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Traffic-Accident Trends

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● IN New York City in September, 1899, H. H. Bliss stepped off a street car and then turned to assist a woman off the car. A passing automobile struck him, and despite first aid by a doctor who was a passenger in the car, Bliss died in Roosevelt Hospital the following day.

That is the earliest recorded motor-vehicle traffic death, and practically the full story as available today. In fact, it is probably almost the full story as recorded by officials in that September of 1899.

Some 52 yr. and 3 mo. later, December, 1951, the millionth motor-vehicle traffic death occurred. No one will ever know just who the victim was, or where or when the accident happened. The facts of the accident are recorded, however, along with thousands of other cases, in official records.

This half century of motor-vehicle accidents, which is coincident with the motor vehicle itself, has seen the problem of traffic safety rise to one of national importance, both in a social and an economic sense. It seems important therefore to look at the trends over this period, especially in relation to highways and motor-vehicle use.

It is unfortunately necessary to measure accident trends in terms of deaths. Reporting of deaths is assumed to be complete, because of established procedures in the vital-statistics field. Nonfatal accidents, on the other hand, are probably not completely reported in any jurisdiction even today and are very poorly reported in some jurisdictions. Certainly over the period under discussion no reliance can be placed on anything but fatal-accident data.

During the early years of the century, data are fragmentary. The earliest year for which the National Safety Council has made an estimate is 1906, when about 400 deaths occurred from motor-vehicle accidents. This represented a population death rate of 0.5 per 100,000 population, hardly enough to arouse any concern.

In that year, however, there were only 108,100 vehicles registered in the country. Thus 400 deaths meant a registration death rate of approximately 37 deaths per 10,000 vehicles. No estimate of mileage exists for this early period, so a mileage rate cannot be calculated.

By 1910, deaths had increased to 1,900 and the population rate to 2.0. With 468,500 vehicles registered, the registration rate was 40.5, up about 10 percent in four years.

By 1920, when there were over 9 million vehicles registered, deaths totaled 12,500. The population rate had risen to 11.7, and the registration rate had dropped to 13.5.

An estimate of the gasoline consumed on highways is available for 1920. The Bureau of Public Roads has published a figure of 3.3 billion gal., which would produce a mileage death rate of between 25 and 30 deaths per 100,000,000 vehicle-miles. (Mileage rates are usually considered to be unavailable prior to 1925, so this figure for 1920 is only a rough estimate based on a consumption rate of 14 mi. per gal.).

Better figures are available for 1925, when the mileage death rate was 17.9 deaths per 100,000,000 vehicle-miles. The registration rate had fallen slightly to 11.0 per 10,000 vehicles and the population rate had risen to 19.1 per 100,000,000 population. Deaths in 1925 totalled 21,900, almost as many as in 1943.

The end of that decade saw 32,900 deaths for 1930, a mileage rate of 16.0 deaths per 100,000,000 vehicle miles and a registration rate of 12.4 per 10,000 vehicles.

Despite a slight drop in 1932 and 1933, when travel decreased for reasons too well known for comment, deaths increased steadily until 1937, reaching a peak then of 39,643. The registration rate that year was 13.3 per 10,000 vehicles, up from 1930. The mileage rate was 14.7 per

100,000,000 vehicle-miles, continuing a slight downward trend.

In 1938, deaths were 32,582, a decrease of nearly 18 percent. The registration rate fell to 11.1 per 10,000 vehicles and the mileage rate to 12.0 per 100,000,000 vehicle-miles. No completely satisfactory explanation has ever been offered for this sharp decline, though many groups or projects have a claim for partial credit.

TABLE 1

MOTOR-VEHICLE DEATHS AND DEATH RATES IN THE UNITED STATES 1906-1951

Year	Deaths	Death Rates: Per 100,000 population	Per 10,000 motor vehicles	Per 100,000,000 vehicle-miles
1906	400	0 5	37 0	-
1907	700	0 8	48 9	-
1908	800	0 9	40 3	-
1909	1,300	1 4	41 7	-
1910	1,900	2 0	40 6	-
1911	2,300	2 5	36 0	-
1912	3,100	3 3	32 8	-
1913	4,200	4 4	33 4	-
1914	4,700	4 8	26 6	-
1915	6,600	6 6	26 5	-
1916	8,200	8 1	22 7	-
1917	10,200	10 0	19 9	-
1918	10,700	10 3	17 3	-
1919	11,200	10 7	14 8	-
1920	12,500	11 7	13 5	-
1921	13,900	12 9	13 3	-
1922	15,300	13 9	12 5	-
1923	18,400	16 5	12 2	-
1924	19,400	17 1	11 0	-
1925	21,900	19 1	11 0	17 9
1926	23,400	20 1	10 6	16 6
1927	25,800	21 8	11 2	16 3
1928	28,000	23 4	11 4	16 2
1929	31,200	25 7	11 8	15 8
1930	32,900	26 7	12 4	16 0
1931	33,700	27 2	13 0	15 6
1932	29,500	23 6	12 2	14 7
1933	31,363	25 0	13 2	15 6
1934	36,101	28 6	14 4	15 7
1935	36,369	28 6	13 9	15.9
1936	38,089	29 7	13 5	15 1
1937	39,643	30 8	13 3	14 7
1938	32,582	25 1	11 1	12 0
1939	32,386	24 7	10 6	11 3
1940	34,501	26 1	10 8	11 4
1941	39,969	30 1	11 6	12 0
1942	28,309	21 2	8.7	10.6
1943	23,823	17.8	7 8	11.5
1944	24,282	18 3	8.1	11 5
1945	28,076	21 3	9 2	11 3
1946	33,411	23 9	9 8	9.8
1947	32,697	22 8	8 7	8 8
1948	32,259	22 1	7 9	8 1
1949	31,701	21 3	7 2	7 5
1950	35,000	23 1	7 2	7 6
1951	37,300	24 3	7 1	7.6

The following year, 1939, was about the same. Then began another steady increase in deaths to the all-time high of 39,969, reached in 1941. Registration and travel were also up, so the registration rate for 1941 was 11.6 per 10,000 vehicles and the mileage rate was 12.0 per 100,000,000 vehicle-miles. The population rate of 30.0 per 100,000 population was exceeded only by the 1937 rate of 30.8.

During the years of World War II, travel fell off sharply and so did deaths. The registration rate fell too, but the mileage rate changed but little. In 1945, the latter was 11.3 per 100,000,000 vehicle-miles. With the end of the war, travel shot up and, in 1947, was higher than in 1941. Deaths, however, did not rise proportionately, and the mileage death rate fell to 8.8 per 100,000,000 vehicle-miles. The registration rate dropped slightly to 8.7 per 10,000 vehicles.

The years of 1948 and 1949 saw similar death records and continuing declines in the rates. In 1950, however, deaths were up, and again in 1951. It appears now that 1952 will be up slightly. Registration and travel both increased during this period so that the registration and mileage rates are nearly constant for the past four years.

TABLE 2

MOTOR-VEHICLE DEATHS AND DEATH RATES IN THE UNITED STATES, 1931 AND 1951

Year	Deaths	Death Rates: Per 100,000 population	Per 10,000 motor vehicles	Per 100,000,000 vehicle miles
1931	33,700	27 2	13 0	15 6
1951	37,300	24.3	7 1	7 6
		Percentage Changes		
1931-1951	+11%	-11%	-45%	-51%

The 50-odd years of motor vehicles have produced a death total of over a million persons. It seems obvious that we have not adjusted ourselves very well to the automobile but are making some progress, slow though it may be. Just 20 yr. ago, we killed one person every 6,400,000 mi. of vehicle operation. Today we drive 13,200,000 mi. per death, more than twice as far. We have experienced very little change on a population basis during these 20 yr. but almost as much improvement on a vehicle-registration basis as on a mileage basis.

During the entire period under discussion, the physical plant — the road system of the country — has not grown in proportion to vehicle registration and use, though it has changed greatly in character. The road census of 1904 showed a total rural mileage of 2,151,379 mi., of which 153,530 mi. were surfaced. In 1931 there was reported a total rural mileage of 3,036,000 mi., a figure which has not changed much for 1951. By

1931, however, surfaced rural roads totaled 830,000 mi. and that has doubled today so that half of our rural mileage is surfaced. Since city-street mileage amounts to only about 10 percent of rural mileage today, it is clear that the important change in highway characteristics has been in the improvement of rural roads.

This is reflected in accident data and is of great importance today to those concerned with accident prevention. In the years prior to 1937, no separation is available between urban and rural deaths. Data are at hand, however, for deaths in cities over 10,000 population and for deaths in smaller cities and rural areas, and these figures show the trend quite clearly. In 1924, for instance, there were 9,300 deaths in cities over 10,000 population and 10,100 in small towns and rural areas. Thus 48 percent of the deaths resulted from accidents in cities over 10,000 population and 52 percent from accidents in smaller cities and rural areas.

This preponderance of deaths in small cities and rural areas has continued. By 1937, it had increased until 69 percent of the deaths occurred from accidents outside cities over 10,000 population.

In that same year, data were first available which classified accidents by all incorporated placed as compared to rural areas outside corporate limits. Though far from being a completely satisfactory definition of "urban" and "rural," such a method probably gives a more accurate picture than the old break at 10,000 population.

The 1937 classification on the new basis shows 59 percent in rural areas. Since rural areas and places under 10,000 represented 69 percent of the total, it follows that cities under 10,000 population accounted for about 10 percent of the deaths.

By 1941 the rural percentage had grown to 64 percent, and the 10 percent for small cities remained constant.

After dropping during World War II, when rural travel declines so greatly, they have risen again until today 7 out of every 10 motor-vehicle deaths is the result of an accident in rural areas. In 1924, this ratio was about 4 out of 10. This reflects notable advances for safety in cities, where deaths have in actual totals gone down from 16,300 in 1937 to 10,700 in 1951. At the same time it presents a tremendous challenge to those responsible for our rural roads and their operation.

The mileage death rate for urban areas has always been below that for rural areas, but though both have been cut, the urban rate has gone down farther than the rural figure. The earliest purely urban and rural rates are for 1937. Then the urban rate was 11.8 deaths per 100,000,000 vehicle-miles, and the rural rate was 17.7.

TABLE 3

U S. MOTOR-VEHICLE DEATHS, URBAN-RURAL LOCATION, 1924-1951

Year	Deaths: Cities over 10,000 pop	Deaths: All Cities	Deaths: Cities under 10,000 & rural	Deaths: Rural	Percentage: In cities under 10,000 & rural	Percentage: In rural areas
1924	9,300	No data available	10,100	No data available	52%	-
1925	10,100		11,800		54%	-
1926	10,100		13,300		57%	-
1927	11,000		14,800		57%	-
1928	11,500		16,500		59%	-
1929	12,200		19,000		61%	-
1930	13,180		19,750		60%	-
1931	12,820		20,850		62%	-
1932	11,070		18,380		62%	-
1933	11,500		19,860		63%	-
1934	12,900		23,200		64%	-
1935	11,800		24,570		68%	-
1936	11,900		26,190		69%	-
1937	12,100	16,300	27,540	23,340	69%	59%
1938	9,650	13,050	22,930	19,530	70%	60%
1939	9,400	12,800	22,990	19,590	71%	61%
1940	9,800	13,500	24,700	21,000	72%	61%
1941	10,100	14,220	29,870	25,750	74%	64%
1942	8,750	11,650	19,560	16,660	69%	59%
1943	8,100	10,550	15,720	13,270	66%	56%
1944	7,600	10,620	16,680	13,660	69%	56%
1945	8,640	11,900	19,440	16,180	69%	58%
1946	8,670	12,400	24,750	21,020	74%	63%
1947	8,100	11,450	24,600	21,240	75%	65%
1948	-	10,600	-	21,660	-	67%
1949	-	9,650	-	22,050	-	70%
1950	-	10,200	-	24,800	-	71%
1951	-	10,700	-	26,600	-	71%

These rates decreased so that by 1941, the peak year for deaths, the urban rate was down 26 percent to 8.7 deaths per 100,000,000 vehicle-miles, and the rural rate was 15.2, off 14 percent. By 1951, the urban rate was 4.5 per 100,000,000 vehicle-miles, 62 percent below 1937, and 48 percent under 1941. The rural rate in 1951 was 10.5, which was 41 percent under 1937 and 31 percent under 1941.

These important decreases in mileage rates are the result of constantly increasing travel volumes, particularly on rural roads, coupled with accident prevention efforts in all areas. Again it would appear that safety had been more effective in cities, however, than in rural areas.

Trends in types and circumstances of accidents reflect chiefly the increased proportion of rural accidents. Details are lacking prior to 1930, but in that year pedestriran deaths were 39 percent of the total. By 1940, pedestrians were still 37 percent of all fatal types, but in 1950 these cases were only 25 percent and, in 1951, 24 percent of the total. From 1930 to 1951, pedestrian deaths fell 30 percent and, from 1940 to 1951, 29 percent.

From 1940 to 1951, pedestrian deaths decreased 31 percent in urban areas, and all deaths dropped 21 percent. In rural areas during the same period, pedestrian deaths decreased 26 percent, and all deaths increased 27 percent.

TABLE 4

U S. MOTOR VEHICLE MILEAGE DEATH RATES, URBAN AND RURAL, 1937-1951

Year	Deaths per 100,000,000 vehicle-miles		Year	Deaths per 100,000,000 vehicle-miles	
	Urban	Rural		Urban	Rural
1937	11.8	17.7	1945	9.2	13 6
1938	9.6	14.5	1946	7.3	12.3
1939	9.0	13 7	1947	6.0	11 4
1940	9 0	13 8	1948	5.3	10.9
1941	8 7	15 2	1949	4.6	10.2
1942	8.4	12.9	1950	4.6	10.6
1943	9.7	13 6	1951	4.5	10.5
1944	9 6	13 5			

Collisions between two or more motor vehicles increased sharply from 1930, when they represented but 18 percent of the total death cases. In 1940 they were 29 percent of the total and were 35 percent in 1950 and 37 percent in 1951. In actual totals, deaths from this type increased 135 percent from 1930 to 1951. From 1940 to 1951, the increase was 37 percent.

Although no separate urban and rural totals are available for 1930, it appears from the trend in cities over 10,000 population (where two-vehicle collisions decreased from 1930 to 1940) that this increase occurred in rural areas. From 1940 to 1951, two-vehicle collisions in rural areas increased 47 percent, and decreased 2 percent in urban areas.

A possibly significant change has occurred in noncollision accidents,. those cases in which a vehicle runs off the road or overturns in the road with no prior collision, or miscellaneous accidents without a collision in the roadway. From 1940 to 1951, this type increased 51 percent in rural areas. Data for cities under 10,000 population and rural areas combined appears to indicate, however, that the rural total in 1930 was much higher than in 1940, so the increase from 1930 to 1951 in rural noncollision deaths was only 10 or 15 percent.

The most-important change, therefore, seems to have taken place in rural two-vehicle collisions. In 1940, this classification accounted for 38 percent of rural deaths, and in 1951, for 44 percent. In 1930, it probably represented only about 20 percent of rural fatals.

The major increase, at least from 1940 to 1951, came in collisions at intersections. In 1940, this type was 8 percent of all rural fatal cases, or a total of about 1,680 deaths. In 1951, these collisions were 12 percent of the rural fatal cases, or about 3,200 deaths.

A smaller increase occurred in the classification of "noncollision, ran off straight road." In 1940 this type was 13 percent of rural fatals, or 2,730 deaths. In 1951, this type represented 16 percent, or 4,260 deaths.

Major decreases occurred in pedestrian nonintersection cases. In 1940, these were 21 percent of all rural fatals, or 4,410 deaths. In 1951, these were 11 percent, or 2,930 deaths.

Little change is apparent in the information on circumstances of accidents in recent years. The violations reported for drivers remain about the same as 10 yr. ago. Ages of drivers in accidents are quite similar to those reported earlier.

The proportion of night accidents has increased some in recent years probably reflecting the growth of night-traffic volumes. In 1930, only 49 percent of fatal accidents occurred during hours of darkness. In 1951, 56 percent of fatal accidents happened during night hours. This is slightly below the 1941 record, however, when 58 percent were in darkness. Perhaps this absence of further change reflects better vehicle headlighting and increased highway lighting and reflectorization.

During recent years interest has been great in the so-called superhighways. Too little information is available on their accident experience, but enough is at hand to emphasize that the pattern on such highways does not fit the ordinary rural highway pattern.

Most obviously, pedestrian accidents are very infrequent, as are intersection accidents. The most prevalent type appears to be rear-end collisions, followed by running-off-roadway accidents. Both of these types would seem to point up the need for wide, surfaced shoulders to permit vehicles to pull off the road to stop and to allow them to accelerate before pulling back into the traffic lane and to provide a margin of safety for a driver who may run off or be forced off the traveled portion of the road.

TABLE 5

MOTOR-VEHICLE DEATHS BY TYPE OF ACCIDENT AND LOCATION, 1930-1951

Year	Total deaths	Deaths from collision with: Pedestrian	Other Motor Vehicle	Other vehicle or object	Deaths from non-collision accidents
			U S		
1930	32,900	12,900	5,880	4,150	9,970
1940	34,501	12,700	10,100	3,900	7,800
1950	35,000	8,700	12,300	3,300	10,700
1951	37,300	9,000	13,800	3,400	11,100
			Urban		
1930		No data available prior to 1937			
1940	13,500	8,100	2,150	1,750	1,500
1950	10,200	5,450	1,950	1,400	1,400
1951	10,700	5,600	2,100	1,400	1,600
			Rural		
1930		No data available prior to 1937			
1940	21,000	4,600	7,950	2,150	6,300
1950	24,800	3 150	10,550	2,050	9,050
1951	26,600	3,400	11,700	2 000	9,500

Research in Michigan and Minnesota has indicated the important effect on accidents of roadside development and has thereby emphasized again the importance of controlling access. Even on superhighways, however, with a limited number of access points, , the problem remains of getting vehicles safely into and out of the traffic stream. The parked or stopped vehicle beside the road needs its own individual access facility, too, which it does not now have in most instances.

All of the data we now have on accidents comes from state and city records, built from reports submitted by participants in accidents or by investigating authorities. In many instances, the investigation is, in reality, not an investigation but merely a reporting process. As a result, the information that is available on casual factors is of limited value. Even data on as important a fact as location may be inaccurate and of limited usefulness.

No discussion of accidents today can be complete without reference to these handicaps. The answer is still not clear, but as a result of the President's Highway Safety Conference in October, 1952, plans are underway to improve the situation.

