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RELATIONSHIPS BETWEEN ROADWAY GEOMETRICS AND ACCIDENTS

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ABSTRACT

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Statewide average and critical rates of accidents were determined from 1970-1972 Kentucky accident records for each type of rural highway. Accident data, obtained from state police computer tapes, were summarized to give the number of accidents on each highway type as well as information on accident severity, road surface conditions, light conditions, road character, and type of traffic control. Four-lane undivided highways had the highest average accident rate; parkways (toll roads) had the lowest rate. The severity of accidents was related to types of accidents, highways, and traffic control and to safety belt usage. Accidents involving pedestrians were the most severe types; single-vehicle accidents ranked next highest in severity. Excluding accidents at railroad crossings, accidents which occurred on curves had the highest severity index. The use of safety belts was associated with reduced severity.

INTRODUCTION

The present criterion used in Kentucky to identify high-accident locations is not specific with respect to type of highway. Intuitively, differences in accident histories should exist; it should be possible to statistically identify or define relationships between the geometrics of a location and its accident history. By noting differences in accident experiences of highway types, benefits realized from a particular change in geometrics could be assessed.

Several high-accident location identification procedures used elsewhere utilize average or critical accident rates *(1, 2)*. A critical rate is determined; rates higher than the critical indicates that a location is hazardous. Through the use of volume and accident data, critical rates for various types of highways can be calculated and used in determining high-accident sites.

Findings presented in this report resulted from a study of accident experience on different highway types encompassing the rural highway system in Kentucky.

PROCEDURE

Accident and traffic volume data were collected for a 3-year period (1970-1972). The accident data were obtained from computer tapes containing all state police reported accidents. Kentucky only recently enacted a uniform accident reporting law, so the state police reports studied were almost exclusively for rural areas. Therefore, only rural accidents were considered. Rural accidents include all accidents occurring in cities with less than 2500 population. Jefferson, Fayette, Campbell, Kenton, and Boone Counties were excluded inasmuch as local police investigate the vast majority of all accidents within those counties.

The volume data were collected from two sources. First, a computer printout was obtained which summarized the number of vehicle miles of travel on different highway types in rural areas. Second, volumes were taken from Kentucky traffic flow maps for those locations which were omitted in the first source.

The rural highway system was divided into the following types of highways:

1) two-lane,
2) three-lane,
3) four-lane undivided,
4) four-lane divided (no access control), and
5) interstate and parkway.

Interstates and parkways was separated into two separate categories for some comparisons.

The accident and volume computer printouts yielded satisfactory information for the "two-lane" and "interstate and parkway" categories. For the remaining three categories, errors were found in the computer information which necessitated manual determination of accident locations. The limited mileage of these highways permitted long-hand manipulation. Once the mileposts were assigned, a computer program was written to obtain accident information. Volumes were obtained from traffic flow maps.

The accident data tape enabled preparation of rather detailed summaries. Accident severity information was obtained as well as information on type of accident, road surface condition, light conditions, road character, and type of traffic control. The information was then summarized by highway type. Also, types of accidents were summarized according to traffic control. Accident severity associated with safety belt usage was studied.

Average critical accident rates per 100 million vehicle miles (MVM) (160 million vehicle kilometers (MVK)) were calculated for each highway type. The following formula was used *(3)*:

$$A_c = A_a + K \sqrt{A_a/M} + M/2$$

where A_c = critical accident rate,

A_a = average accident rate,

K = constant related to level of statistical significance selected (for $P = 0.95$, $K = 1.645$; for $P = 0.995$, $K = 2.576$); and

M = annual 100 million vehicle miles (160 million vehicle kilometers) traveled on a particular highway type.

Critical rates were determined for two probability levels to show the effect the choice of probabili level has on critical rates. Critical accident rates in terms of accidents per mile (kilometer) were determir by multiplying the critical rate by the annual volume.

Each accident was classified according to one of the following types:

1. head-on collision or opposite direction sideswipe,
2. rear-end collision or same direction sideswipe,
3. angle,
4. pedestrian,
5. other collision,
6. single vehicle,
7. fixed object, or
8. other.

Most of the accident types are self-explanatory. "Other collision" refers to collisions with a non-motor vehicle (train, bicycle, and parked car) as well as non-intersection accidents whose directional analysis was not stated. The "other" category refers to accidents involving single vehicles for which the circumstances were not stated.

In some severity comparisons, a term called the severity index *(4)* was used. Severity index was calculated using

$$\text{Severity Index (SI)} = \text{EPDO}/N_t$$

where N_t = total number of accidents,

EPDO = 9.5 (K + A) + 3.5 (B + C) + PDO,

K = number of fatal accidents,

A = number of A-type injury accidents (accidents where an A-type injury was the most severe injury sustained),

B = number of B-type injury accidents,

C = number of C-type injury accidents, and

PDO = number of property-damage-only accidents.

