RELATIONSHIPS BETWEEN ROADWAY GEOMETRICS AND ACCIDENTS

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Statewide average and critical rates of accidents were determined from 1970, 1971, and 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, and 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 use. Accidents involving pedestrians were the most severe, and single-vehicle accidents ranked next highest in severity. Excluding accidents at railroad crossings, accidents that occurred on curves had the highest severity index. The use of safety belts was associated with reduced severity.

•CRITERIA now used in Kentucky to identify high-accident locations are not specific with respect to the type of highway. Intuitively, one knows that differences in accident histories should exist; it should be possible to statistically identify or define relationships between the geometrics and the accident history of a location. If differences are noted in accident experiences of highway types, benefits realized from a particular change in geometrics could be assessed.

Several high-accident location identification procedures use average or critical accident rates (1, 2). A critical rate is determined, and rates higher than the critical indicate 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 for determining high-accident sites.

Findings in this paper 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 1970, 1971, and 1972. The accident data were obtained from computer tapes containing all accidents reported by the state police. Kentucky only recently enacted a uniform accident reporting law; therefore the state police reports studied were almost exclusively for rural areas, and only rural accidents were considered. Rural accidents include all accidents occurring in cities with less than 2,500 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 that summarized the number of vehicle miles (kilometers) of travel on different highway types in rural areas. Second, volumes were taken from Kentucky traffic flow maps for those locations that 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.

The Interstate and parkway division 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 categories, errors were found in the computer information. This necessitated manual determination of accident locations. The limited mileage of these highways permitted long-hand manipulation. When 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 use was studied.

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

$$A_c = A_a + K\sqrt{A_a/M} + \frac{1}{2}M$$

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 MVM (160 MVK) traveled on a particular highway type.

Critical rates were determined for two probability levels to show the effect the choice of probability level has on critical rates. Critical accident rates in terms of accidents per mile (kilometer) were determined 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 nonmotor vehicle (train, bicycle, and parked car) as well as nonintersection 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 (SI) (4) was used. SI was calculated by the following formula:

$$SI = EPDO/N_t$$

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 type A injury accidents (accidents where type A injury was the most severe injury sustained),
B = number of type B injury accidents,
C = number of type C injury accidents, and
PDO = number of property-damage-only accidents.

FINDINGS

The average accident rates by type of highway are given in Table 1. 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 decline. Volumes on this highway type and the four-lane undivided highway are similar. When access control and at-grade intersections are 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 have much higher volumes and higher accident rates.

The critical accident rates by type of highway are given in Table 2. Because of low volumes, two-lane highways have the highest critical rate in terms of accidents per 100 MVM (160 MVK). In terms of accidents per mile (1.6 km) 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 types of accidents for all highways as a group. For three-lane, four-lane divided, and four-lane undivided highways, 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, and there was a significant percentage of rear-end accidents. Two-lane and three-lane highways had a significant percentage of head-on or opposite-direction sideswipe accidents, but 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 increases and the percentage of single-vehicle accidents decreases (6). This was found to be the case in a comparison of the percentages of these accidents occurring on Interstates (high-volume roads) and on parkways (low-volume roads). On parkways, 22 percent were rear-end or same-direction sideswipe accidents, and 73 percent were single-vehicle accidents (including fixed-object and other accidents). On Interstates, 33 percent were rear-end accidents and 59 percent were single-vehicle accidents. 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

Table 1. Average accident rates.

Type of Highway	Accident Rate: Per 100 MVM	Accident Rate: Per Mile per Year	Injury Rate: Per 100 MVM	Injury Rate: Per Mile per year	Fatality Rate: Per 100 MVM	Fatality Rate: Per Mile per Year
Two-lane	239	0.90	154	0.58	9.3	0.04
Three-lane	244	3.47	197	2.79	11.0	0.16
Four-lane, undivided	313	9.35	202	5.97	24.6	0.73
Four-lane, divided[a]	156	5.48	100	3.51	4.7	0.16
Interstate	85	3.72	60	2.61	3.1	0.13
Parkway	80	0.82	54	0.55	4.6	0.05
Interstate and parkway	84	2.37	59	1.65	3.3	0.09
Mean (all roads)	204	1.00	132	0.65	7.9	0.04

Note: 1 mile = 1.6 km.