In their simplest terms, they state that we must separate quantity of data from quality of data. We can hope to obtain information from drivers in a large number of cases, but the information must be of a nature easily reported by drivers with a reasonable degree of accuracy. The same requirements apply to reports from police or others who contact but do not truly investigate an accident.

The quality data (which we do not have in any substantial degree now) must come from specially trained police investigators who will report more accurately than now why the accident happened. Such information can be obtained on only a sample of the total accident experience, at least in the immediate future.

All highway engineers should welcome better causal data. In the past statements have sometimes been made in regard to the proportion of accidents in which the road was a factor. Usually such studies report a very low percentage, seldom over 15 percent.

It seems absurd to even consider such a study based on conventional accident records. Not one report in a thousand can be depended upon to answer the questions of adequate sight distance, proper radius of a horizontal curve, or adequate capacity for the volume carried. True, some reports list "highway defects," usually low shoulders, bumps, holes, and unlighted barricades, which are largely matters of maintenance. Only when we can greatly improve our system of reporting causal factors can we make categorical answers to questions of highway contributions to accidents.

SUMMARY

1. Traffic deaths have been a problem ever since the motor vehicle came into being, and have in general followed the trend of motor vehicle use.

2. Death rates have followed the following patterns:

<u>Population.</u> Gradually increasing to a high of 30.8 per 100,000 population

in 1937, then dropping to 17.8 in 1943, and climbing slowly to 24.3 in 1951.

Registration. Starting high and reaching a low of 10.6 per 10,000 vehicles in 1926, then up to 14.4 in 1934, then down to an all-time low in 1951 of 7.1.

Mileage (Earliest data for 1925). Starting high at 17.9 per 100,000,000 vehicle-miles, dropping sharply from 1937 to 1938, then decreasing steadily to 7.5 in 1949. In both 1950 and 1951, staying low at 7.6.

3. From 1930, when deaths were about evenly divided between urban and rural areas, to 1951 the trend has been toward a predominantly rural problem. In 1951 rural deaths were 71 percent of the total, and were up 60 percent from 1930 while urban deaths were down about a third.

4. The mileage death rate for rural areas has consistently been 50 percent greater than the urban rate, and is today more than twice the urban rate. Both rates have dropped substantially since 1937, when data were first available for their calculation.

5. Changes in the types and circumstances of accidents are primarily due to this urban-rural shift. Pedestrian deaths have decreased, and two-vehicle and noncollision accidents have increased, as might have been expected.

6. The major change in rural fatals, other than a general increase, has been in two-vehicle intersection collisions and in noncollision, ran-off-straight-road accidents, both of which have increased in the past 10 yr., and in pedestrian nonintersection accidents, which have substantially decreased.

7. Few changes can be found in the pattern of accident circumstances and conditions, although there has been a slight increase in night accidents (except that the night percentage has not increased in the last 10 yr.).

8. Major differences are apparent in the accident pattern for the most modern superhighways. Fewer pedestrian and intersection accidents but more rear-end collisions and running-off-roadway accidents are reported.

9. Current research and superhighway experience suggests the need for more attention to the control of access, even by vehicles parked on the shoulder.

10. Good causal information on accidents, particularly on the influence of the highway, must wait upon better accident information. Work is underway to develop this type of data.

Relation Between Number of Accidents and Traffic Volume at Divided-Highway Intersections

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THIS report presents a graphic expression of the accident-volume relation at divided highway intersections. The expression was produced by averaging the past accident experience at 150 intersections. A total of 1, 811 accidents was tabulated in developing the chart.

Uses of the chart include: (1) estimating the probable number of accidents which will occur in a future period and (2) correcting for the influence of volume differences when comparing one intersection accident rate with another.

Interpretation of the expression led to the following conclusions:

1. Accident rates at intersections are much more sensitive to changes in crossroad (minor road) volume than to changes in divided highway (major road) volume.

2. No direct relation exists between intersection accident rates and the sum of the two entering volumes. The existence of such a relation is implied when intersections are compared on the basis of "accidents per million vehicles."

3. Low-crossroad-volume intersections have higher accident rates per crossroad vehicle than do higher-crossroad-volume intersections. This is evidence that the concentration of cross traffic, through the closing of low-volume crossroads and the provision of frontage roads, is an effective means of reducing the number of intersection accidents.

● IN recent years, the California Division of Highways has built a considerable mileage of expressways and, concurrently, a lesser mileage of full freeways. The major difference between these two types of highway is that a freeway can have no intersections at grade while an expressway may have many such intersections. The initial costs of the two types can be estimated fairly accurately, the cost per mile for a freeway being greater because of the structures and additional right-of-way necessary to meet the freeway definition. With a fixed amount of money to spend, the choice, then, is between the construction of a certain number of miles of new expressways or, with the same money, fewer miles of freeways. In all but the most-congested urban areas, the greater mileage of expressways is generally favored.

But what is the cost of the expressway grade intersection after the facility is in use? This cost cannot be so readily estimated, because congestion, delay, and accidents are the items to be considered. It was this question which led to the initiation of the present study of accidents at intersections on divided highways. One study alone will not answer the question completely, but the more light that can be cast on the problem, the better equipped we will be to consider it.

The primary aim of this study is to find the average relation between traffic volume and number of accidents at expressway intersections. With such a guide, the probable number of intersection accidents in a given period can be estimated prior to the construction of a new facility and can be considered in deciding whether or not to construct grade-separation structures at the intersections.

An average relation between traffic volume and number of accidents is useful also in making comparative accident studies of intersections. The relation provides a means of correcting for the influence of volume differences when comparing one intersection accident rate with another. In the case of before-and-after studies, for instance, the after period is often at a higher volume than the before period, and the effect of the increased volume on accidents should be considered when comparing the rates for the two periods.

COLLECTION OF DATA

On 180 mi. of expressway sections of State Routes 4, 6, and 7 (US 99 and US 40) between Bakersfield and Sacramento and between Vallejo and Sacramento, 171 intersections were arbitrarily selected for study. The general location of these intersections is shown in Figure 1. This sample included a wide variety of design types, a few of which were signalized, ranging from simple, uncurbed crossovers to completely channelized intersections. At all of the unsignalized intersections, the divided highway was the preference road. All cross traffic was controlled by stop signs, except that which entered by way of separate turning lanes. Most of these intersections are located on level tangent sections of rural highway, and there are no extreme differences in weather conditions within the sample area.

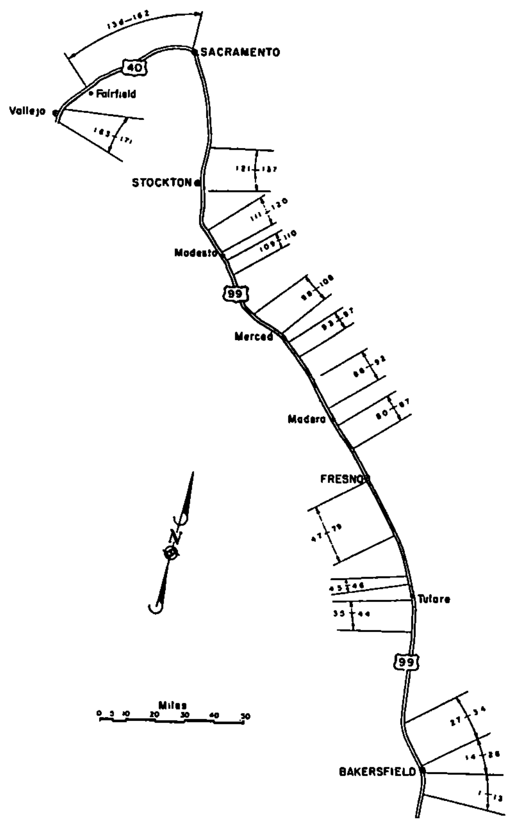

Figure 1. Location of intersections by numbers (see appendix for list).

A complete investigation was made of the physical characteristics of each intersection. First, through reference to plans available at the headquarters office, scale sketches were made which provided design information such as median width, type of intersection (T or cross), skew angle, and the existence of median speed-change lanes, channelizing islands, and curbs. The sketches were then taken into the field where the layouts were verified or corrected wherever any differences were found. Illumination, signalization, and speed zoning information was also verified. Additional data collected in the field included the existence of roadside business and sight restrictions, and notes regarding any unusual conditions observed. At least one and often several photographs were taken of each intersection.

Estimates of the average daily traffic volumes on the divided highway and the crossroad were obtained for each intersection. Annual traffic counts could be used to obtain these estimates at a few of the intersections, but in most cases it was necessary to make special counts to obtain the crossroad volumes. Counting was done mechanically for a period of 24 hr. on week days only. These 24-hr. counts were then converted to ADT by use of appropriate factors obtained from regular monthly count stations in the vicinity. At certain locations along the divided highway between the regular annual count stations, additional counts of the mainline traffic were made. This was done because frequently the distances between the regular stations were too great for the determination of a mainline traffic-volume profile sufficiently accurate for the purpose of this study.

The ADT volumes obtained for use here were not annual averages but were averages for the periods during which accident histories were obtained. The volumes at the several intersections varied on the divided highway from 4,300 to 27,200 and on the cross roads from less than 100 to 7,700.

All reported accidents occurring at the intersections between the date of opening (but not before January 1, 1946) and January 1, 1951, were cataloged by type (left turn, broadside, overtake, etc.), time of occurrence (night or day), and severity (injury, including fatal, or property damage only). The accidents were listed for each intersection by year of occurrence and then summarized for the total period. California Highway Patrol reports were the source of accident data on rural state-highway sections and these were supplemented by accident summaries obtained from city police files for those sections lying within corporate limits. Accident reports covering roughly a quarter of a mile on the state highways in both directions from each of the intersections were scanned to pick up and include in the listings those accidents which were obviously intersection types, even though the point of impact had been outside the immediate intersection area.

The total number of accidents listed was 1,811, while the number at any one intersection ranged from 0 to 79.

ANALYSIS

As mentioned in the introduction, the primary aim of this study is to find the average relation between traffic volume and the number of accidents at expressway intersections. As a first step toward this end, it was necessary to define the variables: intersection volume and intersection accidents. Volume at intersections was defined as the average daily entering traffic. Assuming that total ADT on a two-directional road is equally divided by direction, entering traffic on either road at an intersection will equal the ADT if the road carries the same volume on both sides of the intersection; entering traffic will equal the average of the volumes on the two sides wherever they are different; and, for T-type intersections, entering traffic from the terminated road will equal half of the ADT on that road. Only simple cross and T-type intersections were included in this study.

Intersection accidents were defined as all those reported accidents, regardless of severity, which occurred at the intersection, or which occurred near the intersection and were obviously intersection types. The decision to lump all levels of severity came as a result of investigating the relative merits of using all or just injury accidents as the dependent variable. Approximately 60 percent of the accidents listed were of the noninjury type. Upon temporary removal of this accident type, no improvement in the central tendency of the remaining data was noted, so total accidents, bringing the advantage of larger numbers, was selected as the measure for the dependent variable.

The next step was the choice of a means by which the relation might best be expressed. A direct approach to the problem was possible on the assumption that the effect of volume on the number of accidents is sufficiently significant to appear in a large sample, even though many other variables may not be controlled. Support for this assumption was found when the effect of each variable was investigated independently. This investigation also showed that attempting to find the effect of volume by segregating the intersections into more nearly homogeneous groups only reduced the stability of the result, without altering it appreciably. The three variables considered, then, were volume on the divided highway, volume on the crossroad, and number of accidents per year. Rather than initially combining the two volumes by some arbitrary means to produce a single independent variable, such as the per-million-vehicles base commonly used, a more fundamental relation was sought by providing three dimensions for expression of the three variables.

DEVELOPMENT OF A SURFACE TO EXPRESS THE AVERAGE VOLUME-ACCIDENT RELATION

The three coordinates involved in this study are divided-highway volume in the X direction, crossroad volume in the Y direction, and number of accidents per year in the Z direction. In Figure 2, the surface developed is described in chart form, just as a portion of the surface of the earth is described by a contour map. The two traffic volumes are the plane coordinates, and accident frequencies are shown as elevations by the use of contour lines.

Development of the surface followed an inspection of the original sample of 171 intersections to determine whether or not benefits, such as a reduction in the extreme variations and increased homogeneity, might be realized through small reductions in the size and scope of the sample.

This inspection proved fruitful and resulted in the removal of all intersections with less than 6 mo. of accident history (three), or a divided highway volume of less than 5,500 (two), and all signalized intersections (sixteen). As might be expected, the short accident histories were conducive to extreme variations in the annual rates. The low divided-highway distort the surface and make less evident the effect of volume. The removal of these 21 intersections reduced the sample size by only about 8 percent, but the upper limit on crossroad volume dropped from 7,700 to 3,100. This considerable reduction in scope was inevitable, since the original sample included so few intersections with crossroad vol-

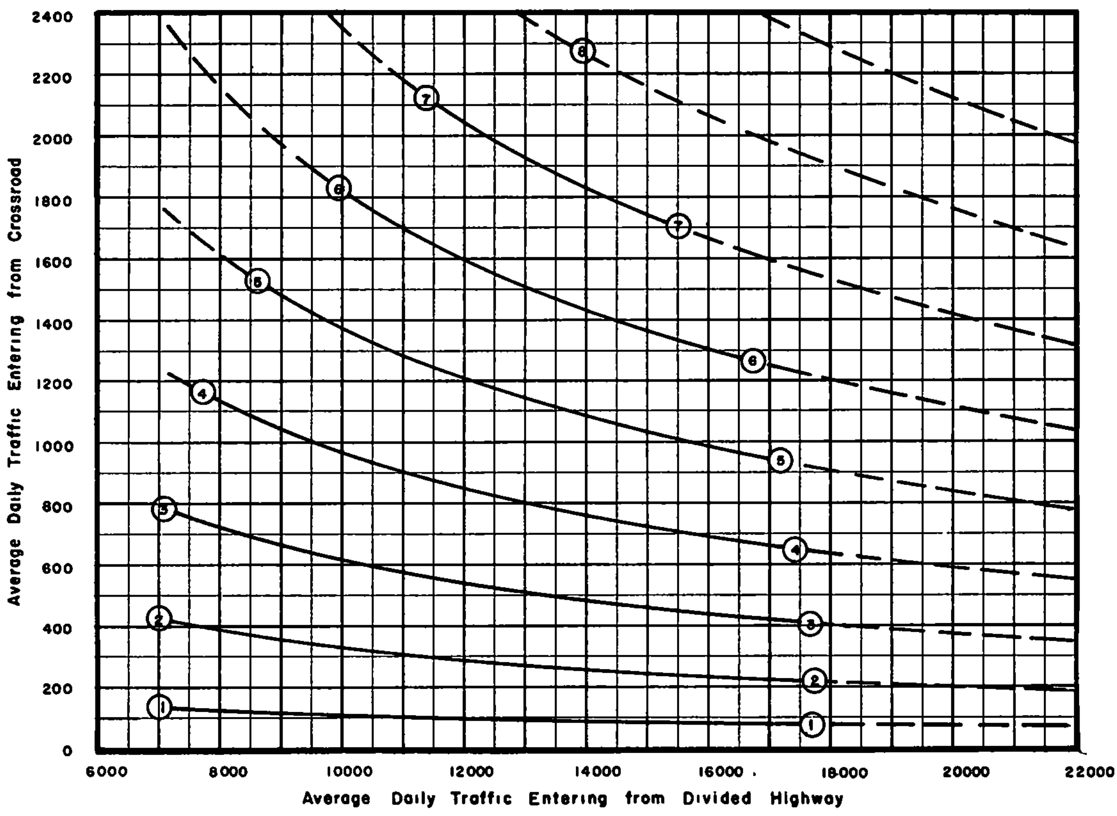

Figure 2. Average number of accidents per year related to volume at divided-highway intersections.

volumes represented a fringe condition which is unusual on expressways, and the small amount of experience obtained in this volume range was of little value. Almost all the signalized intersections were, of course, in the highest-crossroad-volume range, and thus they, too, in this case, represented a fringe condition in relation to the bulk of the sample, which is made up of lower-crossroad-volume intersections. The inclusion of intersections which would introduce an influential characteristic, such as signalization, into a limited part of the volume range covered by this surface could umes greater than 3,100. Further inspection revealed that the remaining physical characteristics, or secondary variables, were generally well distributed throughout both the divided-highway and the crossroad volume ranges.

Actual determination of the surface began with the plotting of the 150 remaining intersections, each at its respective volume combination. These were then grouped and an average volume combination and accident rate obtained for each group. Grouping was by similar volume combinations and followed the chance groupings existing within the sample wherever these were consistent with the effort to include at least four intersections in each group. A few groups in the volume ranges near the limits of the surface included less than four intersections, and the portions of the surface within these ranges are indicated by the dashed contour lines in Figure 2. The 150 intersections formed 24 groups with a range of from 2 to 19 intersections in each and an average number of about 7. The arithmetic mean number of accidents per year was computed for each group and the X and Y coordinates of the centroid of each, located graphically, determined the average volume combination for the group.

With the 150 single-intersection points replaced by 24 group-average points, the next step was the location and description of a regular surface which would best fit the average points. As mentioned earlier, contour lines were used as the means of description and the initial location of these lines was accomplished by interpolation between the mean accident rates at the various group-average points. Regular curves were then fitted, by freehand smoothing, to the initial irregular lines. The surface was also smoothed in a direction approximately normal to the contours by plotting cross sections at selected divided-highway volumes, smoothing these cross sections, and then adjusting the location of the contours accordingly. Twelve of the 24 groups lie within 0.2 contour of the computed surface, and the maximum deviation is 1.1, occurring once.

The shape of the contours developed in the preceding manner suggested that the accident rate might be a function of the product of the two volumes. It was decided to fit a curve to the 24 groups by the method of least squares, and in order to provide some freedom, the exponents of the two volumes were allowed to determine themselves. The result of this fitting was Figure 2, which can be written:

$$N = 0.000783\, V_d^{0.455}\, V_c^{0.633},$$

where $\underline{N}$ is number of accidents per year, $\underline{V_d}$ is ADT entering from divided highway, and $\underline{V_c}$ is ADT entering from the crossroad.

An idea of the fit can be obtained from the following:

	24 Groups	150 Intersections
Net deviation (algebraic)	7.6	-1.9
Sum of squares of deviations	6.38	319.7
Deviation within which ⅔ of the points lie	0.5	1.0

INTERPRETATIONS AND USES OF THE ACCIDENT-VOLUME EXPRESSION

The chart developed in this study is simply a graphic working expression of the accident-volume relation at divided-highway intersections, as revealed by a sample of past experience. As such, exact mathematical limits indicating reliability cannot be assigned to it. However, the approximate spread of the limits for a given degree of reliability was evident in the scatter of the points — the individual-intersection points being widely scattered, but the group-average points showing considerable stability.