FINDINGS

The average number of accidents, injuries, and fatalities per 100 million vehicle miles (160 million vehicle kilometers) by type of highway is provided in Table 1. Table 2 shows the number of accidents, injuries, and fatalities per mile (1.6 kilometers) per year by type of highway. The fatality rates appear high, but this results from including only rural accidents. Four-lane undivided highways had the highest accident, injury, and fatality rates. This was not surprising since that type of highway is frequently a high volume road with a large number of conflict points. When the number of conflict points is reduced by dividing the roadway, the accident rate exhibits a sharp reduction and the injury and fatality rates declined. Volume on this highway type is similar to the four-lane undivided highway type. With access control and at-grade intersections eliminated on interstates and parkways, the accident rate reaches a minimum. The effect of volume on accident rate can be seen in the difference between interstate and parkway rates. Interstates, which have much higher volumes, have a higher accident rate.

The critical accident rates by type of highway are cited in Table 3. The rates are given in terms of accidents per 100 million vehicle miles (160 million vehicle kilometers) for 1-mile (1.6-kilometer) sections and accidents per mile (1.6 kilometers) per year. Because of low volumes, two-lane highways have the highest critical rate in terms of accidents per 100 million vehicle miles (160 million vehicle kilometers). In terms of accidents per mile (1.6 kilometers) per year, four-lane undivided highways have the highest critical rate. If the accident rate for a particular section of highway exceeds the critical accident rate for that highway type, the section may be considered hazardous. The critical accident rates cited were derived from statewide averages for rural highways. In practice, each roadway section would have its own critical rate based on its volume. A graph can be drawn for each highway type to relate the critical rate to the average daily volume *(5)*. As the volume increases, the critical rate will decrease and finally become nearly constant. The graph would also give critical accident rates for various section lengths.

The percentage of accident types occurring on various highways is shown in Figure 1. Rear-end or same-direction sideswipe accidents were the most frequent type accidents for all highway types as a group. For three-lane, four-lane divided, and four-lane undivided highway types, the rear-end accident was the most common. Single vehicle and rear-end accidents were the most common on two-lane roads. Single-vehicle accidents were the most frequent on interstates and parkways, followed by a significant percentage of rear-end accidents. Two-lane and three-lane highways also had a significant percentage of head-on or opposite-direction sideswipe accidents while four-lane divided and undivided highways had a significant percentage of angle accidents. The percentage of fixed-object accidents appears low. This could have resulted from classifying some fixed-object accidents as single-vehicle accidents.

As volumes increase on interstate highways, the percentage of rear-end accidents increase and the percentage of single-vehicle accidents decrease *(6)*. This was found to be the case when the percentages of these accidents occurring on interstates (high-volume roads) were compared to the parkways (low-volume roads). On parkways, 22 percent of the accidents were rear-end or same-direction sideswipe and 73 percent were single-vehicle accidents (including "fixed object" and "other" accidents). On the higher volume interstates, the percentage of rear-end type accidents increased to 33 percent while the single-vehicle accidents decreased to 59 percent. This relationship should be similar for other types of highways, but accident data were not sufficiently stratified by volume to permit comparisons. Accident rates for each type of accident on each type of highway are given in Tables 4 and 5.

Percentages of accident types for a given traffic control device are presented in Table 6. The data provide a general idea of the effects a change in traffic control would have on the type of accidents occurring. For example, changing from a stop sign to a signal may reduce angle accidents but increase rear-end accidents. Also, by comparing the percentages of the types of accidents occurring at a given location to the statewide averages, an abnormal number of a particular type of accident may be detected.

Table 7 shows the relationship between the severity index and type of accident. Pedestrian accidents had a much higher severity index than any other type of accident. Also, single-vehicle accidents exhibited a high severity index. It was interesting to note the difference in severity between angle and rear-end accidents. By changing from a stop sign to a signal, the severity of the accidents may be decreased because angle-type accidents (which are more severe) usually decrease while the rear-end types increase.

The variation in severity index for the various highway types is given in Table 8. Four-lane divided highways had the lowest severity index of any highway type. Parkway accidents had the highest severity index; this may be attributed to the high percentage of single-vehicle accidents as well as high speeds.

Data in Table 9 again demonstrate the decrease in accident severity when a stop sign is replaced with a signal. Also, the relatively low severity of rear-end accidents was shown by noting that the YIELD sign, which is associated with a very high percentage of rear-end accidents, had the lowest severity index of any traffic control. Accidents at railroad crossings had the highest severity index. Accidents on curves were also severe.

Safety belts have been strongly recommended as a means to reduce severity of traffic accidents. Table 10 provides severity indexes associated with safety belt usage. The severity index formula was modified in order to calculate values for occupants rather than accidents:

$$\text{Severity Index (SI)} = [9.5\ (K + A) + 3.5\ (B + C) + O]/N_t$$

where N_t = total occupants involved in state-police-reported accidents which had safety belt usage indicated,

K = total fatalities,

A = total A-type injuries,

B = total B-type injuries,

C = total C-type injuries, and

O = total occupants who sustained no injuries.