[a]No access control.

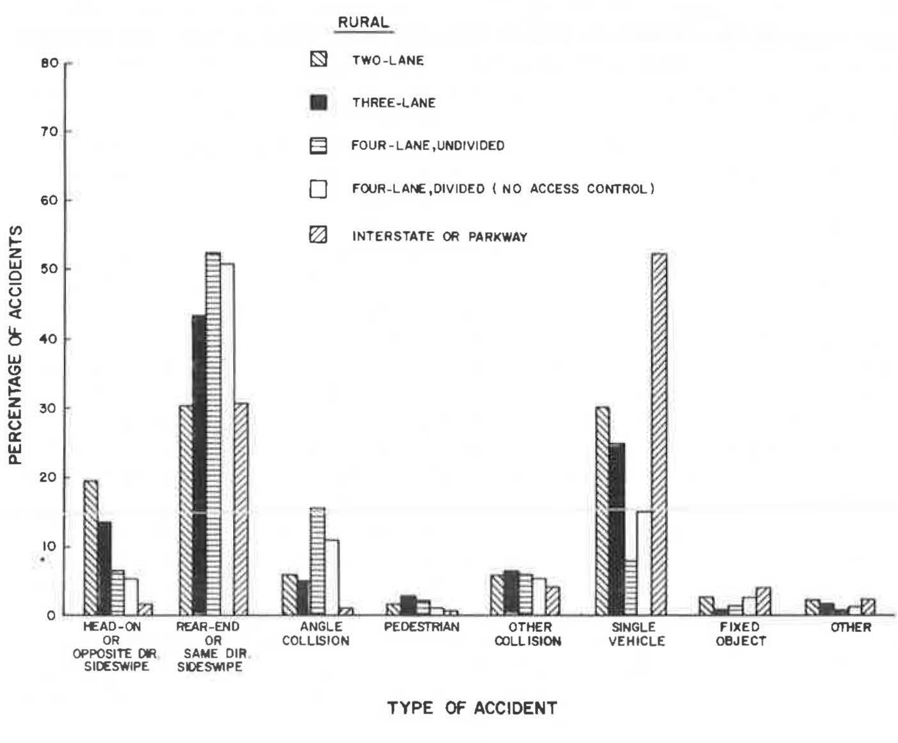
Table 2. Critical accident rates.

Type of Highway	Mean AADT	Accidents per 100 MVM (1-mile section): P = 0.95	Accidents per 100 MVM (1-mile section): P = 0.995	Accidents per Mile per Year: P = 0.95	Accidents per Mile per Year: P = 0.995
Two-lane	1,036	785	1,019	3.0	3.9
Three-lane	5,510	450	553	9.0	11.1
Four-lane, undivided	8,189	498	593	14.9	17.7
Four-lane, divided[a]	9,628	280	342	9.8	12.0
Interstate	11,957	169	210	7.4	9.2
Parkway	2,808	279	360	2.8	3.7
Interstate and parkway	7,703	192	243	5.4	6.8

Note: 1 mile = 1.6 km.

[a]No access control.

Figure 1. Percentage of accident types on various types of highways.



of accident on each type of highway are given in Table 3.

Percentages of accident types for a given traffic control device are given in Table 4. The data provide a general idea of the effects a change in traffic control would have on the type of accident occurring. For example, changing from a stop sign to a signal may reduce angle accidents but increase rear-end accidents. When percentages of the types of accidents occurring at a given location are compared to the statewide averages, an abnormal number of a particular type of accident may be detected.

Table 5 gives the relationship between the SI and types of accidents, highways, and traffic controls. Pedestrian accidents had a much higher SI than any other type of accident; single-vehicle accidents also exhibited a high SI.

Four-lane divided highways had the lowest SI of any highway type, and parkway accidents had the highest SI. This may be attributed to the high percentage of single-vehicle accidents as well as high speeds. The data further show that, when a stop sign is replaced by a signal, the severity of the accidents may be decreased because angle types of accidents (which are more severe) usually decrease, but rear-end types increase. 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. The following are SIs associated with safety belt use.