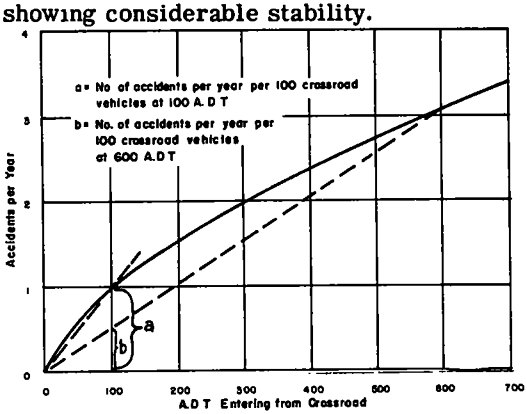

Figure 3. Partial cross section of accident-volume surface at 11,000 A.D.T. on divided highway

The wide scatter of individual points showed that an estimate of the number of accidents at any one intersection for 1 yr. can be made only within wide limits. Chance is largely responsible for the wide limits in such a case, much as it is responsible for our inability to predict heads correctly more than 50 percent of the time on a single toss of a coin, even though we can quite accurately predict the number of heads which will occur in many tosses. It follows, then, that when a relatively large number of intersections, or years, or both, are to be considered, the accident estimate can be made within much narrower limits. These narrower limits would apply, for instance, in estimating the aggregate number of intersection accidents per year which could be expected on a new facility of major project proportions where many intersections are involved. An even better estimate could be made, of course, if it were for a period of several years.

TABLE 1

Construction Project	No. of Intersections Involved	Accident History Available to Establish Actual Rate (Years)	Number of Accidents Per Year	
			Actual	From Chart
A	11	1 4	37.1	35 3
B	13	2.2	15 8	22 9
C	9	1.3	20 4	21.3
D	5	3 3	15.3	19.1
E	7	5.0	17.2	20.1
F	5	2 9	24 6	17 9
G	9	1.5	18 0	15.2
H	5	1.2	9.1	13.0
I	3	3.8	13.8	14 0
J	8	3.1	10.4	10 4
K	5	5 0	9 6	8 5
L	5	5 0	7 0	7 5
M	5	1.2	4.3	7 0
N	4	1.5	4.7	5.4
O	4	1.0	5.0	4.5
P	4	5 0	8.2	4.7

Table 1 is presented to suggest the limits within which such estimates might be made. The table lists the actual aggregate number of intersection accidents per year for groups of intersections from the study. These intersections have been grouped according to the construction project of which they were a part. Each actual number of accidents is compared with the corresponding number which would be obtained from the chart. The differences are actually deviations from the mean for project groups taken from the study sample, but it is probable that the number of accidents could be predicted for similar projects within comparable limits.

An actual case will serve as an example of the method of estimating the number of intersection accidents which will occur on a new facility. This case, presented as Table 2, involved 27 intersections along a proposed 18-mi. section of new expressway. The estimate was made for the 20-yr. period from 1954 to 1974. Traffic volumes for 1964, obtained by the application of appropriate expansion factors, were used as the average volumes for the period. The average accident rates for these volumes were read from the chart and then were multiplied by 20 to obtain the estimated number of accidents in 20 yr.

To be exact, the actual rates for each year, as the volume gradually increases, would need to be summed up. However, the error involved in using just one average volume is small and well within the probable error of other approximations made, such as the future growth of traffic.

TABLE 2

ESTIMATE OF NUMBER OF INTERSECTION ACCIDENTS ON PROPOSED EXPRESSWAY

Intersection Number	1964 ADT Entering Intersection		Estimated Number of Accidents	
	On Divided Highway	On Crossroad	Per Year	In 20 Years (1954-1974)
1	16,700	550	3.5	70
2	16,100	210	1 8	36
3	16,100	40	0.6	12
4	16,100	200	1.8	36
5	16,300	200	1.8	36
6	16,300	10	0 1	2
7	16,400	240	2.0	40
8	16,300	280	2.2	44
9	16,100	110	1 2	24
10	16,000	2,560	9 1	182
11	15,800	2,860	9.6	192
12	15,700	170	1.5	30
13	15,600	1,100	5.3	106
14	15,000	30	0.3	6
15	15,000	450	3 0	60
16	15,000	170	1.5	30
17	15,000	740	4 0	80
18	14,700	30	0.5	10
19	14,800	220	1.9	38
20	16,400	2,660	9.3	186
21	16,400	1,480	6 7	134
22	16,700	1,780	7.4	148
23	15,800	500	3.2	64
24	16,400	190	1 8	36
25	16,000	460	3 1	62
26	16,100	340	2.5	50
27	16,100	20	0.2	4
		TOTAL	85 9	1,718

Interpretations and uses of the chart which have to do with the relative effect of volume rather than the actual estimating of accident rates are less affected by the limitations of the sample. The orientation of the contours, for instance, shows that in these volume ranges the accident rate is much more sensitive to changes in crossroad volume than it is to changes in divided-highway volume. This observation indicates that no direct relation exists between intersection accident rates and the sum of the two entering volumes. As an example, Intersection A might have entering volumes of 13,000 and 1,300, while Intersection B has 14,000 and 300. The sum of the volumes is the same at both but, as read from the chart,

Figure 4. Typical intersection types: (A) Intersection 105, uncurbed crossover; (B) Intersection 146, curbed crossover; (C) Intersection 159, curbed and channelized; (D) Intersection 65, an older design; (E) Intersection 160, a recent design type; (F) Intersection 112, a very-low-volume T intersection; (G) Intersection 75, crossroad count is 2,500 vehicles per day; and (H) Intersection 116, old traveled way used as frontage road.

Intersection A would probably have 4.8 accidents per year, while Intersection B would have only 2.0 accidents per year.

As mentioned in the introduction, the average relation provides a means of correcting for the influence of volume differences when comparing one intersection accident rate with another. The comparison might be between different divided-highway intersection or it may be a comparison of rates at the same intersection for different periods. An example of the second case is the before-and-after intersection study in which the volume is higher during the after period. Such a study might produce the data below:

	Before	After
Divided-highway volume	12,000	13,000
Crossroad volume	900	1,400
Actual accident rate (Acc/Yr.)	8	9

The accident rate for the before period should be adjusted to the after volume, so a more equitable comparison can be made on the basis of constant traffic volume. The factor for making this adjustment is obtained from the chart as follows:

Factor =

$$\frac{\text{Ave. Acc. Rate for After Volume}}{\text{Ave. Acc. Rate for Before Volume}} = \frac{5.7}{4.1} = 1.4$$

This factor is then applied to the before rate:

$$1.4 \times 8 = 11 \text{ Acc/Yr.}$$

This amount, 11, is the probable number of accidents per year which would have occurred under the before condition at the after traffic volume. It is the number which should be compared with the nine accidents that actually did occur in order to measure the amount of improvement.

Looking at the chart once more, it can be seen that the one-accident-per-year contour lies much closer to the zero-accident-per-year contour than it does to the next higher contour. (By the definition of an intersection accident, the zero-accident-per-year contour must very nearly coincide with the zero-crossroad-traffic line.). Figure 3, part of a typical cross section of the surface taken at a divided-highway volume of 11,000 brings out the meaning of this observation. It shows that the average number of accidents per crossroad vehicle is reduced as the volume on the crossroad increases. It follows, then, that the concentration of cross traffic, through the closing of low-volume crossroads and the provision of frontage roads, is an effective means of reducing the number of accidents on divided highways.

For example, assume that a section of divided highway carrying 11,000 ADT intersects six county roads, each with an entering volume of 100 vehicles per day. Reference to the chart, or to Figure 3, shows that if a separate crossing is provided for each road, probably there will be an average of one accident per year at each intersection, or a total of six per year for the daily volume of 600 crossing vehicles. On the other hand, if frontage roads serving a single crossing are provided, the same volume probably will be involved in about three accidents per year.

While concentration is beneficial at low-volume crossroads, evidence was noted during the study that cross-road volumes above the limit of the chart again produce high accident rates per cross-road vehicle. This evidence, plus the fact that these volumes create congestion, gives added support to the belief that the only real solution to the traffic problem at high-volume crossroads is grade separation.

Appendix

List of the 150 intersections used to develop the accident-volume expression.

Intersection Number	Entering ADT Divided Highway	Entering ADT Crossroad	Accidents Per Year	Length of Accident Period (Years)
1	13,100	100	2.4	0.8
2	13,600	100	0.7	1.4
3	13,900	800	6.3	1.4
4	14,200	600	1.4	1.4
5	14,300	300	1.4	1.4
6	14,400	300	2.8	1.4
7	14,500	400	4.2	1.4
8	14,800	300	1.4	1.4
10	14,400	200	4.9	1.4
11	15,900	800	1.4	1.4
12	17,600	1,300	9.1	1.4
13	19,100	900	3.5	1.4
15	21,900	400	3.2	3.8
16	23,100	900	4.7	3.8
17	24,200	800	5.9	3.8
21	15,700	1,800	6.7	1.5
24	19,200	500	3.5	0.6
26	15,600	1,200	1.7	0.6
27	14,300	1,000	3.9	2.1
28	14,400	200	0	2.1
29	13,200	700	0.6	5.0
30	13,900	800	4.4	3.4
31	12,600	400	1.2	5.0
32	10,600	2,200	10.4	5.0
33	9,800	300	2.7	3.3
34	9,700	200	1.2	3.3
35	9,400	200	1.3	1.5
36	9,200	700	3.3	1.5
38	9,700	400	4.7	1.5
39	10,400	300	0.7	1.5
40	11,100	100	0	1.5
41	11,200	100	2.7	1.5
42	11,400	100	0	1.5
43	11,600	400	3.3	1.5
44	11,800	100	2.0	1.5
45	9,300	100	0.9	1.1
46	9,200	200	1.9	1.1
47	9,700	100	0.5	2.2
48	9,300	1,100	2.8	2.2
50	9,600	400	1.4	2.2
51	9,900	500	2.3	2.2
52	10,200	500	2.8	2.2
53	10,200	100	0.9	2.2
54	10,400	100	0.5	2.2
55	10,400	100	0.9	2.2
56	10,700	100	0	2.2
57	10,800	700	2.3	2.2
58	10,900	100	0.5	2.2

List of 150 intersections (continued)

Intersection Number	Entering ADT Divided Highway	Entering ADT Crossroad	Accidents Per Year	Length of Accident Period (Years)
59	11,000	100	0	2.2
60	11,000	100	0.9	2.2
61	10,000	300	0.2	5.0
62	10,000	600	2.8	5.0
63	10,400	400	2.8	5.0
64	11,100	500	1.4	5.0
65	11,700	900	2.0	5.0
66	12,600	900	7.0	5.0
67	13,000	200	1.0	5.0
68	13,000	300	2.1	3.7
69	13,000	2,000	21.3	0.8*
70	14,400	1,000	6.8	2.9
71	14,800	500	2.1	2.9
72	14,900	100	0.7	2.9
73	16,100	400	4.1	2.9
74	16,200	1,400	11.0	2.9
75	15,100	2,500	19.8	4.0
76	15,100	500	2.8	4.0
77	15,200	1,600	6.0	4.0
78	15,200	1,100	5.0	2.4
79	15,200	2,600	7.9	2.4
80	11,600	300	0.7	1.5
81	11,300	100	2.0	1.5
82	11,100	100	1.3	1.5
83	10,700	200	0.7	1.5
84	9,800	100	0.8	5.0
85	9,700	200	2.6	5.0
86	9,400	100	0.6	5.0
87	9,400	200	4.2	5.0
88	11,300	100	0	1.0
89	11,100	100	1.0	1.0
90	10,900	100	0	1.0
91	10,800	200	4.0	1.0
92	6,900	200	2.2	5.0
93	7,500	100	1.8	5.0
94	7,800	300	1.4	5.0
95	7,900	600	1.8	5.0
96	8,500	400	2.4	5.0
97	9,700	2,100	3.8	4.0
98	12,200	200	2.0	3.1
99	11,900	300	3.3	3.1
100	11,700	100	1.6	3.1
101	11,500	300	2.0	3.1
102	10,400	900	5.5	3.1
103	9,400	200	1.7	1.2
104	9,400	200	1.7	1.2
105	9,400	100	0	1.2
106	9,300	100	0.9	1.2
107	9,100	400	0	1.2
109	14,400	400	1.8	5.0
110	16,200	2,700	9.4	5.0

*Period before signals were installed.

List of 150 intersections (continued)

Intersection Number	Entering ADT		Accidents Per Year	Length of Accident Period (Years)
	Divided Highway	Crossroad		
111	11,400	500	3.6	5.0
112	10,500	100	0.6	5.0
113	10,200	100	1.2	5.0
114	9,500	100	0.2	5.0
115	8,800	300	1.4	5.0
116	9,900	1,300	3.0	3.3
117	9,700	400	2.4	3.3
118	9,300	1,100	4.2	3.3
119	8,400	1,300	3.6	3.3
120	8,200	800	2.1	3.3
125	10,300	200	1.0	3.1
126	10,100	100	1.3	3.1
127	10,200	300	0.6	3.1
128	10,000	300	0.7	3.1
129	9,500	700	7.4	3.1
130	9,300	100	1.0	3.1
131	9,400	200	3.9	3.1
132	9,400	100	1.3	3.1
133	9,400	300	1.9	3.1
134	9,500	200	2.6	3.1
135	9,500	400	4.9	3.1
136	9,600	100	2.6	3.1
137	9,500	1,200	9.6	3.3
138	14,500	1,200	8.8	5.0
139	13,600	900	2.6	5.0
140	8,500	200	0.8	5.0
141	8,400	300	1.0	5.0
142	8,400	200	0.4	5.0
143	8,900	100	0.6	4.7
144	9,300	3,100	6.0	4.7
145	6,300	400	0.9	4.7
146	6,800	200	0.4	4.7
147	7,800	1,300	3.5	4.3
148	9,400	1,100	3.0	3.1
149	9,000	100	0.9	3.5
150	9,000	100	0	3.5
151	9,000	100	0.6	3.5
152	9,000	600	3.7	3.5
153	9,000	300	2.3	3.5
154	9,500	100	1.6	3.8
155	10,300	500	3.3	3.3
156	10,600	700	0.3	3.5
157	11,300	1,500	4.0	1.3
158	11,900	100	1.6	1.3
159	11,700	600	0.9	1.2
160	10,900	200	0	1.2
161	10,700	300	2.6	1.2
163	10,500	300	4.2	1.4
169	13,900	400	2.8	1.4
170	13,700	300	2.1	1.4
171	13,000	1,600	6.3	1.4

Interstate Highway-Accident Study

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THE purpose of this study was to find out how accident rates on main rural highways are affected by design features and use characteristics. Fifteen states provided information covering a year's accident experience on about 5,000 mi. of highway.

The basic technique involved dividing the study routes into a large number of short, homogeneous sections, which could then be combined so as to group the sections according to any factors whose effects were of interest. An accident rate, based on vehicle-miles or other suitable units, was computed for each group. The factors studied include number of lanes, average daily traffic volume, degree of curvature, pavement and shoulder widths, frequencies of curves and other sight-distance restrictions, percentage of intersection traffic on the minor road, and many others.

Traffic volume was found to have strong effect on accident rates. On most types of highway sections the accident rate becomes higher with increasing traffic volume (except at extremely high volumes, where there is a slight reversal due to congestion). However, two-lane curves and intersections show a different trend, with the accident rates declining as volumes increase.

Sharp curves have higher accident rates than flat curves for roads carrying the same amount of traffic. The volume effect described above is more pronounced on sharp curves than on flat ones.

Wide pavements and shoulders encourage safety on two-lane curves. On two-lane tangents they do not have any consistent effect.

At intersections, the percentage of the total traffic on the minor road is extremely important. It takes only about 15 percent cross traffic to make an intersection more than twice as hazardous as when the cross traffic is less than 10 percent. Another important intersection characteristic is the number of approaches, e.g., three-way intersections are considerably safer than four-way crossings.

At bridges and underpasses there was found to be great value in having the roadway on the structure several feet wider than the approach pavement.

A number of roadway features do not appear to have any consistent effect on accident rates. These include grade, frequency of curves, and the percentages of commercial and night traffic.

● A POPULAR view has it that every accident has some principal cause, like speeding or driving on the wrong side of the road. The way to prevent accidents, according to this view, is to stop drivers from doing the things that stand highest on the list of principal causes.

The problem is not so simple. Every accident has many causes, if we consider a cause to be any remediable condition whose correction would have prevented the accident. For example, suppose two cars driven at high speed have a head-on collision at night on a two-lane road. The speed of the vehicles is obviously one cause of the collision. Other causes may be the use of blinding headlights, the absence of lighting on the highway, inadequate pavement width, and the fact that the road carries two-way instead of one-way traffic. Any of these may have contributed equally with speed to the accident, but the chances are that speeding will get most of the blame.

It is desirable to examine all the causes of an accident instead of concentrating on a single cause, because a wide variety of corrective measures may be suggested by a broad approach. Classifying accidents according to all their circumstances, regardless of how unimportant any particular circumstance may seem at first, offers the hope of discovering significant relationships between accident frequencies and associated circumstances which might otherwise escape notice.

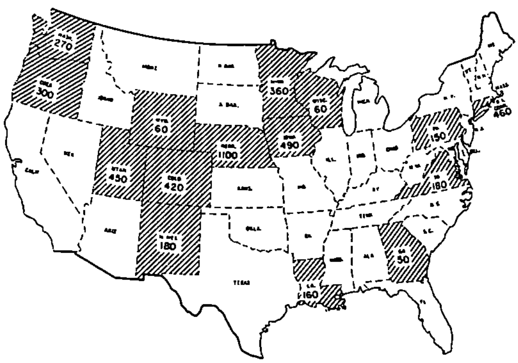


Figure 1. Mileage of study routes.

DESCRIPTION OF THE STUDY

The present study is an attempt to find out how rural traffic-accident rates are affected by various physical features of the highway and by certain use characteristics, such as average daily traffic and percentage of commercial vehicles. These are by no means the only causes of accidents. But if it should turn out, for instance, that roads with flat curves are appreciably safer than roads with sharp curves, then it would be possible to predict with some assurance the accident savings that would result from building flatter curves into the highways. Accidents have many causes, and an effective accident-reduction program ought to use the full range of remedies. This study is intended to throw light on those remedies which are in the domain of the highway designer.

Summary of the Findings

The most significant factors affecting accident rates are traffic volume, degree of curvature, pavement and shoulder width on curves, percentage of cross traffic at intersections, and the width of bridge roadways, both absolutely and in relation to their approach pavements. In most cases the effects are in the expected directions, but there are certain exceptions.