The table shows that the severity index for occupants who used safety belts was much lower (1.66) than for those who did not use safety belts (2.44). This adds further credance to the supposition that safety belt usage can greatly reduce the severity of most accidents. The difference between the severity indexes involving vehicles without safety belts and vehicles equipped with safety belts which were not used was larger than would be anticipated. A higher severity index for occupants in vehicles not equipped with safety belts may be expected since the older vehicles tend to be in worse mechanical condition than the newer cars. Also, some safety features have been added to the newer cars. Still, the large difference was surprising.

It was interesting to note the percentage of vehicle occupants who used safety belts. Of the total vehicle occupancy, six percent used safety belts. Counting only vehicles equipped with safety belts, 11 percent of the occupants were wearing safety belts. This percentage did not change significantly from 1970 to 1972. A total of 44 percent of the occupants were in vehicles not equipped with safety belts while 50 percent of the occupants were in a vehicle which had a safety belt, but it was not used.

The percentage of vehicle occupants injured or killed in relation to safety belt usage is another illustration of the effectiveness of safety belts. Of the occupants who used safety belts, 17 percent received a non-fatal injury while 0.4 percent were fatalities. In contrast, of the occupants who did not use a safety belt, 30 percent received a non-fatal injury while 1.7 percent were fatalities. It should be noted that these percentages pertain to vehicle occupants whose safety belt usage was coded on the accident tape. The percentages showed that a person not wearing a safety belt has approximately twice the probability of being injured and four times the probability of being killed compared to a person who does wear a safety belt.

The average severity index of all rural accidents changed from year to year (Table 11). Accident severity has reduced slightly from 1970 to 1972. This decrease may be attributable to new vehicle safety features and(or) increased traffic volumes which result in lower speeds and, thereby, less severe accidents.

Figure 2 shows the percentage of intersection-related accidents versus type of highway. Four-lane divided and undivided (no access control) highways had the highest percentage of intersection related accidents. The percentage drops drastically when at-grade intersections are eliminated -- as on interstates or parkways.

Figure 3 relates road surface conditions to accidents. Between 20-30 percent of the total accidents occurred during wet-weather conditions. Therefore, if this percentage is greatly exceeded, a remedy such as improved drainage or resurfacing may be necessary. Interstates and parkways had the highest percentage of accidents during snowy or icy conditions. Higher traffic speeds may be a contributing factor.

The percentages of accidents which occurred during daylight and darkness are given in Figure 4. The percentages during darkness varied from 27 to 35 percent. If the percentage on a particular road section significantly exceeds these percentages, lighting may be advisable.

The percentages of accidents on each highway type involving curvature and grade are shown in Figures 5 and 6, respectively. Table 12 cites the percentage of accidents for various highway types versus type of traffic control. Two-lane highways had the highest percentage of accidents which involved curvature. Three-lane highways had the highest percentage of accidents involving grade; this is logical inasmuch as most three-lane highway sections are built to provide a passing lane on long grades.

IMPLEMENTATION

The tables which give rural statewide average accident rates for the various highway types are a means of assessing whether a particular section of roadway is hazardous. More accurate judgments can be made using graphs which relate critical accident rate, volume for each type of highway, section length, and probabilities *(5)*.

The tables and figures which relate type of highway, accident, and traffic control, and severity index are a means of determining if a certain location or section of roadway deviates greatly from the average. Also, the effect of a change in traffic control or geometrics can be estimated. The figures which relate the percentage of accidents to road surface and light condition only provide a set of references for judging normalcy or abnormalcy in other or more specific data sets. The tables and figures presented herein are intended to show rural statewide average conditions which can be useful for comparative purposes. Deviations from the averages can provide indications of the need for remedial action.

Finally, the section of the study dealing with safety belt usage provides quantitative results as to the benefits of using safety belts. The numbers presented are an effective means of illustrating the results of using safety belts.

