887	5326	4822	4682	-4486	-4220	-3958	-3881
321-1	1221	1018	846	800	180	88	18	1
320-3	1026	843	689	649	375	263	174	152
209-5	1061	874	717	676	340	232	146	125
210-1	1317	1105	924	875	84	1	-60	-75
211-1	1254	1048	873	826	147	58	-9	-26
211-2	1258	1052	876	829	143	55	-12	-28
211-3	1195	995	825	779	207	111	39	21
211-4	1247	1042	867	820	154	65	-3	-19
211-5	1319	1107	925	877	82	-1	-62	-76
113-7	1009	828	676	636	392	278	188	165
113-8	1071	883	725	683	330	223	138	117

113-9	1023	841	688	647	378	265	176	154
114-2	970	793	645	606	431	313	219	195
114-3	1055	869	713	671	346	237	151	129
114-4	1050	865	709	667	351	241	155	133
114-5	1082	893	734	692	319	213	129	109
114-6	1109	918	756	713	292	188	108	88
114-7	978	801	652	612	423	305	212	188
366-1	1226	1023	850	804	175	83	14	-3
384-1	1221	1019	846	800	180	88	17	0
286-1	1518	1286	1087	1033	-117	-180	-223	-233
286-2	1153	958	792	747	248	148	72	53
286-3	1195	995	825	780	206	111	38	21
287-1	2153	1863	1610	1541	-751	-757	-746	-740
573-2	2389	2079	1807	1733	-988	-973	-943	-932
573-1	1396	1176	987	937	6	-69	-123	-136
151-3	1270	1062	885	838	131	44	-22	-38
337-1	1240	1035	861	815	162	71	3	-14
337-2	1166	969	802	757	235	137	62	43
440-1	1228	1025	852	806	173	81	12	-5
440-2	1286	1077	898	851	115	29	-35	-50
93-8	2310	2007	1741	1668	-909	-901	-877	-868
49-15	1589	1350	1145	1089	-188	-244	-281	-289
262-1	1277	1069	891	844	124	37	-28	-43
262-2	1431	1208	1016	965	-30	-101	-152	-164
262-3	1449	1224	1031	979	-48	-118	-167	-178
382-4	1669	1422	1210	1152	-267	-316	-346	-352

213-3	1453	1227	1034	982	-51	-121	-170	-181
2446-1	2754	2413	2113	2031	-1353	-1307	-1250	-1230
315-5	2342	2036	1768	1694	-941	-930	-904	-894
29-3	960	784	637	598	441	322	227	203
Surf. Type								
Slag asph. conc.	780	624	494	460	621	482	369	340
Other asph. conc.	775	619	490	456	626	487	374	344
Bit. surf. treat.	763	608	481	447	639	498	383	353

Note: Observed accident rates by surface type:

Surf. Type	1	2	3	4
Slag asph. conc.	1316	1037	957	897
Other asph. conc.	572	468	277	277
Bit. surf. treat.	415	317	219	183

Observed accident rates by highway control-section are listed in Appendix A.