Volume of traffic has a strong effect on the accident rate on nearly all types of highway sections. In general, except for curves and intersections on two-lane roads, the accident rate becomes higher as the volume is increased. There is often a slight reversal of this trend at very high volumes, presumably because extreme congestion inhibits the drivers' ability to make passing maneuvers.

At curves and intersections on two-lane roads the trend goes the other way. Here the accident rates become lower with increased traffic volume. This effect has been well substantiated, but the reason for it remains a matter of speculation. A plausible theory is that the two-lane curves and intersections present conditions which most drivers recognize as hazardous, particularly when there is a considerable amount of traffic. Accordingly, the driver pays enough extra attention when these facilities are busy to more than compensate for the added potential danger.

Sharp curves have higher accident rates than flat curves. The volume effect described in the preceding paragraph is more pronounced on sharp curves than on flat ones.

Wide pavements and shoulders help to reduce the accident rates on two-lane curves. This is in contrast to the two-lane tangents, where no particular effect could be traced to the width of the pavement or the shoulders.

The percentage of cross traffic at an intersection has a tremendous effect on its accident rate. It takes only about 15 percent cross traffic to make an intersection more than twice as hazardous as

TABLE 1

LENGTH AND AMOUNT OF TRAVEL ON THE STUDY ROUTES

State	Year	Approximate length			Travel in study year		
		Tan.	Curves	Total	Tan	Curves	Total
		mi.			Million Veh-mi.		
Colorado	1941	350	70	420	380 4	77.3	457 7
Connecticut	1941	300	150	450	639.1	249 0	888.1
Connecticut	1946	310	150	460	508.6	200.0	708 6
Georgia	1940	40	10	50	40 5	13 7	54 2
Iowa	1941	430	60	490	303.2	41 9	345.1
Louisiana	1941	130	30	160	175 0	30 9	205 9
Minnesota	1946	290	70	360	180 4	48 0	228.4
Nebraska	1941	1,000	100	1,100	547 5	57 3	604.8
New Mexico	1941	160	20	180	64 9	5 0	69 9
Oregon	1941	210	90	300	220 9	58 0	278.9
Pennsylvania	1941	100	50	150	133 2	74 0	207 2
Utah	1941	370	80	450	238 9	46 0	284.9
Virginia	1941	150	30	180	275 4	54 9	330 3
Washington	1941	200	70	270	469 1	135.8	604.9
Wisconsin	1941	50	10	60	70 3	11 0	81.3
Wyoming	1941	50	10	60	22 4	4 4	26 8
Total		4,140	1,000	5,140	4,269.8	1,107.2	5,377.0

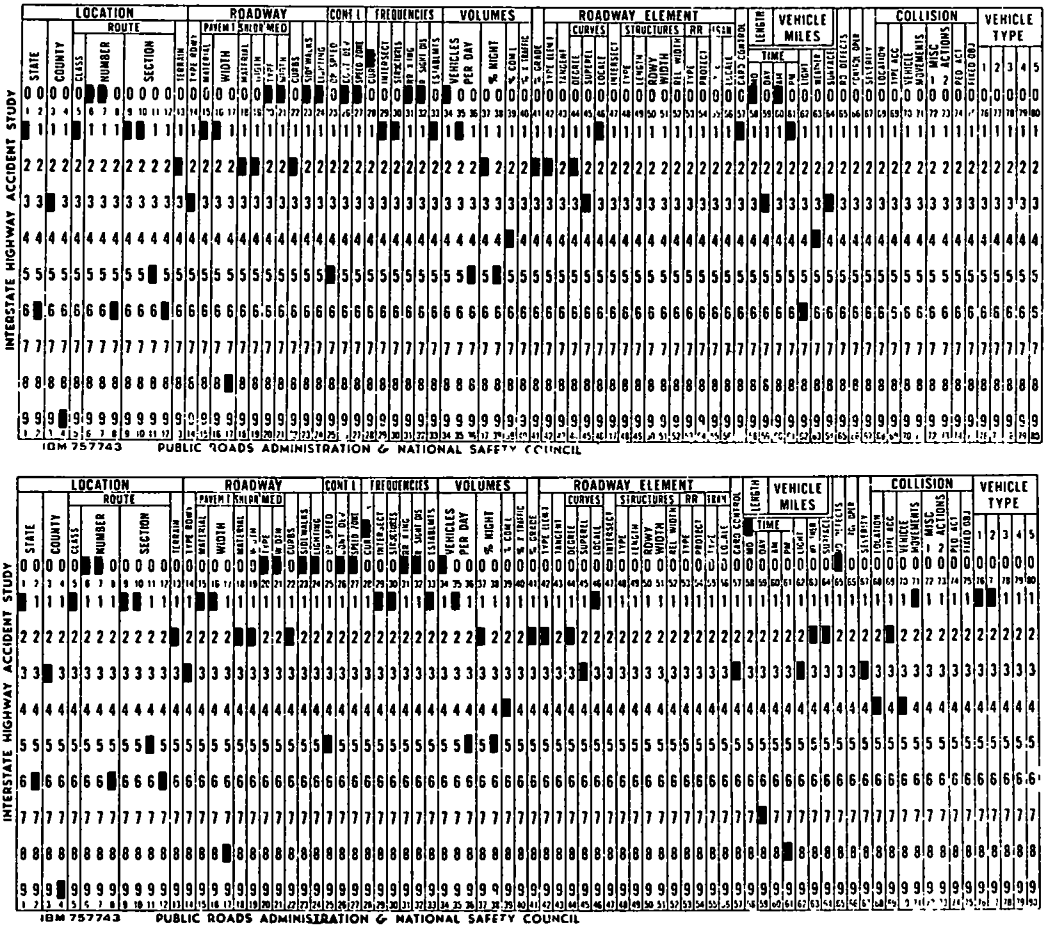


Figure 2. A highway card (above) and an accident card (below) on the same highway section.

when the cross traffic is well below 10 percent.

Another important intersection characteristic is the number of approaches. Three-way intersections (T's and Y's) have mardekly lower accident rates than four-way crossings. This is not necessarily an argument for staggering all crossings, however, as the increased number of intersections and the additional turning and weaving might easily nullify the apparent advantage.

Wide roadways are desirable at two-lane bridges and underpasses, and they should be several feet wider than the approach pavements. Of the two types of structures, underpasses are considerably more hazardous.

A number of roadway features did not appear to have any consistent effect on the accident rates. These include grade, pavement and shoulder widths, frequency of curves, frequency of sight restrictions, and the percentages of commercial and night traffic.

Technique of Study

To make it possible to study a large number of different highway features, the roads included in the study were divided into short homogeneous sections. Each of these sections was substantially uniform in grade, pavement width, shoulder width, degree of curvature, traffic volume, etc. Any place where a change occurred in any of these characteristics was made a dividing line between one section and another. Intersections and structures were also regarded as sections, because of their special characteristics, e.g., volume of traffic on the intersecting road, relative width of bridge roadway and adjoining pavement. The presence of an intersection of a structure was treated as a break between highway sections. Each accident was assigned to the highway section where it occurred.

TABLE 2

NUMBER OF HIGHWAY SECTIONS,
BY TYPE OF ROADWAY ELEMENT

State	Tan	Curves	Intersections	Structures	Railroad crossings	Other	Total
Colorado	1,239	571	604	207	13	2	2,636
Conn 1941	1,634	1,356	1,027	311	9	106	4,443
Conn 1946	1,628	1,317	1,020	329	9	106	4,409
Georgia	160	84	16	6			266
Iowa	1,434	493	686	293	13		2,919
Louisiana	333	148	108	64	19	11	683
Minnesota	1,402	533	612	54	13	2	2,616
Nebraska	2,683	559	1,107	298	34		4,681
New Mexico	416	77	16	58			567
Oregon	626	771	322	122	9		1,850
Pennsylvania	338	239	12	203		11	803
Utah	896	530	276	51	18	27	1,798
Virginia	832	240	263	92	2	14	1,443
Washington	1,093	610	537	83	17		2,340
Wisconsin	232	69	91	16	2	2	412
Wyoming	132	58	30	4	1		225
Total	15,078	7,655	6,727	2,191	159	281	32,091

The basic techniques for the study were devised by the National Safety Council in cooperation with the Bureau of Public Roads in 1945, following a pilot study on US 1 in Virginia.

All 48 states were invited to participate in the study, using as data the 1941 accidents on rural sections of the Interstate Highway System.[1] Only 15 states were able to do so, although a number of others expressed interest in the project. The chief obstacles to wider participation by the state highway departments were insufficient manpower to prepare the strip maps and the coding sheets, inability to locate accidents accurately, and incomplete accident reporting, in the sense that too many accidents went unreported. Two brief reports of preliminary findings have already been published.[2]

The participating states are given in Figure 1 and Table 1. For each state the table gives the year for which accidents were submitted[3], the number of miles of roadway included in the study, and the total amount of travel on those roads during the study year.

The data were recorded on punch cards. The original coding procedure called for two sets of cards.[4] One set, called highway cards, contains a card for each highway section. The second set, called accident cards, contains a card for each accident. In Figure 2, the upper picture is of a typical highway card; below it is an accident card representing an accident on the same highway section. The first 56 columns, which identify and describe the highway section, are identical on the two cards. This makes it possible to classify accidents according to various highway features without having to refer to the highway cards.

The punch in Column 57 indicates which type of card it is. The remaining columns serve different purposes on the two types of cards. On a highway card they give the length of the section and the annual vehicle-mileage of travel on it. On an accident card these columns contain information about the circumstances of the accident.

TABLE 3

NUMBER OF ACCIDENTS,
BY TYPE OF ROADWAY ELEMENT

State	Tan	Curves	Intersections	Structures	Railroad crossings	Other	Total
Colorado	676	130	225	80			1,111
Conn 1941	1,374	560	426	11		16	2,387
Conn 1946	1,223	439	287	81	1	67	2,098
Georgia	64	32	17	8			121
Iowa	461	100	98	20	1		680
Louisiana	531	39	107	14	2		693
Minnesota	254	46	170	13	5		488
Nebraska	638	77	121	29	6		871
New Mexico	89	10	9	1			109
Oregon	926	106	366	118			1,516
Pennsylvania	265	140	22	19		55	501
Utah	447	120	116	16	7		706
Virginia	648	164	250	51		2	1,115
Washington	1,962	509	1,119	86	17	1	3,694
Wisconsin	197	7	68	2			274
Wyoming	45	4	8				57
Total	9,800	2,483	3,409	549	39	141	16,421

A third type of card, the summary card, has recently been punched and used in some of the later analyses. There is one of these cards for each highway section, with the columns at the end of the card containing information about the number of accidents on the section.

Tables 2 to 4 indicate the size of the study. Table 2 shows the number of highway sections in each state, subdivided by

[1] 1941 was selected as the most-recent year in which driving conditions were normal A few of the states used other years (see Table 1), and some main rural highways were used which are not part of the Interstate Highway System

[2] C F McCormack, "A Plan for Relating Traffic Accidents to Highway Elements," AASHO Convention Group Meetings, 1944, pp 117-119 D M Baldwin, "The Relation of Highway Design to Traffic Accident Experience," AASHC Convention Group Meetings, 1946, pp. 103-109

[3] In addition to 1941, Pennsylvania submitted cards for accidents in the first 5 mo of 1942 These cards have not been used in any of the analyses covered in this report

[4] An outline of the punching code is presented in the appendix

types of roadway elements. Nearly half of the 32,091 highway cards represent tangent sections, and one fourth represent curve sections. About two thirds of the remainder represent intersections. The rest are for structures, railroad crossings, toll stations, and transitions of various kinds.

TABLE 4

NUMBER OF ACCIDENTS, BY SEVERITY, AND RATIOS AND ADJUSTMENT FACTORS

State	Number of Accidents				Ratio			Adjustment factor[1]
	Fatal	Injury	Other	Total	Total to fatal	Total to fatal-plus-injury	Injury to fatal	
Colorado	46	382	683	1,111	24 2	2 60	8 3	2 07
Conn 1941	51	1,018	1,318	2,387	46 8	2 23	20 0	1 07
Conn 1946	42	758	1,298	2,098	50 0	2 62	18 0	1 00
Georgia	8	47	66	121	15 1	2 20	5 9	3 31
Iowa	30	274	376	680	22 7	2 24	9 1	2 20
Louisiana	22	260	411	693	31 5	2 46	11 8	1 59
Minnesota	10	178	300	488	48 8	2 60	17 8	1 02
Nebraska	46	406	419	871	18 9	1 93	8 8	2 65
New Mexico	11	59	39	109	9 9	1 56	5 4	5 05
Oregon	39	288	1,189	1,516	38 9	4 64	7 4	1 29
Pennsylvania	20	193	288	501	25 0	2 35	9 7	2 00
Utah	33	283	390	706	21 4	2 23	8 6	2 34
Virginia	102	434	579	1,115	10 9	2 24	4 3	4 59
Washington	84	975	2,635	3,694	44 0	3 49	11 6	1 14
Wisconsin	9	89	176	274	30 4	2 80	9 9	1 64
Wyoming	4	27	26	57	14 2	1 84	6 8	3 52
Total	557	5,671	10,193	16,421	29 5	2 64	10 2	

[1] 50 divided by the total-to-fatal ratio These adjustment factors are used in computing the type 1 accident rates

Table 3 shows similar information regarding the accident cards. In all, there were 16,421 accidents, of which 60 percent were on tangents and 16 percent on curves.

Table 4 classifies the accident cards by severity within each state. There are cards for 557 fatal accidents, 5,671 personal-injury accidents, and 10,193 property-damage accidents.

Table 4 also lists certain ratios for each state. The ratio of the total number of accidents to the number of fatal accidents is a rough measure of the completeness of accident reporting. It has its limitations, however, for while all fatal accidents are probably reported, it is most unlikely that the true total-to-fatal ratio is the same in every state. In any event, this ratio is the basis of an adjustment which is used in some of the rate computations.

The ratio of all accidents to those involving either deaths or injuries has a similar interest. It might also be used for adjustments, but this has not been done so far. This ratio varies much less among the different states than does the total-to-fatal ratio.

The table also shows the ratio of the number of injury accidents to the number of fatal accidents in each state, and the last column lists the adjustment factors based on the total-to-fatal ratio.

METHOD OF ANALYSIS

It was difficult to decide how to combine the detailed data from different states. The reporting requirements vary, and it cannot be assumed that the reporting laws are fully complied with in every state. There are three essentially different ways of dealing with this problem. One way is to use a system of weights involving an adjustment factor for each state. A state which is believed to report only half its accidents would have an adjustment factor of 2, so that each reported accident would count as two adjusted accidents. This is substantially the approach that was used by McCormack and Baldwin in their earlier reports of preliminary findings from this study. The trouble with adjustments is that they give the most weight to the least reliable data, and that the adjustment factors are computed on the basis of a dubious assumption.

A second approach would dispense with adjustments but would use only the data from states whose reporting meets a certain standard. This avoids the distortions caused by the adjustment process, but it has the drawback of reducing the amount of usable data. A variation of this approach would use only the fatal accidents (in all the states), or only the fatal and injury accidents. To use only fatal accidents is impractical, however, for it would reduce the study to only 557 accidents. The use of both fatal and injury accidents has more to commend it, but there would still be a heavy reduction in the amount of data available for analysis. Moreover, it is doubtful that fatal (or fatal and injury) accidents are affected by highway features in the same way as accidents of all degrees of severity combined.

The third approach is to ignore the problem altogether and simply count up all the accidents in all the participating states, irrespective of the variation in reporting standards For all its crudeness, this method turns out to be generally superior to the other two.

All three of these approaches have been used. (The choice among them is explained in the final section of the report.) In the ensuing discussion they will be called

Type 1 rates, Type 2 rates, and Type 3 rates respectively. The Type 1 rates use all the participating states, with the number of accidents in each state multiplied by the adjustment factor given in the last column of Table 4.[5] The Type 2 rates do not use adjustments, and use only those states having a total-to-fatal ratio of at least 25. The Type 3 rates use all the participating states, without adjustment.

Once it has been decided which material to use and whether the count should be of actual or of adjusted accidents, the puted and examined to see if there is a steady trend or other close relation between accident rate and grade. If the rates show indications of a trend but are somewhat irregular, it is possible to make a statistical test of whether or not a trend really exists.