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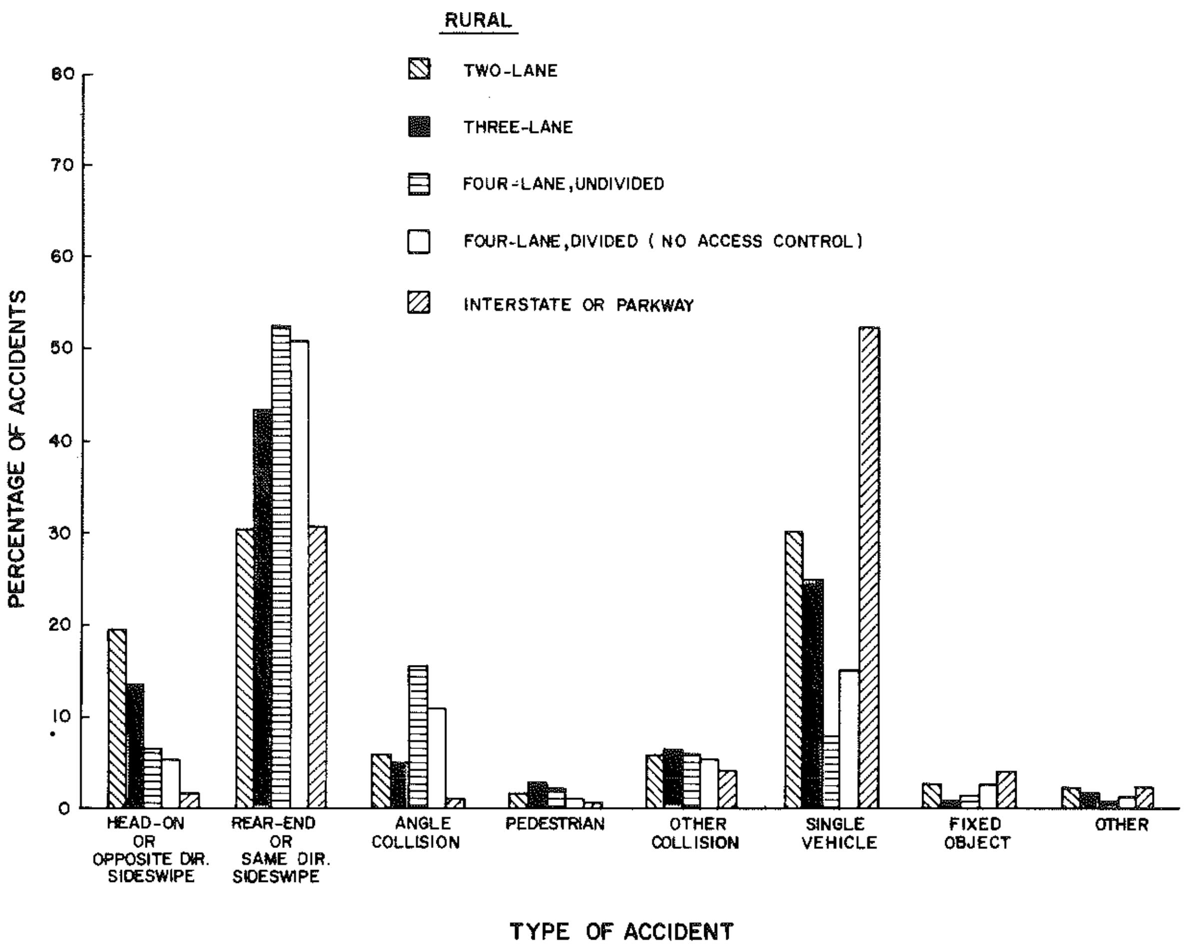

Figure 1. Percentage of Accident Types Occurring on Various Types of Highways.