Safety Belt Use	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

The SI formula was modified so that values could be calculated for occupants rather than for accidents:

$$SI = [9.5\ (K + A) + 3.5\ (B + C) + O]/N_t$$

where

- N_t = total occupants involved in state police-reported accidents, which had safety belt use indicated,
- K = total fatalities,
- A = total type A injuries,
- B = total type B injuries,
- C = total type C injuries, and
- O = total occupants who sustained no injuries.

The SI was much lower for occupants who used safety belts than for those who did not use safety belts. This adds further credence to the supposition that safety belt use can greatly reduce the severity of most accidents. The difference between the SI of vehicles without safety belts and the SI of vehicles equipped with safety belts (which were not used) was larger than would be anticipated. A higher SI 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. Some safety features have been added to the newer cars; still, the large difference was surprising.

Of the total vehicle occupants, 6 percent used safety belts. Eleven percent of the

Table 3. Accident rates by type of highway and 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
Accidents per 100 MVM								
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[a]	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
Accidents per mile								
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[a]	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

Note: 1 mile = 1.6 km.
[a]No access control.

Table 4. Percentages of various types of accidents for types of traffic controls.

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 5. Severity indexes for various types of accidents, highways, and traffic controls.

Item	Type	Severity Index
Accident	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
Highway	Two-lane	2.85
	Three-lane	2.96
	Four-lane, undivided	2.84
	Four-lane, divided[a]	2.75
	Interstate	2.82
	Parkway	3.07
	Interstate and parkway	2.86
	Mean (all roads)	2.84
Traffic control	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

[a]No access control.

occupants of vehicles equipped with safety belts were wearing them. This percentage did not change significantly from 1970 to 1972. Forty-four percent of the occupants were in vehicles not equipped with safety belts, but 50 percent of the occupants were in vehicles that had safety belts that were not used.

The percentage of vehicle occupants injured or killed in relation to safety belt use further illustrates the effectiveness of safety belts. Of the occupants who used safety belts, 17 percent received a nonfatal injury, and 0.4 percent were fatalities. In contrast, of the occupants who did not use a safety belt, 30 percent were nonfatally injured and 1.7 percent were killed. It should be noted that these percentages pertain to vehicle occupants whose safety belt use was coded on the accident tape. The percentages show that a person who does not wear 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 SIs of all rural accidents were as follows: 2.91 in 1970, 2.85 in 1971, and 2.78 in 1972. This decrease in severity may be attributable to new vehicle safety features or increased traffic volumes that result in lower speeds and 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 on Interstates or parkways, where there are no at-grade intersections.

Figure 3 shows road surface conditions versus accidents. Between 20 and 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 that occurred during daylight and darkness are shown 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. Two-lane highways had the highest percentage of accidents that 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. Table 6 gives the percentage of accidents for various highway types versus type of traffic control.

IMPLEMENTATION

The tables that 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 by using graphs that relate critical accident rate, volume for each type of highway, section length, and probabilities (5).

The tables and figures that relate type of highway, accident, and traffic control and SI are a means of determining whether a certain location or section of roadway deviates greatly from the average and of estimating the effect of a change in traffic control or geometrics. The figures that relate the percentage of accidents to road surface and light condition provide only a set of references for judging normalcy or abnormalcy in other or more specific data sets. The tables and figures presented here are intended to show rural statewide average conditions that 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 use provides quantitative results about the benefits of using safety belts. The numbers given are an effective means of illustrating the results of using safety belts.

Figure 2. Percentage of intersection-related accidents on various types of highways.