The slope of the "best" straight line — the regression coefficient — is computed, with each rate weighted in proportion to the amount of travel on which it is based. Also computed are the confidence limits of this slope, from which one can tell at

TABLE 5

ACCIDENT RATES ON TANGENTS, BY GRADE AND ROADWAY TYPE

Grade	Two-lane roads		Three-lane roads		Four-lane roads					
					Undivided		Divided [1]		Controlled access	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles
Type 1 accident rates (All states, using adjustment factors)										
Percent										
Less than 3	5,442	3 7	194	6 1	1,043	6 0	827	4 7	504	2.2
3 - 3 99	321	4 0	18	5 6	136	7 1	83	3 4	139	2 9
4 - 4 99	253	3 6	6	7 7	65	6 8	56	4 4	59	1 6
5 - 5 99	322	4 4	3	4 4	49	6 8	9	3 6	46	2 1
6 - 6 99	86	4 0	1	10 0	29	10 2	1	1 4	13	1 7
7 or more	49	3 9	5	14 4	26	10 1	6	15 6	13	1 5
Less than 3	5,442	3 7	194	6 1	1,043	6 0	827	4 7	504	2 2
3 or more	1,031	4 0	33	6 8	305	7 5	155	4 1	270	2 3
Type 2 accident rates (Selected states,[2] without adjustment)										
Less than 3	3,507	3 0	100	6 5	644	3 3	701	3 0	504	1.6
3 - 3 99	219	3 3	14	3 4	78	3 5	78	2 5	139	1 7
4 - 4 99	175	2 7	1	1 2	12	2 0	43	3 0	59	1 5
5 - 5 99	259	4 2	0	0 0	18	3 7	6	1 8	46	1 4
6 - 6 99	50	2 9	0	-	0	-	1	2 5	13	1 6
7 or more	48	3 7	0	-	5	6 3	0	-	13	1 5
Less than 3	3,507	3 0	100	6 5	644	3 3	701	3 0	504	1 6
3 or more	751	3 4	15	2 7	113	3 4	128	2 6	270	1 6
Type 3 accident rates (All states, without adjustment)										
Less than 3	5,442	2 2	194	2.6	1,043	2 7	827	2 9	504	1 6
3 - 3 99	321	2 3	18	2 5	136	2 8	83	2 5	139	1 7
4 - 4 99	253	2 2	6	2 3	65	2 0	56	2 6	59	1.5
5 - 5 99	322	3 1	3	0 9	49	2 3	9	1 8	46	1 4
6 - 6 99	86	2 2	1	2 0	29	2 4	1	1 4	13	1.6
7 or more	49	3 7	5	3.1	26	2 6	6	3.3	13	1.5
Less than 3	5,442	2 2	194	2 6	1,043	2 7	827	2 9	504	1.6
3 or more	1,031	2 5	33	2 2	305	2 4	155	2 5	270	1 6

[1]Excluding highways with controlled access This applies to all the tables
[2]States having a total-to-fatal ratio of 25 or more This applies to all the tables

process of computing a rate involves (1) counting the total number of accidents on sections in a particular category, (2) adding up the total vehicle-mileage on these sections, and (3) dividing the former sum by the latter to get the rate in terms of accidents per million vehicle-miles. To study the effect of grade, for example, the highway sections are divided into several groups on the basis of their grades. Then the rates for these groups are com- a glance how reliable the estimated slope is and whether or not it is significantly different from zero. These quantities are presented in those cases where they will aid in understanding the analyses.[6]

[5]Use of these adjustment factors involves the assumption that the total-to-fatal ratio would be the same in every state if the reporting standards were identical There is at least one state in the present study for which this assumption is clearly unreasonable See Footnote 12

[6]For those to whom the correlation coefficient is more familiar than the regression coefficient, it should be pointed out that the two are closely related ($b = r\,\sigma_y/\sigma_x$, where $\underline{b}$ is the regression coefficient, $\underline{r}$ the correlation coefficient, and σ_y and σ_x the standard deviations of $\underline{y}$ and $\underline{x}$ respectively) The significance of the departure of b from zero is the same as that for r The use of b has two advantages, however, over the use of r (1) it is of more inherent interest, since it may be more important to know about a relationship of steep slope with low reliability than one of small slope with high reliability, (2) if the true relationship is a straight line, the estimated value of b is normally distributed while that of r is highly skewed So the estimate of b is much less affected by sample size than that of r

RESULTS: ACCIDENT RATES VERSUS HIGHWAY FEATURES

For study purposes the highway sections have been classified as tangents, curves, intersections, structures, and miscellaneous (railroad grade crossings, toll stations, and transitions in width of roadway or median). These are further subdivided according to the number of lanes on the study route.

Some of the material is presented in tables, some in bar graphs. Most of the tables present the three types of accident rates already described. As a guide to the reliability of the various rates, there is presented, along with each rate, the actual number of accidents on which it is based.

The graphs, with one exception, show only the Type 3 rates, i. e., the ones which use accidents from all the states without any adjustments. On these graphs the bars differ in width according to the number of vehicle-miles on which each rate is based.

TANGENTS: EFFECT OF GRADE

Two-Lane Roads

Table 5 shows how the accident rates on tangents vary with the gradient of the highway. On two-lane roads there does not appear to be any particular relation between accident rate and grade, no matter which of the three rate types is considered.[7] For each of the three types the slope (regression coefficient) is positive, i. e., the accident rate tends, on the average, to increase as the grade increases. However, none of the three slopes is significantly different from zero at the 5-percent level of significance.[8] This means that the amount of scatter is such that there is more than a 5-percent chance that the true slope may be zero or negative.

The three types of accident rates differ considerably. The Type 1 rate is the highest, because it includes accidents which are assumed to have occurred without being reported. The Type 3 rate is the lowest, because it uses only the accidents that were actually reported and includes states in which the reporting is known to be poor. The Type 2 rate is in between. It might be thought that this rate would be the most reliable, because it includes only the accidents actually reported in states where reporting is presumed to be good; but it suffers from being based on a smaller sample than the other two types of rates.

A disturbing feature in all three types of rates is the large amount of apparently meaningless fluctuation. For example, the Type 2 rate takes the values 3. 0, 3. 3, 2. 7, 4. 2, 2. 9, and 3. 7 as the grades increase steadily. These fluctuations are too large to be due to sampling variation. They cannot be a result of the adjustment process, for they are just as prominent in the unadjusted rates (Type 2 and 3) as in the adjusted one; anyway, the same effect is found within individual states. Nor are they peculiar to the effect of grade; similar fluctuations occur with most other highway features. They may be due to the oversimplification caused by studying only one or two features at a time while ignoring all the rest, or they may be a result of the difficulty in obtaining absolutely accurate data. This could have the effect of obscuring relations which really exist. There is some evidence to support the latter belief.[9]

To sum up, the accident rate on two-lane tangents does not appear to be significantly affected by grade.

Three-Lane Roads

On three-lane tangents, as on the two-lane tangents, most of the travel was on roads of less than 3-percent grade, large fluctuations are present in the accident rates, and no reliable relation is found between accident rate and the percent of grade. The slopes for the Types 1 and 3 rates lack statistical significance, as with the two-lane roads. The Type 2 rate has a significant negative slope, with the rate declining as the grades become steeper; but the decline is meaningless, because

[7] This statement refers to the total correlation between accident rate and grade, ignoring all other highway features It may be that, when the appropriate other features are held constant, there is a significant partial correlation All the statements which will be made in connection with single-factor analyses refer to total correlations only

[8] The 5-percent level is widely used in statistical analyses

[9] After submitting the data for the present study, Minnesota conducted another study of the same highway which in some respects parallels the work being described here The collection of data was all new, none of the information being carried over from the earlier work Very great care was used in checking all information, particularly with regard to the exact locations of accidents The value of this care is demonstrated by the greater consistency of the results in their report, "Minnesota Rural Trunk Highway Accident, Access Point and Advertising Sign Study" (1951)

it is due to a peculiar distribution of travel among the different states. The high rate for roads of less than 3-percent grade is caused entirely by the figures from one state, Oregon, which included no roads with higher grades. If Oregon data are excluded from the Type 2 rate, the significant relation disappears.

Four-Lane Roads, Undivided

On four-lane tangents without a median, it seems unlikely that the grade has any effect on the accident rate, even though the Type 1 rate does have a significant upward slope of 0.69 ± 0.48 per percent grade. (This means that the rate increases by about 0.69 for each 1-percent increase in the grade. There is a 95-percent chance that the true slope is between $0.69 - 0.48 = 0.21$ and $0.69 + 0.48 = 1.17$.) The Type 3 rate, which uses the very same accidents and vehicle-mileage, tends to become smaller as the grades increase out in a way which does not indicate a statistically significant trend. The Type 2 rate is irregular but shows a slight tendency to increase as the grades increase.

This is an example of how each type of accident rate can point to a different conclusion. It appears that grades in the range used on main rural highways do not have any appreciable effect on the accident rate for four-lane undivided tangents, especially in view of the fact that the significant rate of increase for the Type 1 rate is due to a peculiar circumstance which distorts the true picture.[10]

Four-Lane Roads, Divided

For four-lane tangents having a median but no control of access, the accident rates are also inconclusive. None of the slopes is statistically significant, but there is some tendency for the rate to decline as the grade increases.

Four-Lane Roads, Divided, with Controlled Access

On these roads, too, the grade does not have any particular effect on the accident rates.

[10]Virginia, whose adjusted accident rate is much higher than that of any of the other states, contributes increasing proportions of the total travel as the grades increase This makes the Type 1 rate appear to increase, even though there is no increase when Virginia is considered by itself or when all the other states are considered with only Virginia excluded See Footnote 12.

Summary

On tangent highway sections there does not appear to be any relation between grade and accident rates. In these analyses the roads have been classified only by grade, so it remains possible that grade may have some effect on the accident rate when the appropriate other features are held constant.

TANGENTS: EFFECT OF VOLUME

Two-Lane Roads

Figure 3 shows how the accident rate on two-lane tangents varies with the average daily traffic when all other characteristics of the highway section are ignored. This is a typical example of the type of bar graph used in this report. Each bar conveys three distinct pieces of information. The height of the bar indicates the Type 3 accident rate for the set of roads which the bar represents. The horizontal position of the bar indicates the average daily traffic volume on the roads represented. The width of the bar indicates the number of vehicle-miles of travel on which the rate is based. No scale is shown for these widths, since it is only the relative widths that matter. The scales are different in each graph.

To be concrete, the first bar in Figure 3 shows that the Type 3 rate is 1.3 for roads carrying from 0 to 900 vehicles per day. The next bar shows the rate to be for 1.6 for roads carrying from 1,000 to 1,900 vehicles per day, and that this rate is based on about five times as much experience as the first rate. And so on.

The graph suggests a definite pattern, which in fact is the same for all three types of rates.[11] The accident rate increases steadily with increasing volume, reaching a maximum for roads carrying 8,000 to 9,000 vehicles per day. Heavier traffic reduces the accident rate somewhat, presumably because the extreme congestion at such high volumes makes it difficult for drivers to engage in passing maneuvers. The latter point is of small interest to the highway designer, who would hardly recommend two-lane construction for a road expected to carry as many as 9,000 vehicles per day.

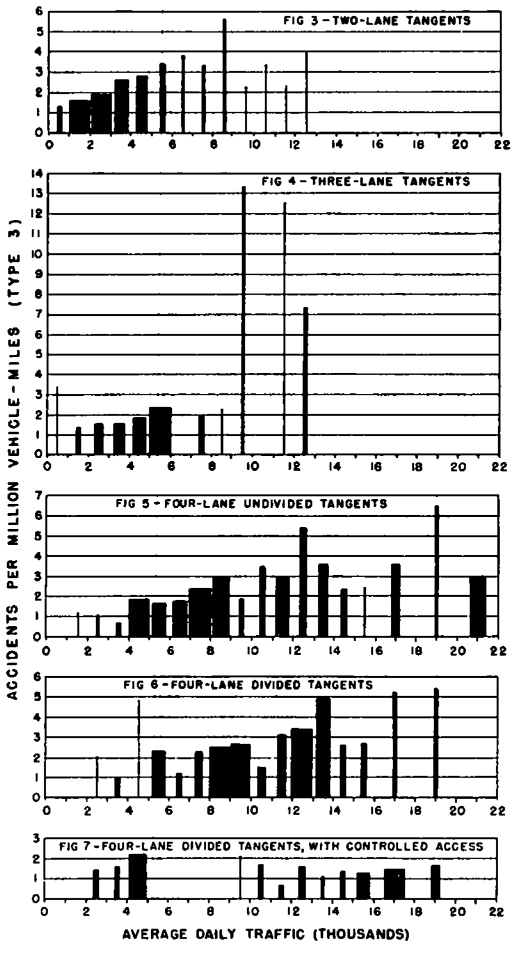
In the range that is of principal interest the relation is simple and straightforward:

[11]Information concerning all three types of rates is presented in Table 6.

higher traffic volumes mean higher accident rates.

Three-Lane Roads

There is a similar increase on three-lane tangents, as shown in Figure 4. The Type 1 and Type 3 rates[11] both increase significantly as the traffic volume becomes larger. The information for the Type 2 rate is too fragmentary to be of much value.



Figures 3-7. Accident rates on tangents, by volume of traffic.

Four-Lane Roads, Undivided

Figure 5 represents the condition on four-lane undivided tangents. All three types of accident rates[11] have a pattern similar to that for the 2-lane tangents: the rate goes up until a certain volume is reached, after which it drops down again. But the three types of rates do not have their maxima at the same traffic volume. The Type 1 rate reaches its peak between 5,000 and 10,000 vehicles per day, while the Type 2 and Type 3 rates are highest for volumes between 15,000 and 20,000. The Type 1 rate would have its peak in this same range if the Virginia figures were omitted.[12]

Four-Lane Roads, Divided

Figure 6 shows the same information for four-lane divided tangents without controlled access. The pattern is the same as before, with the accident rate going up as traffic volume increases. If there is any volume above which the accident rate begins to drop, it is beyond the range of these data, for which the maximum volume is 20,000 vehicles per day.[13]

Four-Lane Roads, Divided, with Controlled Access

The accident rates for these roads are shown in Figure 7. The rates appear to be somewhat lower for high volumes than for low volumes.

The appearance is misleading. The volumes under 5,000 come almost exclusively from Pennsylvania, while the volumes over 5,000 are all from Connecticut. The comparison is not so much between low volumes and high volumes as between Pennsylvania and Connecticut. Pennsylvania's accident rate is higher than Connecticut's, even though the average volumes are 4,000 and 15,000 respectively.

Examination of the trend within each state shows that in Pennsylvania, where the volumes range from 3,000 to 5,000 vehicles per day, the accident rate increases steadily with increasing volume, but it is hard to draw conclusions from such a small range of volumes. In Connecticut the range is wide, and there is no significant trend. The evidence at hand does not indicate that traffic volume has

[12] The Virginia data play a disturbing role in many of the Type 1 rates They have a low total-to-fatal ratio, with the consequently high adjustment factor of 4.59 Yet this adjustment factor seems excessive, for the adjusted accident rates are usually much higher for Virginia than for the other states For example, on four-lane undivided tangents carrying between 5,000 and 9,900 v p d , the adjusted accident rate for Virginia is 10.4 while it is only 3.7 for all the other states combined Both rates are based on more than 200 accidents

[13] The Type 1 rate is higher in the 10,000 to 14,900 group than in the 15,000 to 19,900 group, but this is due to the peculiar effect of Virginia discussed in Footnote 12

any particular effect on the accident rate on four-lane divided tangents with controlled access.

Below 5,000 the information is fragmentary. Between 5,000 and 10,000 vehicles per day, the three-lane roads are

TABLE 6

ACCIDENT RATES ON TANGENTS, BY VOLUME OF TRAFFIC AND ROADWAY TYPE

Average daily traffic	Two-lane roads		Three-lane roads		Four-lane roads					
					Undivided		Divided		Controlled access	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles
Type 1 accident rates (All states using adjustment factors)										
Vehic per day										
0 - 4,900	5,007	3 6	79	5 3	129	5 6	25	3 1	265	4.0
5,000 - 9,900	1,396	4 3	102	6 6	481	7 3	388	4 0	3	2 1
10,000 - 14,900	71	3 6	46	10 4	422	6 9	465	5 3	166	1 4
15,000 or more	0	-	0	-	317	4 1	126	5 1	340	1 5
Type 2 accident rates (Selected states, without adjustment)										
0 - 4,900	2,868	2 9	5	2 0	18	1 4	19	1 4	265	2 0
5,000 - 9,900	1,320	3 8	64	4 8	117	3 2	280	2 4	3	2 1
10,000 - 14,900	71	3 3	46	8 1	309	3 5	380	3 5	166	1.4
15,000 or more	0	-	0	-	314	3 7	126	4 4	340	1 5
Type 3 accident rates (All states, without adjustment)										
0 - 4,900	5,007	2 1	79	1 6	129	1 6	25	1 6	265	2 0
5,000 - 9,900	1,396	3 6	102	2 9	481	2 2	388	2 4	3	2 1
10,000 - 14,900	71	3 3	46	8 1	422	3.5	465	3 4	166	1.4
15,000 or more	0	-	0	-	317	3 6	126	4 4	340	1 5

Summary

The foregoing material is summarized in Table 6. In most cases the average daily traffic has a considerable effect on the accident rate on tangent highway sections. The common pattern is for the accident rate to increase as the volume increases. At very-high volumes the accident rate usually drops somewhat, probably because of congestion.

As between the different types of roads at the same volumes, the conclusions depend on which type of accident rate is examined. Judged by the Type 1 rate, the safest roads at volumes below 10,000 vehicles per day are the four-lane divided roads without controlled access, followed closely by the two-lane roads; the four-lane undivided roads are the worst in this volume range. Above 10,000 vehicles per day the four-lane divided roads with controlled access are far and away the safest, while the three-lane roads have much the highest accident rates.

The Type 3 rates show little difference between road types for volumes under 5,000 v.p.d., while the two-lane roads have the highest Type 3 rate for volumes between 5,000 and 10,000. Above 10,000 the conclusion is the same as before: the three-lane roads are the most hazardous, while the controlled-access four-lane roads are the safest.

The Type 2 rates are still different. Below 5,000 the information is fragmentary. Between 5,000 and 10,000 vehicles per day, the three-lane roads are the worst, while the four-lane divided roads without controlled access are the safest of those for which the samples are adequate. Above 10,000 vehicles per day the conclusion is the same as for the Types 1 and 3 rates.

TWO-LANE TANGENTS: EFFECTS OF OTHER FEATURES

Since traffic volume has a pronounced effect on accident rates, it is desirable to group the roadway sections by volume before studying the effects of other factors. Alternatively, the volume itself can be made one of the independent variables in a multiple regression analysis, a procedure which separates the effects of different factors. Both approaches have been used.

TABLE 7

ACCIDENT RATES ON TWO-LANE TANGENTS, BY WIDTH OF PAVEMENT

Pavement width	Type 1 (All States, using adjustment factors)		Type 2 (Selected States, without adjustment)		Type 3 (All States, without adjustment)	
Feet	Number	Per mil vehic -miles	Number	Per mil vehic -miles	Number	Per mil vehic -miles
16 or less	246	5 5	246	3 3	246	4 3
18	1,795	4 0	742	2 9	1,795	2 1
20	3,263	3 4	2,434	3 0	3,263	2 3
21 or 22	506	4 7	359	3 1	506	2 6
23 or 24	299	3 8	138	3 9	209	1 9
25	45	2 4	38	1 9	45	1 6
26	47	4 0	47	3 6	47	3 3
27	47	3 3	42	3 4	47	2 5
28	132	4 6	132	3 6	132	3 6
29 or more	94	3 1	81	2 8	94	2 5

Grade and Volume Together

With grade and volume as independent variables, the multiple analysis corroborates the earlier conclusion that grade has no statistically significant effect on the accident rate, while volume does.

TABLE 8

ACCIDENT RATES ON TWO-LANE TANGENTS BY WIDTH OF SHOULDERS

Shoulder width	Type 1 (All States using adjustment factors)		Type 2 (Selected States without adjustment)		Type 3 (All States, without adjustment)	
Feet	Number	Per mil vehic -miles	Number	Per mil vehic -miles	Number	Per mil vehic -miles
Curb	10	2 9	3	0 8	10	1 4
0 - 4 9	2 673	3 9	2,012	3 1	2,673	2 6
5 - 7 9	2 789	3 6	1 556	3 1	2 789	2 0
8 - 9 9	525	3 6	338	3 0	525	2 4
10 or more	476	4 1	350	3 3	476	2 8

Pavement Width Alone

If the two-lane tangents are classified solely according to their pavement width, irrespective of traffic volume, shoulder width, or other factors, the results are as shown in Table 7. The evidence is confusing. It is not even clear whether 24-ft. pavements are safer than 20 -ft. pavements; the Type 3 rate suggests that they are, while the Types 1 and 2 rates indicate that they are not. Neither is it definitely established that very narrow pavements have the highest accident rates. The Types 1 and 3 rates indicate that they do, but the Type 2 rate shows pavements of 16 ft. as having a lower accident rate than those of 24 ft.