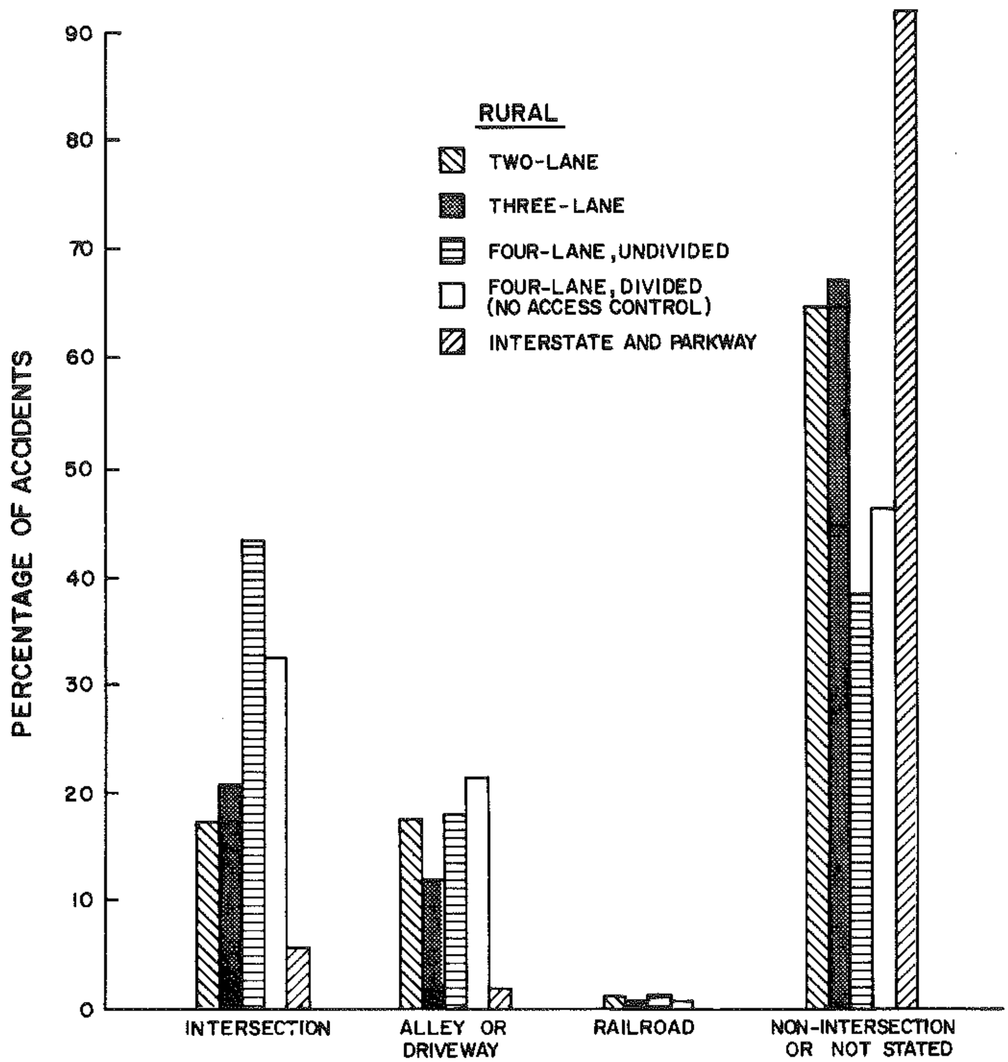

Figure 2. Percentage of Intersection-Related Accidents on Varoius Types of Highways.

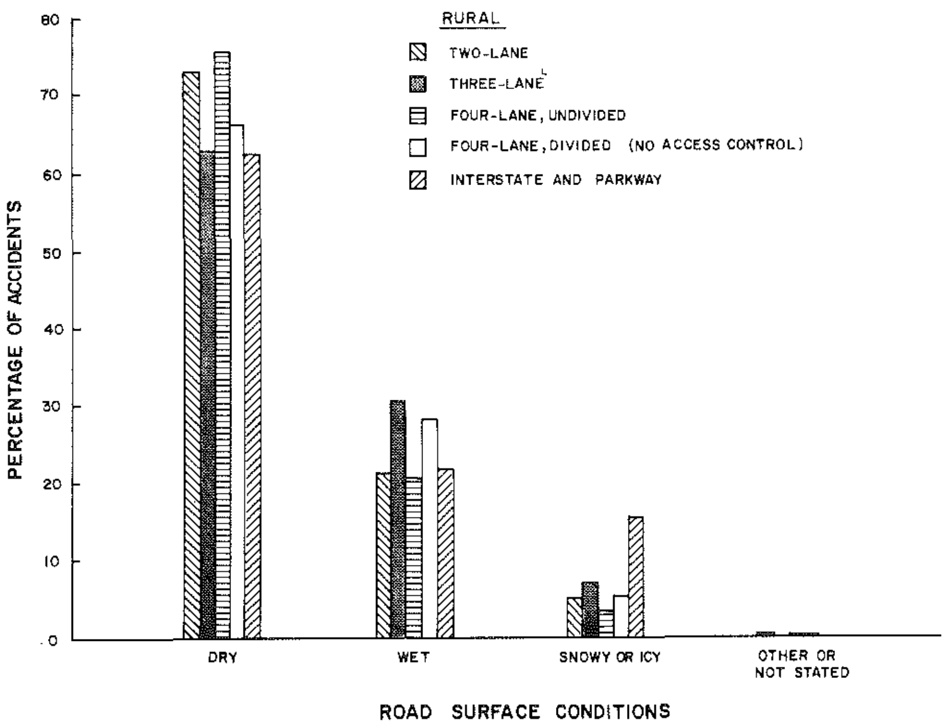

Figure 3. Percentage of Accidents Related to Road Surface Conditions on Various Types of Highways.