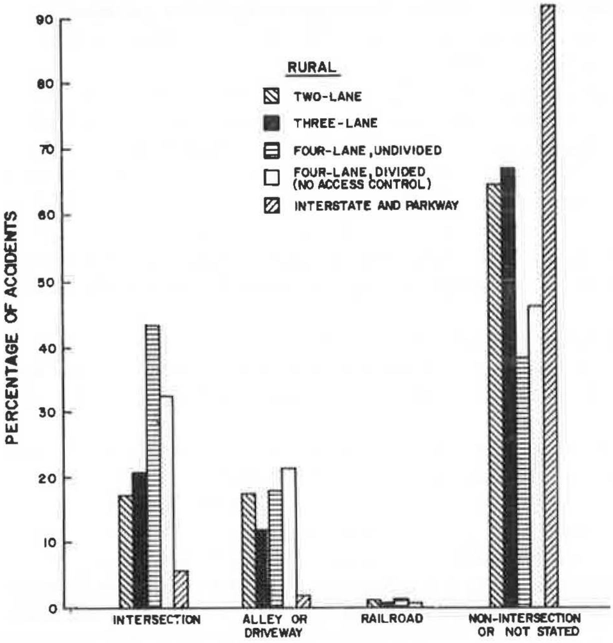


Figure 3. Percentage of accidents versus road surface conditions on various types of highways.

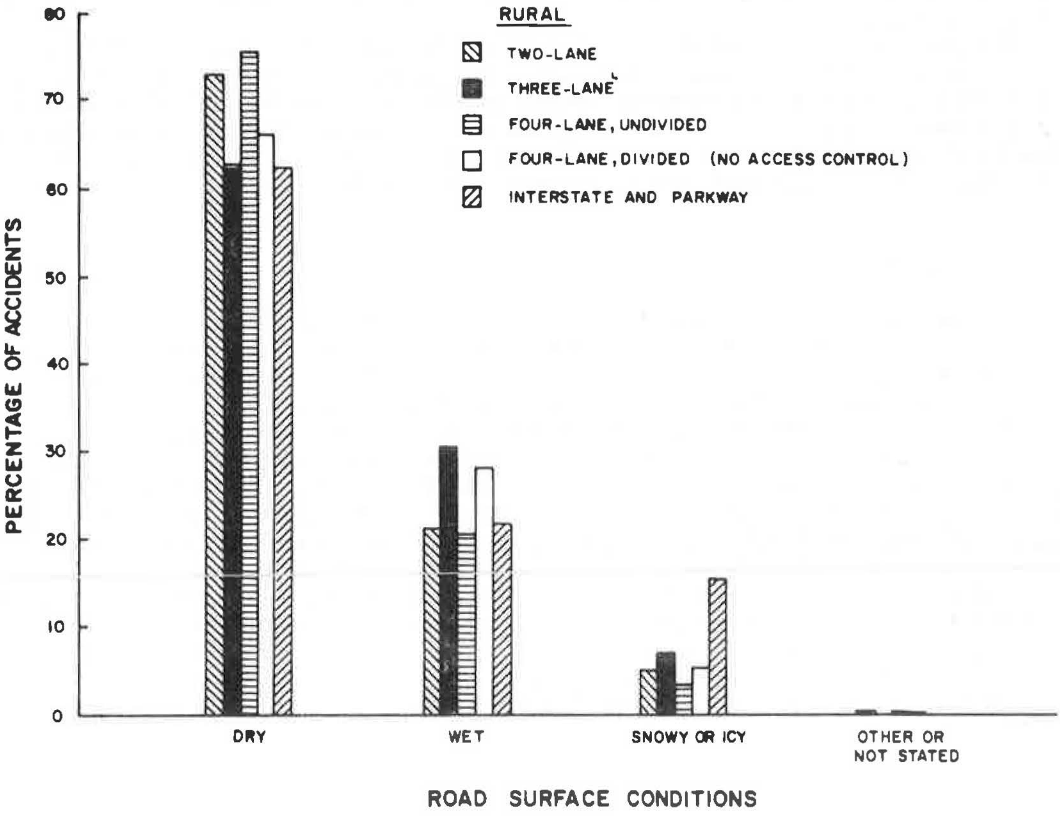


Figure 4. Percentage of accidents versus lighting conditions on various types of highways.