Shoulder Width Alone

Similar information about the effect of shoulder width is presented in Table 8. There is no indication that shoulder width, considered alone, has any bearing on the accident rates.

Pavement Width, Shoulder Width, and Volume

With the roads grouped according to traffic volume in 5,000 v.p.d. intervals, a multiple analysis has been made in each group, using pavement width and shoulder width as the independent variables. The complete table is too complicated for inclusion here, but a condensed version is given as Table 9.

None of the effects is statistically significant. In neither the 0-to-4,900 nor the 5,000-to-9,900 volume group is there a statistically significant effect on either the Type 1 or the Type 3 accident rate due to

TABLE 9

ACCIDENT RATES (TYPE 3) ON TWO-LANE TANGENTS, BY VOLUME OF TRAFFIC, PAVEMENT WIDTH, and SHOULDER WIDTH

Pavement width	Less than 5 feet: Number	Less than 5 feet: Per mil vehicle-miles	5 - 7 9 feet: Number	5 - 7 9 feet: Per mil vehicle-miles	8 - 9 9 feet: Number	8 - 9 9 feet: Per mil vehicle-miles	10 feet or more: Number	10 feet or more: Per mil vehicle-miles	Total: Number	Total: Per mil vehicle-miles
	0 - 4,900 vehicles per day (Shoulder width)									
Feet										
16 or less	97	2 8	96	5 2	0	-	1	3 3	194	3 6
18	679	2 0	871	2 1	82	2 0	58	3 8	1,690	2 1
20	991	2 7	1,027	1 6	223	1 8	66	1 6	2,307	2 0
21-22	193	2 4	25	1 4	65	2 5	117	2 9	400	2 4
23-24	67	2 5	167	1 5	16	2 1	9	2 7	259	1 7
25 or more	35	2 3	61	1 6	0	-	55	2 6	151	2 1
Total	2,062	2 4	2,247	1 8	386	2 0	306	2 5	5,001	2 1
	5,000 - 9,900 vehicles per day									
16 or less	4	4 0	48	20 0	0	-	0	-	52	15 3
18	14	1 7	73	3 5	12	2 0	2	2 5	101	2 8
20	469	3 5	237	3 0	104	7 9	71	2 9	881	3 5
21-22	49	3 0	29	2 7	23	11 5	5	1 7	106	3 3
23-24	13	9 3	27	7 3	0	0 0	0	-	40	6 8
25 or more	33	3 9	88	2 9	0	-	92	4 4	213	3 6
Total	582	3 4	502	3 4	139	6 3	170	3.5	1,393	3 6
	All volumes									
16 or less	101	2 8	144	7 0	0	-	1	3 3	246	4 3
18	693	2.0	944	2 1	94	2 0	60	3 7	1,791	2 1
20	1,497	2 9	1,297	1 8	327	2 4	137	2 1	3,258	2 3
21-22	242	2 5	54	1 9	88	3 2	122	2 8	506	2.6
23-24	80	2 8	194	1 7	16	1 9	9	2.7	299	1 9
25 or more	68	2 8	150	2 2	0	-	147	3 5	365	2 7
Total	2,681	2 6	2,783	2 0	525	2 4	476	2 8	6,465	2 2

(1) pavement width, for constant shoulder width; (2) shoulder width, for constant pavement width; or (3) pavement width and shoulder width acting together.[14] That is, the material in this study indicates that neither pavement width nor shoulder width nor any combination of them has a determinable effect on the accident rates on two-lane tangents.

TABLE 10

ACCIDENT RATES ON TWO-LANE TANGENTS BY FREQUENCY OF CURVES

Frequency of curves	Type 1 (All States, using adjustment factors)		Type 2 (Selected States without adjustment)		Type 3 (All States, without adjustment)	
No. per mile	Number	Per mil vehic -miles	Number	Per mil vehic -miles	Number	Per mil vehic -miles
0 - 0.4	1,251	4.0	442	3.1	1,251	1.7
0.5 - 0.9	1,463	3.9	649	3.4	1,463	2.1
1.0 - 1.4	580	3.4	329	2.7	580	2.0
1.5 - 1.9	771	3.4	573	2.4	771	2.2
2.0 - 2.9	588	4.2	492	3.8	588	3.1
3.0 - 3.9	552	3.1	508	3.0	552	2.6
4.0 - 4.9	806	3.8	806	3.5	806	3.5
5.0 - 5.9	405	3.2	405	3.0	405	3.0
6.0 - 6.9	55	5.5	55	4.3	55	4.3
7 or more	0	-	0	-	0	-

"frequency sections" averaging 10 to 15 mi. in length. Every card contains all the frequency information for the frequency section to which it belongs.

Table 10 shows how the accident rates on two-lane tangents vary with the average number of curves per mile. As usual, the result depends on which figures are examined. The only rates with a significant trend are the Type 3 rates, which go up as the curves become more frequent. The Types 1 and 2 rates suggest an opposite conclusion, that the tangent sections interspersed with one or two curves per mile are safer than those in places where curves are quite rare. Either conclusion, once established, has a plausible explanation, but the figures are confusing. Even the simple fact that all three types of rates have their highest values for curve frequencies of six or more curves per mile is not so simple as it seems, for the state which supplied all these sections,

TABLE 11

ACCIDENT RATES (TYPE 3) ON TWO-LANE TANGENTS, BY VOLUME OF TRAFFIC, FREQUENCY OF CURVES, AND LENGTH OF TANGENT

Frequency of curves	0 - 4,900 vehicles per day — Length of tangent: Less than 1 mile		1 - 1.9 miles		2 - 2.9 miles		3 miles or more		Total	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles
Number per mile										
Less than 0.5	66	1.9	64	1.5	135	2.5	881	1.6	1,146	1.7
0.5 - 0.9	213	1.9	279	2.2	197	2.0	466	1.5	1,155	1.8
1 - 1.9	492	2.0	232	1.7	75	1.5	231	2.6	1,030	2.0
2 - 2.9	342	2.7	51	2.8	4	1.0	7	3.3	404	2.7
3 or more	1,071	2.9	95	2.4	26	2.8	26	4.9	1,218	2.9
Total	2,184	2.5	721	2.0	437	2.0	1,611	1.7	4,953	2.0
5,000 - 9,900 vehicles per day										
Less than 0.5	16	8.4	0	-	0	-	68	4.0	84	4.4
0.5 - 0.9	88	4.7	17	3.5	119	4.9	63	3.8	287	4.5
1 - 1.9	190	2.9	33	1.4	0	0.0	45	3.8	268	2.6
2 - 2.9	128	4.1	51	5.3	0	-	0	-	179	4.3
3 or more	408	3.2	93	4.8	19	5.3	31	8.4	551	3.6
Total	830	3.4	194	3.4	138	4.8	207	4.2	1,369	3.6
All volumes										
Less than 0.5	82	2.2	64	1.5	135	2.5	949	1.6	1,230	1.7
0.5 - 0.9	301	2.3	296	2.2	316	2.6	529	1.6	1,442	2.0
1 - 1.9	714	2.2	265	1.7	75	1.5	276	2.8	1,330	2.1
2 - 2.9	470	3.0	102	3.7	4	1.0	7	3.3	583	3.1
3 or more	1,488	2.9	188	3.7	73	4.1	57	6.3	1,806	3.1
Total	3,055	2.7	915	2.2	603	2.4	1,818	1.8	6,391	2.3

Frequency of Curves

In the belief that driver behavior and accident experience might be affected by the frequencies of occurrence of curves, intersections, and other such features, the study routes have been divided into

[14]For (1) and (2) the statistical tests are t tests of the partial regression coefficients. For (3) they are F tests of the multiple correlation coefficients. The two types of tests are equivalent when there is only one independent variable.

Oregon, has a still higher accident rate for frequencies between 4.0 and 4.9.

Curve Frequency, Tangent Length, and Volume

Table 11 gives a multiple breakdown of the Type 3 accident rates by curve frequency, tangent length, and traffic volume. The length is that of the entire

TABLE 12

ACCIDENT RATES (TYPE 3) ON TWO-LANE TANGENTS, BY VOLUME OF TRAFFIC, FREQUENCY OF INTERSECTIONS, AND FREQUENCY OF STRUCTURES

Frequency of intersections	Number of structures per mile					
	Less than one		One or more		Total	
No. per mile	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles
0 - 4,900 vehicles per day						
Less than 0 5	357	1 8	19	1 9	376	1 8
0 5 - 0 9	798	1 9	47	1 3	845	1 8
1 - 1 9	2,425	1 9	280	2 2	2,705	1 9
2 - 2 9	675	2 8	28	7 6	703	2 9
3 or more	359	2 7	13	5 9	372	2 7
Total	4,614	2 0	387	2 2	5,001	2 1
5,000 - 9,900 vehicles per day						
Less than 0 5	23	5 0	0	-	23	5 0
0 5 - 0 9	23	11 5	0	-	23	11 5
1 - 1 9	382	4 3	87	4 0	469	4 2
2 - 2 9	553	3 5	48	20 0	601	3 8
3 or more	278	2 5	0	-	278	2 5
Total	1,259	3 5	135	5 6	1,394	3 6
All volumes						
Less than 0 5	380	1 9	19	1 9	399	1 9
0 5 - 0 9	821	1 9	47	1 3	868	1 9
1 - 1 9	2,835	2 1	367	2 5	3,202	2 1
2 - 2 9	1,262	3 1	76	12 5	1,338	3 2
3 or more	646	2 6	13	5 9	659	2 6
Total	5,944	2 2	522	2 6	6,466	2 3

TABLE 13

ACCIDENT RATES ON TWO-LANE TANGENTS, BY FREQUENCY OF ROADSIDE ESTABLISHMENTS (INCLUDING DWELLINGS)

Frequency of establishments	Type 1 (All States, using adjustment factors)		Type 2 (Selected States, without adjustment)		Type 3 (All States, without adjustment)	
No. per mile	Number	Per mil vehic -miles	Number	Per mil vehic -miles	Number	Per mil vehic -miles
0 - 0 9	650	4 3	220	5 3	650	1 8
1 0 - 4 9	2,131	3 4	904	2 6	2,131	1 8
5 0 - 9 9	1,567	4 4	1,205	3 3	1,567	2 9
10 0 - 19 9	1,770	3 5	1,637	3 2	1,770	2 9
20 0 - 49 9	356	4 0	293	2 9	356	3 1
50 or more	0	0 0	0	0 0	0	0 0

TABLE 14

ACCIDENT RATES ON TWO-LANE TANGENTS, BY FREQUENCY OF SIGHT-DISTANCE RESTRICTIONS

Frequency of restrictions	Type 1 (All States, using adjustment factors)		Type 2 (Selected States, without adjustment)		Type 3 (All States, without adjustment)	
No per mile	Number	Per mil vehic -miles	Number	Per mil vehic -miles	Number	Per mil vehic -miles
0 - 0 9	3,472	3 7	1,833	2 8	3,472	2 0
1 0 - 1 9	1,061	4 3	588	4 0	1,061	2 5
2 0 - 2 9	891	4 1	811	3 4	891	3 1
3 0 - 3 9	684	3 3	661	3 0	684	3 0
4 0 - 4 9	354	3 1	354	2 9	354	3 0
5 0 - 5 9	12	2 7	12	2 7	12	2 7

TABLE 15

ACCIDENT RATES (TYPE 3) ON TWO-LANE TANGENTS, BY VOLUME OF TRAFFIC, PERCENT COMMERCIAL TRAFFIC, AND PERCENT NIGHT TRAFFIC

Commercial traffic	Night traffic							
	0 - 19 percent		20 - 29 percent		30 - 39 percent		Total	
	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
0 - 4,900 vehicles per day								
Percent								
0 - 9.9	1	5.0	0	-	108	2.8	109	2.8
10 - 14.9	786	3 0	281	2.1	503	2.7	1,570	2.7
15 - 19.9	249	3.7	564	1.6	470	2.5	1,283	2.1
20 - 24.9	8	1.3	866	2.2	850	1.4	1,724	1.7
25 or more	0	-	221	1.7	94	1 3	315	1.6
Total	1,044	3.1	1,932	1.9	2,025	1.8	5,001	2.1
5,000 - 9,900 vehicles per day								
0 - 9 9	0	-	0	-	68	2.5	68	2.5
10 - 14 9	303	6.4	183	4.2	194	2.8	680	4.2
15 - 19.9	204	6.8	0	0.0	235	2.7	439	3.8
20 - 24.9	0	-	72	3.5	111	2.3	183	2.7
25 or more	0	-	9	1.4	15	1.9	24	1.7
Total	507	6.5	264	3.8	623	2.6	1,394	3.6
All volumes								
0 - 9.9	1	5.0	0	-	176	2.7	177	2.7
10 - 14.9	1,117	3.6	464	2.6	697	2.8	2,278	3.1
15 - 19.9	453	4.7	564	1.6	739	2.6	1,756	2.4
20 - 24.9	8	1.3	938	2.3	970	1.5	1,916	1.8
25 or more	0	-	230	1.7	109	1.4	339	1.6
Total	1,579	3.8	2,196	2.0	2,691	2.0	6,466	2.3

tangent, even though it may be broken up into a number of shorter sections by the presence of minor intersections or structures. The multiple regression analysis corroborates the confusing conclusions from the analysis of curve frequency alone. In the lowest volume group, the effect of adding curves is to reduce the Type 1 accident rate and to increase the Type 3 rate. There is no significant effect at higher volumes.

The value of the multiple analysis becomes apparent when we examine the effect of tangent length on the Type 3 accident rates for volumes under 5,000 vehicles per day. The totals for all curve frequencies combined indicate a high positive correlation between accident rate and tangent length. Even when the detailed breakdown is used, the simple correlation with tangent length is still statistically significant. Yet it falsifies the truth. For there is a large negative correlation between tangent length and curve frequency, i. e., long tangents have a strong tendency to be associated with low curve frequencies. To determine the effect of different tangent lengths on roads having the same curve frequency we must use the partial correlation coefficient of accident rate with tangent length. This coefficient is not statistically significant for any volume group.

Structure Frequency, Intersection Frequency, and Volume

This breakdown of accident rates is given in Table 12. There are no statistically significant effects of structure frequency or intersection frequency. However, there is some tendency for the Type 3 rates to increase with increasing intersection frequency when the traffic volume is low and to decrease with increasing intersection frequency when the traffic volume is high.

Frequency of Roadside Establishments

Table 13 shows the effect on the accident rates of the frequency of roadside establishments (including dwellings).[15] The results are perplexing. Only the Type 3 rate comes anywhere near showing a significant trend; these figures suggest that adding roadside establishments makes a road more hazardous. The Type 2 rate, on the other hand, seems to indicate that only roads that are particularly bad are those having less than one establishment per mile. The Type 1 rate is quite irregular.

[15] This has been studied in more detail by Minnesota and Michigan The Minnesota study is cited in Footnote 9 supra, while the Michigan study, published in 1952, is entitled "Accident Experience in Relation to Road and Roadside Features"

Frequency of Sight-Distance Restrictions

For this study a restriction has been defined as a stretch of road where the sight distance is less than 600 ft. in flat or rolling terrain, or less than 400 ft. in mountainous terrain.

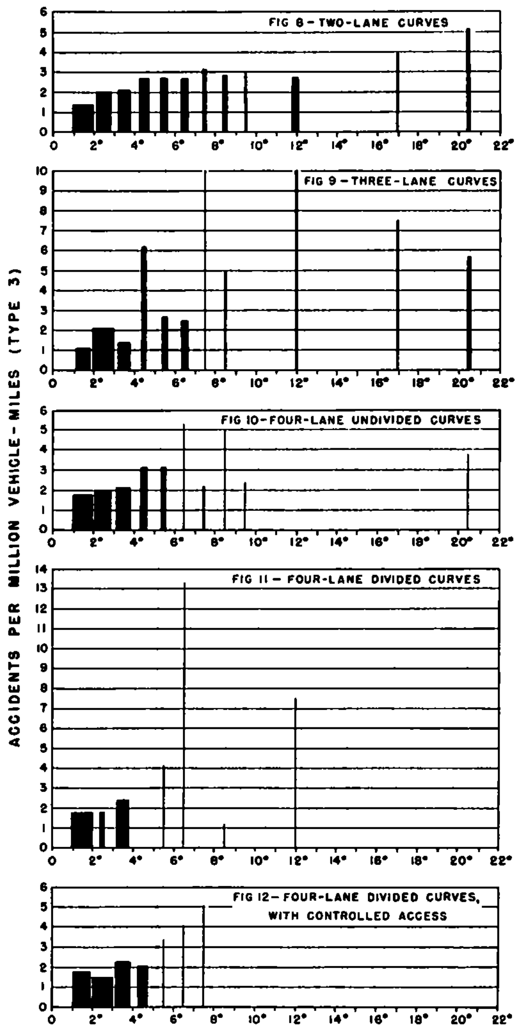
The relation of accident rates to the frequency of sight restrictions is shown in Table 14. The Type 3 rates are the most meaningful. Their slope is statistically significant, with the accident rate rising as the restriction frequency increases from zero up to about three restrictions per mile. The Types 1 and 2 rates have maximums when there are between one and two restrictions per mile; they drop steadily as the frequency of restrictions increases above this number.

Commercial Traffic, Night Traffic, and Volume

Table 15 presents a three-way breakdown of the Type 3 accident rates by traffic volume, the percentage which is commercial traffic, and the percentage of the traffic that flows after dark. The multiple analysis indicates that the accident rate is reduced by increasing the percentage of night traffic when the percentage of commercial traffic remains the same, and it also falls off with increasing commercial traffic when the night traffic is held fixed. Both these effects were unexpected.

Summary

Of all the characteristics studied for their effects on the accident rate on two-lane tangents, traffic volume is the only one whose effect is entirely clear. The effects of the frequencies of curves, intersections, roadside establishments, and sight restrictions are all uncertain, while grade, pavement width, shoulder width, tangent length, and frequency of structures do not have any independent effects on the accident rates. The effects of commercial traffic and night traffic are inconclusive.



Figures 8-12. Accident rates on curves, by degree of curvature.