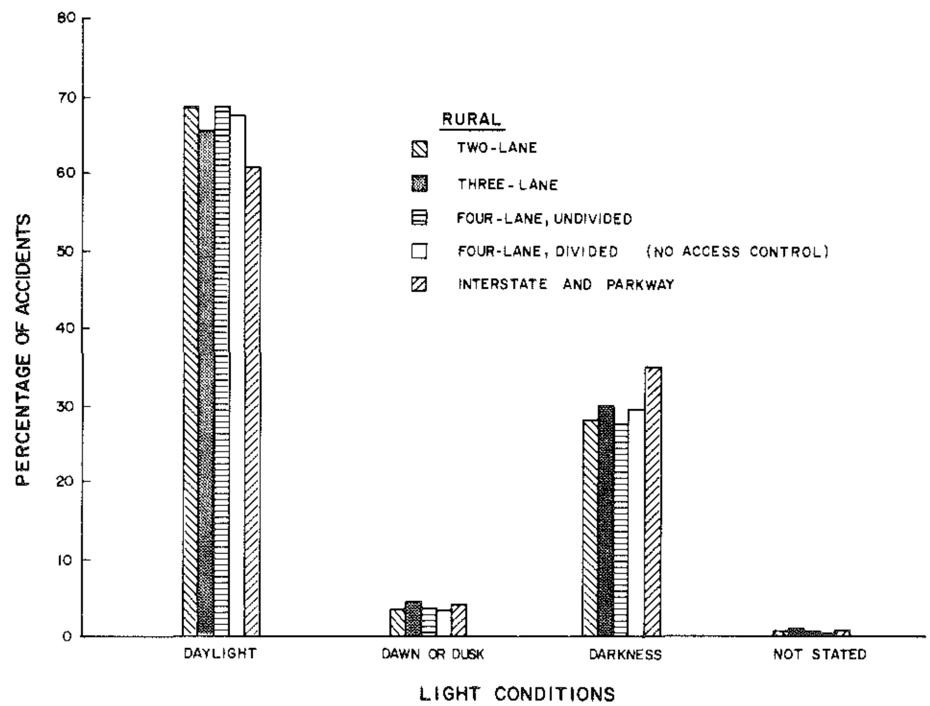

Figure 4. Percentage of Accidents Related to Lighting Conditions on Various Types of Highways.

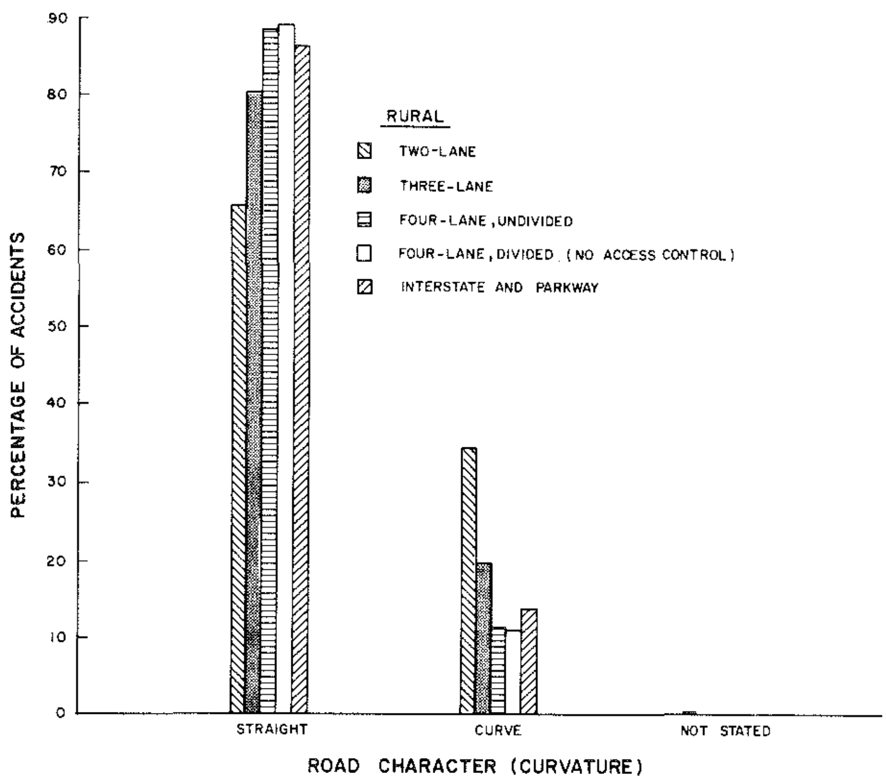

Figure 5. Percentage of Accidents Related to Horizontal Alinement on Various Types of Highways.

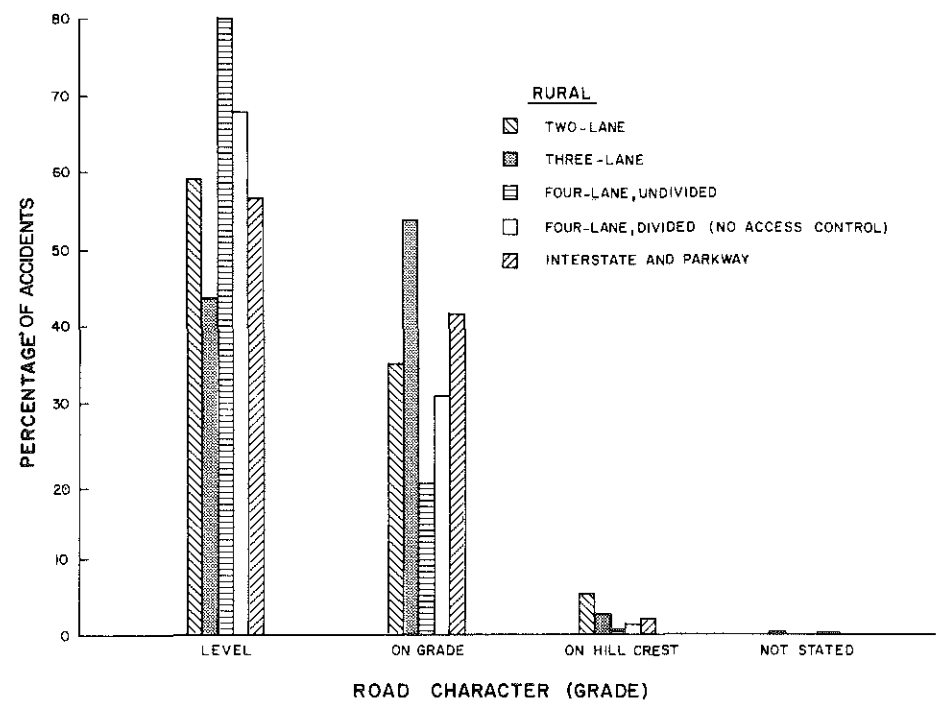

Figure 6. Percentage of Accidents Related to Vertical Alinement on Various Types of Highways.