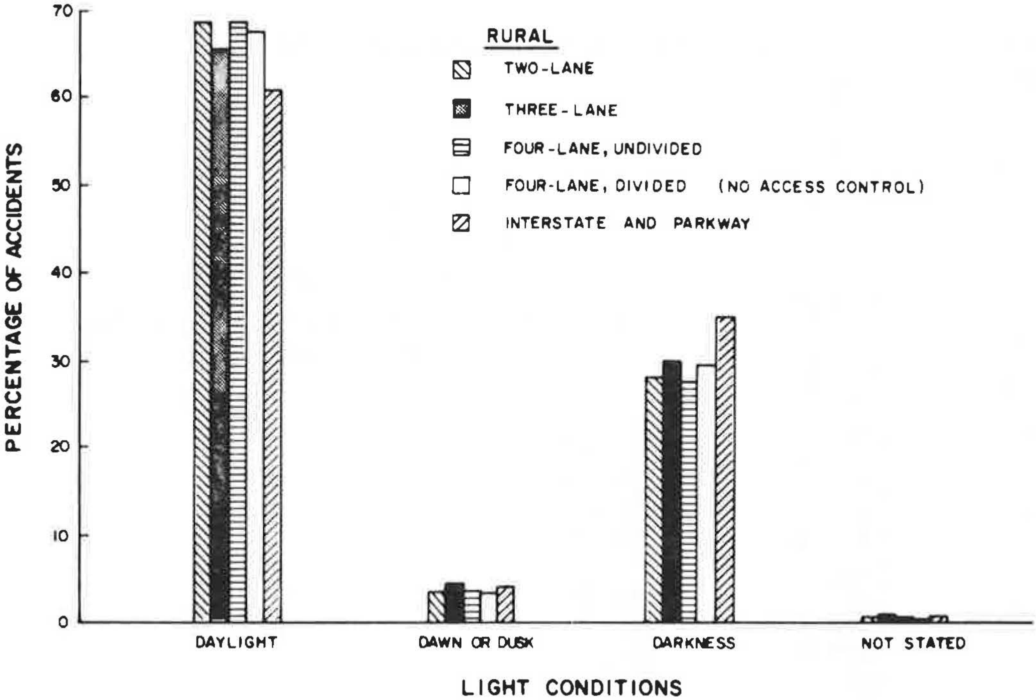


Figure 5. Percentage of accidents versus horizontal alignment on various types of highways.

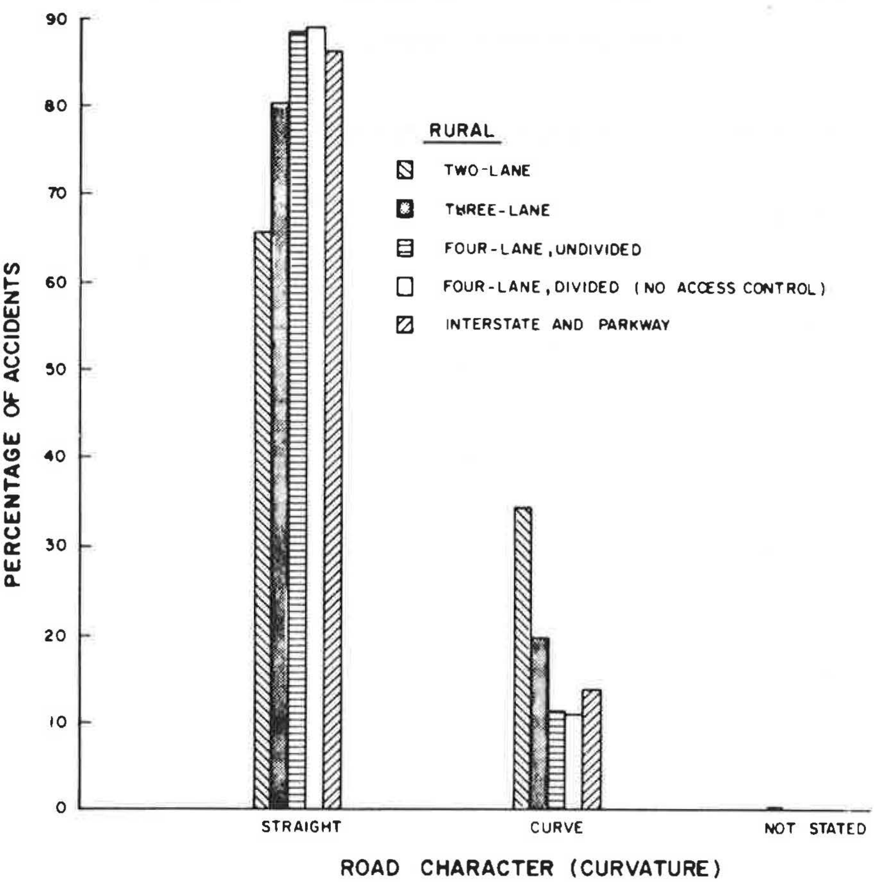


Figure 6. Percentage of accidents versus vertical alignment on various types of highways.