CURVES: EFFECT OF DEGREE OF CURVATURE

Two-Lane Roads

The Type 3 accident rates on two-lane curves, by degree of curvature, are presented in Figure 8.[16] The relation is clear-cut: the sharper the curve, the higher the accident rate. As a matter of fact, the slopes are highly significant for all three types of rate. In accident-rate units per degree, the slopes are 0.19 ± 0.07 for the Type 1 rate, 0.12 ± 0.05 for the Type 2, and 16 ± 0.05 for the Type 3. Thus, whichever type of accident rate is used, the number of accidents per million vehicle-miles increases by about 0.15 for each additional degree of curvature.

Three-Lane Roads

Here, too, there seems to be a steady increase in hazard with increasing curvature, though the data are somewhat sparse. Figure 9 shows the rates based on a total of 39 accidents.

Four-Lane Roads, Undivided

Figure 10 gives the corresponding information for four-lane undivided curves. The Type 3 rate has the same upward trend as on the two- and three-lane roads, although the slope is not statistically significant; the Types 1 and 2 rates are more irregular.

Four-Lane Roads, Divided

On these roads, too, the accident rate increases as the curves become sharper. The rates are presented in Figure 11.

Four-Lane Roads, Divided, with Controlled Access

Figure 12 shows the relation of curvature to accident rate for roads of this type. As before, the trend is statistically significant, with the accident rates increasing by about 0.4 for each additional degree of curvature.

Summary

There is a direct relation between curvature and accident rate on all types of highways. Sharp curves have high accident rates, gradual curves have low accident rates, in-between curves have in-between accident rates.

Among different types of roads with the same degree of curvature, the data do not indicate any consistent relation.

Table 17 compares tangents with curves on each type of roadway.[17] There is no clear superiority one way or the other. The Type 3 rates, which are the most con-

[16] All three types of accident rates are given in Table 16

[17] These rates are for all the tangent and curve sections included in the study, irrespective of other factors.

TABLE 16

ACCIDENT RATES ON CURVES, BY DEGREE OF CURVATURE AND ROADWAY TYPE

Curvature	Two-lane roads		Three-lane roads		Four-lane roads					
					Undivided		Divided		Controlled access	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles
	Type 1 accident rates (All states, using adjustment factors)									
Degrees										
0 - 2.9	504	2.6	11	5 6	98	4 9	95	2.4	180	2.4
3 - 5 9	596	3 6	11	9 8	90	8.4	65	4 2	162	3 4
6 - 9.9	338	3 6	6	14 1	16	7 9	5	11 9	38	5 6
10 or more	354	4 8	11	28 0	3	5 8	12	30 6	0	-
	Type 2 accident rates (Selected states, without adjustment)									
0 - 2.9	340	1.8	0	-	43	1.9	33	0 7	180	1.6
3 - 5 9	447	2.5	0	0.0	33	2 1	52	2 7	162	2.3
6 - 9.9	287	2 9	0	-	10	2 9	1	1.2	38	4 5
10 or more	281	3.4	1	10 0	0	-	0	-	0	-
	Type 3 accident rates (All states, without adjustment)									
0 - 2 9	504	1 6	11	1.7	98	1 9	95	1 8	180	1 6
3 - 5.9	596	2 5	11	2.8	90	2 6	65	2.4	162	2 3
6 - 9.9	338	2.8	6	3 5	16	3.3	5	3 1	38	4.5
10 or more	354	3.5	11	7.3	3	1 2	12	6 7	0	-

TABLE 17

ACCIDENT RATES ON TANGENTS AND CURVES,[1] BY ROADWAY TYPE

	Two-lane roads		Three-lane roads		Four-lane roads					
					Undivided		Divided		Controlled access	
	Number	Per mil vehicle miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
	Type 1 accident rates (All states, using adjustment factors)									
Tangents	6,474	3 7	227	6.1	1,348	6.4	982	4 6	774	2.2
Curves	1,794	3 3	39	10 2	210	6 5	177	3.8	380	2.9
	Type 2 accident rates (Selected states, without adjustment)									
Tangents	4,259	3 1	115	5 3	757	3.3	829	2.9	774	1 7
Curves	1,355	2 5	1	2.5	86	1 9	86	1.3	380	2 0
	Type 3 accident rates (All states, without adjustment)									
Tangents	6,474	2 3	227	2.5	1,348	2.7	982	2.9	774	1.7
Curves	1,794	2.3	39	2.8	210	2 2	177	2.1	380	2.0

[1]All volumes, grades, curvatures, etc

TABLE 18

ACCIDENT RATES ON CURVES, BY VOLUME OF TRAFFIC AND ROADWAY TYPE

Average daily traffic	Two-lane roads		Three-lane roads		Four-lane roads					
					Undivided		Divided		Controlled access	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles
	Type 1 accident rates (All states, using adjustment factors)									
Vehicles per day										
0 - 4,900	1,387	3 5	21	9 1	25	5 7	1	. 1.1	140	3 8
5,000 - 9,900	403	3.0	18	11 7	96	7 6	43	4 4	0	0 0
10,000 - 14,900	4	0.6	0	-	69	3.4	117	4 1	45	1 8
15,000 or more	0	-	0	-	20	1 9	27	6 5	63	1.4
	Type 2 accident rates (Selected states, without adjustment)									
0 - 4,900	957	2 5	1	2 5	2	0 6	0	0 0	140	1 9
5,000 - 9,900	394	2 7	0	-	20	1.5	18	0 7	0	0 0
10,000 - 14,900	4	0 6	0	-	34	2 0	111	2 9	45	1 8
15,000 or more	0	-	0	-	20	1 8	27	5.9	63	1.3
	Type 3 accident rates (All states, without adjustment)									
0 - 4,900	1,387	2 3	21	2 6	25	1 7	1	0 3	140	1.9
5,000 - 9,900	403	2 7	18	3 1	96	2.3	43	1 4	0	0.0
10,000 - 14,900	4	0 6	0	-	69	2 4	117	2 9	45	1 8
15,000 or more	0	-	0	-	20	1 8	27	5.9	63	1.3

sistent, indicate that tangents and curves are equally safe on two-lane roads. Tangents are a little safer than curves on three-lane and controlled-access four-lane-divided roads, while they are somewhat more hazardous on the four-lane roads lacking control of access. None of these differences is large enough to warrant any strong conclusions.

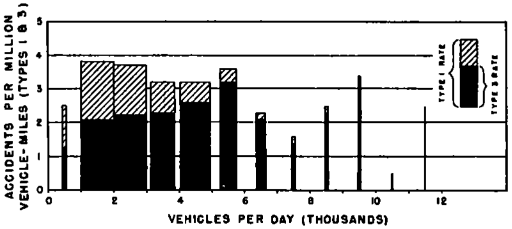


Figure 13. Accident rates on two-lane curves (all degrees), by volume of traffic.

CURVES: EFFECT OF VOLUME

Two-Lane Roads

Table 18 and Figure 13 show how the accident rate on two-lane curves varies with the average daily volume of traffic. The Type 1 rate has a statistically significant tendency to become smaller as the traffic increases. The Types 2 and 3 rates do not vary significantly but have a slight tendency to increase with increasing traffic.

The decline shown by the Type 1 rate was unexpected, but the conclusion which it suggests is almost certainly correct. Table 19 gives a state-by-state breakdown of these rates. This table shows that every state having more than six accidents (actual, not adjusted) at volumes over 5,000 v.p.d. has a lower accident rate for these volumes than for volumes below 5,000. It has also been proved by multiple regression analysis that this decline is not a hidden effect of the degree of curvature.

Why should the accident rate decline with increasing traffic on two-lane curves, when it goes the opposite way on two-lane tangents? Analysis of the types of collisions at different volumes indicates that the distribution of accident types is practically identical for all volume groups. So one can only speculate. Perhaps the extra alertness required for driving on narrow curved roads in heavy traffic is what pulls the accident rate down. A similar decline in accident rate with increasing traffic volume is found at two-lane intersections, where the same alertness factor may be involved. It is not found at curves or intersections on wider roads.

Three-Lane Roads

For three-lane curves the data are pretty meager (see Table 18), but such evidence as there is points to a positive correlation between accident rate and traffic volume.

Four-Lane Roads, Undivided

On four-lane undivided curves, each type of rate increases to a maximum and then falls off gradually as the traffic volume increases. The Type 1 rate has its maximum between 5,000 and 10,000 vehicles per day, the Type 2 has its maximum between 15,000 and 20,000 the Type 3 has its maximum between 10,000 and 15,000. This is similar to the pattern for four-lane undivided tangents.

Four-Lane Roads, Divided

The accident rates on four-lane divided curves show a persistent increase with traffic volume. The information is on the skimpy side, but the trend seems definite. The Types 2 and 3 rates have statistically significant slopes, with the accident rate increasing by about 0.3 of a unit for each additional thousand vehicles per day.

TABLE 19

STATE-BY-STATE ACCIDENT RATES (TYPE 1) ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC

State	0 - 4,900 v p d.			5,000 - 9,900 v p d.		
	Adjusted accidents	Million vehicle-miles	Rate	Adjusted accidents	Million vehicle-miles	Rate
Colorado	238	71 2	3 3	12	1 3	9.2
Conn 1941	269	95.1	2 8	220	80 9	2.7
Conn. 1946	282	112 0	2 5	69	29 2	2 4
Georgia	106	13 7	7 7	0	0	-
Iowa	220	40 5	5 4	0	1.4	0 0
Louisiana	56	27 4	2 0	2	0.2	10 0
Minnesota	41	33 8	1 2	0	0	-
Nebraska	201	54 7	3 7	0	0.4	0 0
New Mexico	50	5 0	10 0	0	0	-
Oregon	108	46 7	2 3	17	8 7	2.0
Utah	206	31 6	6 5	7	1.9	3 7
Virginia	23	3 0	7 7	0	0	-
Washington	294	63 2	4.7	120	27 0	4 4
Wisconsin	11	10.7	1 0	0	0	-
Wyoming	14	4.4	3.2	0	0	-
Total	2,119	613 0	3.5	447	151 0	3.0

Four-Lane Roads, Divided, with Controlled Access

Here the situation is similar to that of the four-lane divided tangents with controlled access. The apparent decline in the accident rate with increasing volume is mainly due to the difference between Pennsylvania and Connecticut. As in the earlier case, the high volumes are all from Connecticut, while practically all of the traffic below 5,000 v.p.d. is from Pennsylvania.

Summary

On all but the two-lane roads, the accident rate on curves varies with volume in much the same way as on tangents. The general tendency is for higher-than-average volumes to cause higher-than-average accident rates, with some decline in the accident rate at extremely high volumes.

The two-lane curves are different. They show a negative correlation between accident rate and traffic volume throughout the volume range. This is thought to be due to the greater care with which people drive under conditions which are obviously dangerous.

TWO-LANE CURVES: EFFECTS OF OTHER FEATURES

Degree and Volume Combined

There are two basically different ways in which curvature and volume together might affect the accident rates. Even if the effects were really independent, there might be intercorrelation between the two factors, i.e., a tendency for the roads having higher-than-average curvature to have either higher-than-average or lower-than-average volume, so that an effect of curvature might appear to be an effect of volume, or vice versa. Multiple regression analysis separates the effects and assigns each to its proper cause.

Or there could be interaction between the two factors. This means the kind of situation in which the effect of volume at low degrees of curvature is different from its effect at high degrees, and the effect of curvature at low volumes is different from that at high volumes.

Both of these possibilities were investigated. The intercorrelation between degree and volume is negligible, and the partial correlations between the Type 1 accident rate and each of the two factors are both statistically significant, with the same signs as the simple correlations. In other words, for roads of the same curvature the average effect of increased volume is to reduce the accident rate by a significant amount, and for roads carrying the same volume the average effect of increased curvature is to increase the accident rate by a significant amount.

The interaction between curvature and volume can be tested by making a two-way classification of the highway sections by both curvature and volume. This is done in Table 20. The Type 1 rate shows no particular interaction, since it drops with increasing volume in each curvature group. The Types 2 and 3 rates do show interaction, and it is exactly the sort one would expect. At low degrees of curvature, i.e., on the curves which are most like tangents,

TABLE 20

ACCIDENT RATES ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC AND DEGREE OF CURVATURE

Curvature	0 - 4,900 v p d.		5,000 v p d or more	
Degrees	Number	Per million vehicle-miles	Number	Per million vehicle-miles
Type 1 accident rates (All States, using adjustment factors)				
0 - 2 9	395	2 7	111	2 1
3 0 - 5 9	423	3.7	173	3.4
6.0 or more	569	4 4	123	3 1
Type 2 accident rates (Selected States, without adjustment)				
0 - 2.9	231	1 8	109	2 0
3 0 - 5.9	278	2 3	169	3 1
6 0 or more	448	3 2	120	2 9
Type 3 accident rates (All States, without adjustment)				
0 - 2 9	395	1 6	111	1 9
3.0 - 5.9	423	2 3	173	3 1
6 0 or more	569	3.2	123	2 8

the hazard increases with volume, just as on the tangent sections. On curves sharper than 6 deg. it is the other way around; here the accident rate is lower when there is more traffic volume.

Another way of looking at this interaction is in terms of the effect of changing the curvature at different fixed volume levels. This effect is the same for all three types of rates. At volumes below 5,000 v.p.d., the accident rate rises steadily with increasing curvature. At volumes over 5,000, the accident rate is lower on sharp curves than on moderate curves.

These facts strengthen the belief that traffic volume affects the accident rate differently on two-lane curves from the way it does on two-lane tangents.

Degree, Grade, and Volume

Table 21 gives the Type 3 accident rates by degree of curvature and grade for two-lane curves carrying various ranges of traffic volume. At low volumes the accident rate goes up with increasing curvature, while the effect of grade is not statistically significant. At higher volumes it is not the curvature but the grade that matters; steeper grades make the accident rates larger.[18]

TABLE 21

ACCIDENT RATES (TYPE 3) ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC, DEGREE OF CURVATURE, AND GRADE

Curvature	Grade: Less than 3%		3% or more		Total	
Degrees	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
0 - 4,900 vehicles per day						
0 - 2 9	317	1 4	78	2 0	395	1. 6
3 - 5 9	317	2 3	106	2 4	423	2 3
6 - 9.9	194	3.0	69	2 3	263	2 8
10 or more	155	3 4	150	3 8	305	3 6
Total	983	2 1	403	2 7	1,386	2 3
5,000 - 9,900 vehicles per day						
0 - 2 9	86	1 9	22	2 9	108	2 0
3 - 5 9	117	2 8	55	4 1	172	3.2
6 - 9.9	51	2 6	22	3 1	73	2.7
10 or more	27	2 5	22	3 9	49	3 0
Total	281	2 4	121	3 6	402	2.7
All volumes						
0 - 2.9	405	1 6	100	2 2	505	1.6
3 - 5.9	434	2 4	161	2.8	595	2.5
6 - 9 9	245	2 9	93	2.5	338	2.8
10 or more	182	3 2	172	3.8	354	3 5
Total	1,266	2.2	526	2.8	1,792	2 3

Degree and Frequency of Curves

Figure 14 shows the accident rates on two-lane curves (of all degrees) as a function of curve frequency. The Type 1 rate is highest when curves are very rare, suggesting that a curve is most hazardous when it is unexpected. The Types 2 and 3 accident rates have their high values when there are more than five curves per mile.

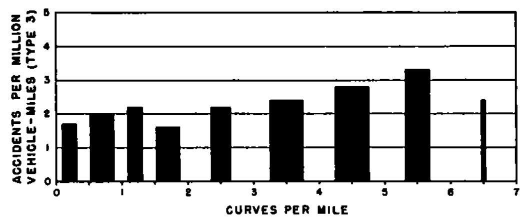


Figure 14. Accident rates on two-lane curves (all degrees), by frequency of curves.

TABLE 22

ACCIDENT RATES ON TWO-LANE CURVES, BY DEGREE OF CURVATURE AND FREQUENCY OF CURVES

Frequency of curves	Curvature: 0 - 2.9°		3° - 5.9°		6° - 9.9°		10° or more	
	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
Type 1 accident rates (All states, using adjustment factors)								
Number per mile								
0 - 0.9	128	3.0	110	5.4	13	4.2	31	8.9
1.0 - 2.9	178	2.3	163	3.7	96	4.5	53	4.2
3.0 - 4.9	125	2.1	223	2.9	170	3.3	139	4.3
5.0 - 6.9	75	3.3	100	3.2	59	2.8	130	4.6
Type 2 accident rates (Selected states, without adjustment)								
0 - 0.9	42	1.6	47	3.2	2	1.1	4	1.4
1.0 - 2.9	105	1.4	97	2.1	65	2.9	30	2.6
3.0 - 4.9	118	2.0	203	2.5	161	3.2	117	3.3
5.0 - 6.9	75	3.1	100	2.9	59	2.6	130	3.9
Type 3 accident rates (All states, without adjustment)								
0 - 0.9	128	1.4	110	2.7	13	2.0	31	4.3
1.0 - 2.9	178	1.4	163	2.1	96	2.9	53	2.6
3.0 - 4.9	125	1.9	223	2.5	170	2.9	139	3.4
5.0 - 6.9	75	3.1	100	2.9	59	2.6	130	3.9

Table 22 separates the figures into

[18] This peculiar pattern occurs with both the Type 1 and the Type 3 rates (the Type 2 rates were not computed). In the 0 to 4,900 volume group the partial correlation with curvature is the only significant one, while in the 5,000 to 9,900 volume group the partial correlation with grade is the only significant one

TABLE 23

ACCIDENT RATES (TYPE 3) ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC, FREQUENCY OF CURVES, AND FREQUENCY OF SIGHT-DISTANCE RESTRICTIONS

Frequency of curves	Less than 1		1 - 1 9		2 - 2 9		3 or more		Total	
	Number	Per mil vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles
0 - 4,900 vehicles per day (Restrictions per mile)										
Number per mile										
Less than 0 5	76	1.7	7	1.9	0	0.0	3	7 5	86	1 7
0 5 - 0.9	138	1.8	33	3.2	3	0.9	0	0 0	174	1 9
1 - 1 9	182	1 8	40	1 7	3	0 9	0	-	225	1 7
2 - 2.9	38	1 9	98	2 4	16	1.7	0	0 0	152	2 1
3 or more	9	0.6	41	3 8	181	2 7	518	2.9	749	2 8
Total	443	1 7	219	2.4	203	2.5	521	2 9	1,386	2 3
5,000 - 9,900 vehicles per day										
Less than 0 5	1	1 7	0	-	0	-	0	-	1	1 7
0.5 - 0 9	22	3 5	0	0.0	0	-	0	-	22	3 3
1 - 1 9	72	2.1	3	3.8	0	-	0	-	75	2 1
2 - 2 9	0	0.0	36	2 4	0	-	0	-	36	2.4
3 or more	0	-	4	1 1	131	2 7	133	3.2	268	2.9
Total	95	2 3	43	2.2	131	2 7	133	3 2	402	2 7
All volumes										
Less than 0.5	77	1 7	7	2.2	0	0.0	3	7 5	87	1 7
0 5 - 0 9	160	1.9	33	3 0	3	0 9	0	0 0	196	2 0
1 - 1 9	256	1.8	43	1 7	3	0 9	0	-	302	1 8
2 - 2.9	38	1 9	134	2.4	16	1 7	0	0.0	188	2.2
3 or more	9	0 6	45	3 1	314	2.7	651	2.9	1,019	2 8
Total	540	1 8	262	2.4	336	2 5	654	2 9	1,792	2.3