TABLE 1

ACCIDENTS, INJURIES, AND FATALITIES PER 100 MILLION VEHICLE MILES (160 MVK) (1970-1972)

TYPE OF HIGHWAY	ACCIDENT RATE	INJURY RATE	FATALITY RATE
Two-Lane	239	154	9.3
Three-Lane	244	197	11.0
Four-Lane, Undivided	313	202	24.6
Four-Lane, Divided (No Access Control)	156	100	4.7
Interstate	85	60	3.1
Parkway	80	54	4.6
Interstate and Parkway	84	59	3.3
Mean (All Roads)	204	132	7.9

TABLE 2

ACCIDENTS, INJURIES, AND FATALITIES PER MILE (1.6 KM) PER YEAR (1970-1972)

TYPE OF HIGHWAY	ACCIDENT RATE	INJURY RATE	FATALITY RATE
Two-Lane	0.90	0.58	0.04
Three-Lane	3.47	2.79	0.16
Four-Lane, Undivided	9.35	5.97	0.73
Four-Lane, Divided (No Access Control)	5.48	3.51	0.16
Interstate	3.72	2.61	0.13
Parkway	0.82	0.55	0.05
Interstate and Parkway	2.37	1.65	0.09
Mean (All Roads)	1.00	0.65	0.04

TABLE 3

CRITICAL ACCIDENT RATES

		CRITICAL ACCIDENT RATES			
		ACCIDENTS PER 100 MVM (1-MILE (1.6 KM) SECTION)		ACCIDENTS PER MILE (1.6 KM) PER YEAR	
TYPE OF HIGHWAY	MEAN AADT	P = 0.95	P = 0.995	P = 0.95	P = 0.995
Two-Lane	1036	785	1019	3.0	3.9
Three-Lane	5510	450	553	9.0	11.1
Four-Lane, Undivided	8189	498	593	14.9	17.7
Four-Lane, Divided (No Access Control)	9628	280	342	9.8	12.0
Interstate	11957	169	210	7.4	9.2
Parkway	2808	279	360	2.8	3.7
Interstate and Parkway	7703	192	243	5.4	6.8

TABLE 4

ACCIDENTS PER 100 MVM (160 MVK) BY TYPE OF HIGHWAY AND TYPE OF ACCIDENT (1970-1972)

	TYPE OF ACCIDENT							
TYPE OF HIGHWAY	HEAD-ON OR OPPOSITE DIRECTION SIDESWIPE	REAR-END OR SAME DIRECTION SIDESWIPE	ANGLE COLLISION	PEDESTRIAN	OTHER COLLISION	SINGLE VEHICLE	FIXED OBJECT	OTHER
Two-Lane	46	73	15	3	15	73	8	6
Three-Lane	32	106	12	5	18	62	3	6
Four-Lane, Undivided	20	164	50	6	20	43	7	3
Four-Lane, Divided (No Access Control)	8	80	18	1	9	32	6	2
Interstate	1	28	0	1	5	44	4	2
Parkway	1	18	1	1	2	45	5	7
Interstate and Parkway	1	26	1	1	4	44	4	3

TABLE 5

ACCIDENTS PER MILE (1.6 KM) PER YEAR BY TYPE OF HIGHWAY AND TYPE OF ACCIDENT (1970-1972)

	TYPE OF ACCIDENT							
TYPE OF HIGHWAY	HEAD-ON OR OPPOSITE DIRECTION SIDESWIPE	REAR-END OR SAME DIRECTION SIDESWIPE	ANGLE COLLISION	PEDESTRIAN	OTHER COLLISION	SINGLE VEHICLE	FIXED OBJECT	OTHER
Two-Lane	0.17	0.28	0.06	0.01	0.06	0.28	0.03	0.01
Three-Lane	0.46	1.50	0.18	0.07	0.25	0.88	0.05	0.08
Four-Lane, Undivided	0.61	4.89	1.49	0.19	0.59	1.27	0.21	0.10
Four-Lane, Divided (No Access Control)	0.28	2.79	0.62	0.04	0.34	1.13	0.20	0.08
Interstate	0.07	1.21	0.01	0.02	0.21	1.92	0.18	0.10
Parkway	0.01	0.18	0.01	0.01	0.01	0.47	0.06	0.07
Interstate and Parkway	0.04	0.73	0.01	0.02	0.12	1.25	0.12	0.08