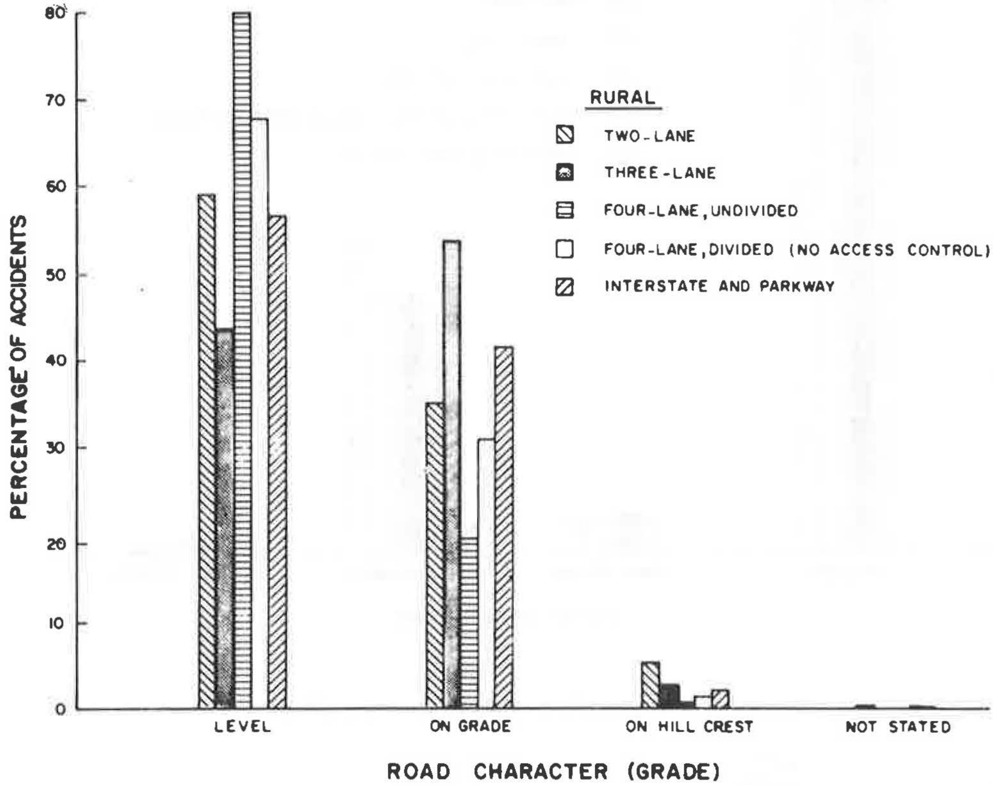


Table 6. Percentages of rural highway accidents for type of highway and type of traffic control.

Traffic Control	Type of Highway				
	Two-Lane	Three-Lane	Four-Lane Undivided	Four-Lane Divided[a]	Interstate and Parkway
Stop sign	5.9	3.9	12.5	8.2	1.3
Signal	0.5	4.5	13.4	6.0	0.3
Yield sign	0.3	0	1.2	1.3	0.9
Flashing beacon	0.5	0.6	1.2	1.9	0.6
No passing zone	3.7	2.3	1.0	0.4	0.4
Curve sign	1.9	0.6	0.2	0.3	0.5
Speed limit zone	3.6	2.5	2.2	2.2	4.1
Advisory speed sign	0.7	1.7	0.3	0.7	3.5
Railroad gates or signal	0.3	0.3	0.4	0.1	0
Centerline	63.0	79.3	62.8	76.0	83.8
Officer or watchman	0.3	0.6	0.1	0.7	0.8
Other	19.3	3.7	4.7	2.2	3.8

[a]No access control.

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