TABLE 6

PERCENTAGES OF VARIOUS TYPES OF ACCIDENTS AS A FUNCTION OF TYPE OF TRAFFIC CONTROL

	TYPE OF ACCIDENT							
TRAFFIC CONTROL	HEAD-ON OR OPPOSITE DIRECTION SIDESWIPE	REAR-END OR SAME DIRECTION SIDESWIPE	ANGLE COLLISION	PEDESTRIAN	OTHER COLLISION	SINGLE VEHICLE	FIXED OBJECT	OTHER
Stop Sign	4.1	29.6	51.9	0.2	1.2	12.0	0.7	0.3
Signal	6.2	55.9	28.6	0.3	2.2	5.0	2.0	0.2
Yield Sign	4.0	56.2	22.5	0	3.6	12.0	0	1.6
Flashing Beacon	5.8	51.9	14.9	1.6	7.7	13.3	5.0	0.5
No Passing Zone	25.1	28.0	3.9	1.6	8.9	29.7	1.2	1.5
Curve Sign	29.1	9.0	1.9	0.5	4.8	52.5	1.4	0.7
Speed Limit Zone	17.3	29.9	5.0	1.7	15.6	27.5	1.1	1.9
Advisory Speed Sign	11.6	29.6	3.3	1.3	11.9	38.2	2.8	1.2
Railroad Gates or Signals	8.7	18.9	3.1	1.0	46.4	18.9	2.6	0.5
Centerline	12.8	35.7	2.7	1.4	7.8	35.3	1.4	3.0
Officer or Watchman	4.4	62.4	1.7	1.7	16.6	9.6	3.1	0.4
Other	37.4	16.8	2.7	1.4	11.4	27.1	1.3	1.9

TABLE 7

SEVERITY INDEX FOR VARIOUS TYPES OF ACCIDENTS

TYPE OF ACCIDENT	SEVERITY INDEX
Head-On or Opposite Direction Sideswipe	2.84
Rear-End or Same Direction Sideswipe	2.10
Angle Collision	2.60
Pedestrian	7.60
Other Collision	2.59
Single Vehicle	3.58
Fixed Object	2.70
Other	1.99

TABLE 8

SEVERITY INDICES

TYPE OF HIGHWAY	SEVERITY INDEX
Two-Lane	2.85
Three-Lane	2.96
Four-Lane, Undivided	2.84
Four-Lane, Divided (No Access Control)	2.75
Interstate	2.82
Parkway	3.07
Interstate and Parkway	2.86
Mean (All Roads)	2.84

TABLE 9

SEVERITY INDICES AS A FUNCTION OF TYPE OF TRAFFIC CONTROL

TRAFFIC CONTROL	SEVERITY INDEX
Stop Sign	2.70
Signal	2.27
Yield Sign	2.03
Flashing Beacon	2.45
No Passing Zone	2.72
Curve Sign	3.13
Speed Limit Zone	2.66
Advisory Speed Sign	2.80
Railroad Gates or Signals	3.81
Centerline	2.94
Officer or Watchman	2.21
Other	2.62

TABLE 10

VEHICLE OCCUPANT'S SEVERITY INDEX AS A FUNCTION OF SAFETY BELT USAGE

SAFETY BELT USAGE	SEVERITY INDEX
Safety Belts Used	1.66
Safety Belts Not Used	2.44
No Safety Belts in Vehicle	3.00
Vehicle Equipped with Safety Belts	1.95

TABLE 11

AVERAGE SEVERITY INDEX FOR ALL HIGHWAY TYPES

YEAR	SEVERITY INDEX
1970	2.91
1971	2.85
1972	2.78

TABLE 12

PERCENTAGES OF RURAL HIGHWAY ACCIDENTS AS A FUNCTION OF TYPE OF HIGHWAY AND TYPE OF TRAFFIC CONTROL

TYPE OF HIGHWAY	TYPE OF TRAFFIC CONTROL											
	STOP SIGN	SIGNAL	YIELD SIGN	FLASHING BEACON	NO PASSING ZONE	CURVE SIGN	SPEED LIMIT ZONE	ADVISORY SPEED SIGN	RAILROAD GATES OR SIGNALS	CENTER-LINE	OFFICER OR WATCHMAN	OTHER
Two-Lane	5.9	0.5	0.3	0.5	3.7	1.9	3.6	0.7	0.3	63.0	0.3	19.3
Three-Lane	3.9	4.5	0	0.6	2.3	0.6	2.5	1.7	0.3	79.3	0.6	3.7
Four-Lane, Undivided	12.5	13.4	1.2	1.2	1.0	0.2	2.2	0.3	0.4	62.8	0.1	4.7
Four-Lane, Divided (No Access Control)	8.2	6.0	1.3	1.9	0.4	0.3	2.2	0.7	0.1	76.0	0.7	2.2
Interstate and Parkway	1.3	0.3	0.9	0.6	0.4	0.5	4.1	3.5	0	83.8	0.8	3.8