TABLE 24

ACCIDENT RATES (TYPE 3) ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC, PAVEMENT WIDTH, AND SHOULDER WIDTH

Pavement width	Less than 5 feet		5 - 7.9 feet		8 - 9 9 feet		10 feet or more		Total	
	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles
0 - 4,900 vehicles per day (Shoulder width)										
Feet										
16 or less	28	1 5	5	1.1	0	-	0	-	33	1 4
18	257	2 7	153	2 0	4	1 3	1	0.7	415	2.4
20	473	3 0	219	1.9	40	1.4	33	2 2	765	2 4
21-22	58	2.3	5	0.7	2	1 7	26	2.3	91	2.0
23-24	22	2 5	31	1.4	1	0 3	0	0.0	54	1 6
25 or more	15	1 3	5	1 2	0	-	9	4.2	29	1 6
Total	853	2 7	418	1 8	47	1 3	69	2.3	1,387	2 3
5,000 - 9,900 vehicles per day										
16 or less	1	0 9	1	0 7	0	-	0	-	2	0.8
18	7	3 5	12	1 2	5	5 0	0	-	24	1 8
20	230	3.2	84	2 4	3	1 2	10	2 0	327	2 9
21-22	6	2 7	13	2 3	0	-	3	3 3	22	2 5
23-24	0	-	2	0.6	1	3.3	0	-	3	0 8
25 or more	9	4 7	8	2 0	0	-	7	2.8	24	2 9
Total	253	3 2	120	2 0	9	2 4	20	2 4	402	2.7
All volumes										
16 or less	29	1 5	6	1 0	0	-	0	-	35	1.4
18	264	2 7	165	1 9	9	2 2	1	0 7	439	2.3
20	705	3 1	305	2 0	43	1.4	43	2.1	1,096	2 5
21-22	64	2.3	18	1 4	2	1.7	29	2.4	113	2.1
23-24	22	2 5	33	1 3	2	0 6	0	0.0	57	1.5
25 or more	24	1 7	13	1 6	0	-	16	3 6	53	2 0
Total	1,108	2 8	540	1.8	56	1 4	89	2 3	1,793	2 3

several ranges of curvature. At first glance the most prominent feature of this table is that the Types 1 and 3 accident rates have their greatest values for the highest curvature and the lowest frequency. But closer study of the supporting facts shows that this is due to five curves in Iowa which contribute 11 out of the 31 accidents in this group. The other 20 accidents in the group occurred at rates similar to those for other curvatures and frequencies.

The table does not suggest any general conclusions about the effect of curve frequency on the accident rates. The degree of curvature, as before, is positively correlated with the accident rates.

Curve Frequency, Sight-Restriction Frequency, and Volume

Table 23 gives the accident rates on two-lane curves by curve frequency and sight-restriction frequency for various volume groups. There is a high intercorrelation between the two frequencies, so that while high values of both frequencies cause higher accident rates than low values of both frequencies, it is impossible to tell which of the two frequencies is responsible.[19]

Since the preceding section seemed to indicate that curve frequency did not have any consistent effect, it can only be concluded that the effect of curve frequency is not very clear.

TABLE 25

ACCIDENT RATES (TYPE 3) ON TWO-LANE CURVES, BY VOLUME OF TRAFFIC, PERCENT COMMERCIAL TRAFFIC, AND PERCENT NIGHT TRAFFIC

Commercial traffic	Night traffic: 0 - 19 percent		20 - 29 percent		30 - 39 percent		Total	
	Number	Per mil. vehicle-miles	Number	Per mil vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
0 - 4,900 vehicles per day								
Percent								
0 - 9 9	0	-	0	-	83	3 0	83	3.0
10 - 14 9	297	3.1	79	2.3	188	2 6	564	2.8
15 - 19.9	42	2.9	138	1.9	198	2.5	378	2.2
20 - 24.9	1	1.0	105	1.5	164	1.6	270	1.5
25 or more	0	-	71	2 9	21	2.0	92	2 6
Total	340	3.0	393	1.9	654	2.2	1,387	2.3
5,000 - 9,900 vehicles per day								
0 - 9.9	0	-	0	-	38	3.0	38	3.0
10 - 14.9	88	3.7	11	1.5	92	2.4	191	2.7
15 - 19.9	18	3.5	0	0 0	64	2.1	82	2 1
20 - 24.9	0	-	3	2.5	83	2.9	86	2.9
25 or more	0	-	5	2.9	0	-	5	2.9
Total	106	3.6	19	1.8	277	2.5	402	2.7
All volumes								
0 - 9.9	0	-	0	-	121	3.0	121	3.0
10 - 14.9	385	3.2	90	2.2	280	2.5	755	2 7
15 - 19.9	60	3.1	138	1.8	264	2.3	462	2.2
20 - 24.9	1	1.0	108	1.5	249	1.9	358	1 7
25 or more	0	-	76	2 9	21	2.0	97	2 8
Total	446	3.1	412	1.9	935	2.3	1,793	2 3

Pavement Width, Shoulder Width, and Volume

This breakdown is given in Table 24. On two-lane curves the effect of pavement width is too irregular to be statistically significant, but 24-ft. sections are consistently safer than 20-ft. sections. The partial correlation with shoulder width is significant; the accident rate goes down by about 0.15 of a unit, on the average, for each additional foot of shoulder. These results differ from the situation on two-lane tangents, where neither pavement width nor shoulder width has a consistent effect on the accident rate.

[19] In statistician's language, the multiple correlation is statistically significant, but the partial correlations are not.

Commercial Traffic, Night Traffic, and Volume

Table 25 shows the effects, on two-lane curves, of commercial traffic and night traffic. Neither effect is statistically significant.

Summary

The effect of volume in reducing the accident rate on two-lane curves seems to be stronger for sharp curves than for flat curves. This is logical, for one would expect flat curves to be intermediate, in their accident potential, between sharp curves and tangents.

The frequency of curves does not appear to have any consistent effect on the accident rate, even when the curves are subdivided by degree of curvature. The frequency of sight restrictions has a similarly uncertain effect.

Wide shoulders definitely help to reduce

TABLE 26

ACCIDENT RATES AT INTERSECTIONS AT GRADE[1] ON TWO- AND THREE-LANE ROADS, BY TOTAL VOLUME OF TRAFFIC AND PERCENTAGE OF CROSS TRAFFIC

Cross traffic	Two-lane roads: 0 - 4,900 v p d, Number	Per ten million vehicles	5,000 - 9,900 v p d., Number	Per ten million vehicles	10,000 or more v p.d., Number	Per ten million vehicles	Three-lane roads: 0 - 4,900 v.p.d., Number	Per ten million vehicles	5,000 - 9,900 v p d, Number	Per ten million vehicles	10,000 or more v p d, Number	Per ten million vehicles
Type 1 accident rates (All states, using adjustment factors)												
Percent												
0 - 9	678	3 6	229	2 2	9	0.9	17	4 1	25	9.6	24	34 4
10 - 19	116	11 3	56	6 3	0	0 0	0	0 0	0	-	0	-
20 or more	162	9 2	118	8.7	3	1 9	0	0 0	30	40 8	0	-
Type 2 accident rates (Selected states, without adjustment)												
0 - 9	363	2 0	213	1.8	9	0 8	2	3 3	6	2 1	24	26.7
10 - 19	63	7.1	54	5.5	0	0 0	0	-	0	-	0	-
20 or more	118	6.9	117	8 1	3	1 9	0	-	30	25 0	0	-
Type 3 accident rates (All states, without adjustment)												
0 - 9	678	2.0	229	1.8	9	0 8	1	1.7	25	3 5	24	26 7
10 - 19	116	6.0	56	5.3	0	0 0	0	0.0	0	-	0	-
20 or more	162	6.5	118	7.5	3	1.9	0	0.0	30	25.0	0	-

[1]Excluding rotary intersections

TABLE 27

ACCIDENT RATES AT INTERSECTIONS AT GRADE[1] ON FOUR-LANE ROADS, BY TOTAL VOLUME OF TRAFFIC AND PERCENTAGE OF CROSS TRAFFIC

Cross traffic	Undivided roads: 0 - 4,900 v p d, Number	Per ten million vehicles	5,000 - 9,900 v.p.d., Number	Per ten million vehicles	10,000 or more v p d, Number	Per ten million vehicles	Divided roads[2]: 0 - 4,900 v p d, Number	Per ten million vehicles	5,000 - 9,900 v p.d., Number	Per ten million vehicles	10,000 or more v p.d, Number	Per ten million vehicles
Type 1 accident rates (All states, using adjustment factors)												
Percent												
0 - 9	33	8.8	184	9 9	302	4 6	15	3 6	131	5 4	309	7.8
10 - 19	15	22.9	22	48 7	123	32 3	7	17 5	25	10 8	130	28 3
20 or more	0	0 0	34	56 7	236	42 2	0	-	13	13.6	97	22.4
Type 2 accident rates (Selected states, without adjustment)												
0 - 9	13	4 6	62	3 8	255	3 1	15	3.3	91	3.4	238	4 5
10 - 19	14	28.0	8	8 0	123	28 6	7	17.5	25	11 4	130	24.5
20 or more	0	-	15	21.4	227	36 0	0	-	13	11 8	97	19 4
Type 3 accident rates (All states, without adjustment)												
0 - 9	33	3 4	184	3 5	302	3 0	15	3 2	131	3 2	309	4.2
10 - 19	15	21 4	22	14 7	123	28 6	7	17 5	25	10.0	130	24 5
20 or more	0	0 0	34	18.9	236	35 2	0	-	13	11 8	97	19 4

[1]Excluding rotary intersections
[2]Excluding those with controlled access

the accident rate on two-lane curves, and 24-ft. pavements are consistently safer than 20-ft. pavements. This is in contrast to the situation on two-lane tangents, where shoulder width has no particular effect.

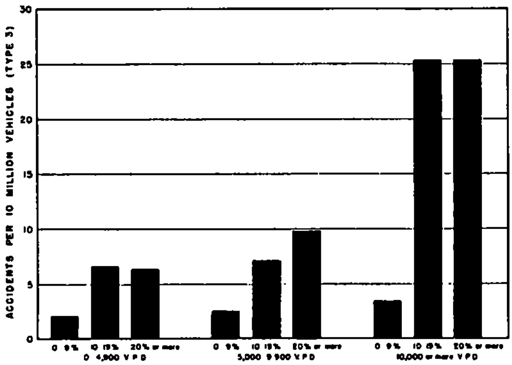


Figure 15. Accident rates at intersections (all roadway types), by total volume and percentage of cross traffic.

The effect of grade is peculiar. At low traffic volumes there is no particular effect, but on roads carrying more than 5,000 v.p.d. the accident rates are higher on roads with steep grades.

Finally, the percentages of commercial and night traffic have no recognizable effect on the accident rates on two-lane curves.

INTERSECTIONS: EFFECT OF TOTAL VOLUME AND CROSS TRAFFIC

The accident rates at intersections are computed somewhat differently than on tangents and curves, since the length of an intersection is not particularly relevant to its accident potential. The base which has been used instead of vehicle mileage is the total number of vehicles using the intersection. To keep the numbers at a manageable size, the accident rates have been expressed in terms of the number of accidents per 10 million vehicles.

The only intersections analyzed have been intersections at grade, excluding rotaries.

Two-Lane Roads

This classification consists of the intersections along the two-lane roads included in the study, irrespective of the number of lanes on the side or cross road. By volume is meant the total number of vehicles entering the intersection from all approaches; the "percentage of cross traffic" is the percentage of this total volume which enters the intersection from roads other than the study route.

Table 26 presents the accident rates at these intersections for various traffic vol-

TABLE 28

ACCIDENT RATES (TYPE 3) AT INTERSECTIONS AT GRADE[1] ON TWO-LANE ROADS, BY TOTAL VOLUME OF TRAFFIC, PERCENTAGE OF CROSS TRAFFIC, TYPE OF INTERSECTION, AND PERCENTAGE OF NIGHT TRAFFIC

Night traffic	0 - 9 percent cross traffic						10 or more percent cross traffic					
	3 -way intersection		4 -way intersection		Total		3 -way intersection		4 -way intersection		Total	
	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles
0 - 4,900 vehicles per day												
Percent												
10 - 19	83	2 9	48	5 0	131	3 4	18	15 0	30	23 1	48	19 2
20 - 29	143	2 0	185	3.9	328	2.8	58	5 4	67	7.1	125	6 2
30 - 39	112	0 9	107	1 8	219	1 2	53	4 5	52	5.3	105	4 9
Total	338	1 5	340	2 9	678	2.0	129	5 4	149	7 2	278	6 3
5,000 - 9,900 vehicles per day												
10 - 19	33	2 8	39	5 2	72	3 7	43	13 4	18	13.8	61	13 6
20 - 29	35	3 3	19	5 0	54	3.8	9	11 2	23	14 4	32	13.3
30 - 39	69	0 9	31	2 2	100	1 1	58	4 3	37	6 1	95	4.8
Total	137	1 3	89	3.5	226	1.8	110	6 3	78	8.7	188	7.1
All volumes												
10 - 19	118	2 8	89	5 1	207	3 5	61	13.9	48	18 5	109	15.6
20 - 29	178	2 2	204	4 0	382	2.9	67	5 8	90	8 1	157	6 9
30 - 39	186	0 9	138	1 9	324	1 1	112	4 3	89	5 4	201	4.7
Total	482	1 4	431	3 0	913	1 9	240	5 7	227	7 5	467	6 5

[1]Excluding rotary intersections, interchanges at grade separations, and intersections with more than four approaches.

umes and percentages of cross traffic. The percentage of cross traffic is of crucial importance. At every volume level where there is an adequate sample, the accident rate is more than twice as high when the cross traffic exceeds 10 percent of the total as when the cross traffic is less than 10 percent. Additional increases in cross traffic to 20 percent or more do not cause appreciable further increases in the accident rates.

TABLE 29

ACCIDENT RATES (TYPE 3) AT INTERSECTIONS AT GRADE[1] ON TWO-LANE ROADS BY TOTAL VOLUME OF TRAFFIC, PERCENTAGE OF CROSS TRAFFIC, AND PERCENTAGE OF COMMERCIAL TRAFFIC

Commercial traffic	0 - 9 percent cross traffic		10 or more percent cross traffic	
Percent	Number	Per ten mil. vehicles	Number	Per ten mil. vehicles
0 - 4,900 vehicles per day				
5 - 9 9	11	0.6	8	3 3
10 - 14 9	208	2 3	88	6 4
15 - 19 9	174	1 9	121	6 3
20 - 24 9	215	1 8	57	6 0
25 or more	80	3 1	16	9 4
Total	688	2 0	290	6 3
5,000 - 9,900 vehicles per day				
5 - 9 9	6	0.5	23	6 6
10 - 14 9	128	2 7	83	7 5
15 - 19 9	65	1 7	64	9 1
20 - 24 9	21	0.8	39	4.6
25 or more	8	1 9	2	2 9
Total	288	1 7	211	6 9
All volumes				
5 - 9 9	17	0 5	31	5 3
10 - 14 9	340	2 4	172	6 7
15 - 19 9	244	1 8	192	7 0
20 - 24 9	236	1 6	96	5 2
25 or more	88	2 9	18	7 5
Total	925	1 9	509	6.4

[1]Excluding rotary intersections

The effect of traffic volume on the accident rate is worth noting. Increased volume reduces the accident rate in most cases. This is the same effect that was noted for two-lane curves. The two effects may possibly be related, since neither of them occurs on roads of more than two lanes.

Three-Lane Roads

Table 26 also gives the same information for three-lane roads. The information is meager, but the intersections having less than 10 percent cross traffic appear to be much safer than the others. High volumes are associated with high accident rates.

Four-Lane Roads, Undivided

As with other roadway types, cross traffic between 10 and 19 percent makes an intersection on a four-lane undivided road much more dangerous than if the cross traffic is below 10 percent. Further increases in cross traffic are less important. The total traffic volume has no consistent effect (see Table 27).

TABLE 30

ACCIDENT RATES AT STRUCTURES (ON TWO-LANE ROADS WITH APPROACH PAVEMENTS LESS THAN 30 FEET WIDE), BY RELATIVE WIDTH OF STRUCTURE ROADWAY AND ADJOINING PAVEMENT

Relative Width	Bridges and overpasses		Underpasses	
Feet	Number	Per ten mil vehicles	Number	Per ten mil vehicles
Type 1 accident rates (All States, using adjustment factors)				
Structure narrower by more than 1 ft	21	9 2	0	-
Structure from 1 ft narrower to 1 ft wider	56	5 8	2	2 9
Structure wider by				
1 1 - 3 0	81	7 7	6	6 4
3 1 - 5 0	87	5 2	2	7 5
5 1 - 7 0	17	2 3	5	5 6
7 1 - 9 0	4	0 2	0	0 0
9 1 - 13 0	14	1 0	9	6 0
13 1 - 19 0	4	0 4	0	0 0
19 1 or more	10	1 6	3	2 5
Type 2 accident rates (Selected States, without adjustment)				
Structure narrower by more than 1 ft	15	5 0	0	-
Structure from 1 ft narrower to 1 ft wider	28	4 7	2	3 3
Structure wider by				
1 1 - 3 0	70	4 5	6	6 0
3 1 - 5 0	61	4 1	1	10 0
5 1 - 7 0	10	1 3	2	2 5
7 1 - 9 0	4	0 2	0	0 0
9 1 - 13 0	7	0 5	7	5 0
13 1 - 19.0	4	0.5	0	-
19 1 or more	10	1 5	2	1 4
Type 3 accident rates (All States, widhout adjustment)				
Structure narrower by more than 1 ft.	21	5 7	0	-
Structure from 1 ft narrower to 1 ft wider	56	3 6	2	2 9
Structure wider by				
1 1 - 3 0	81	4 0	6	5 5
3 1 - 5 0	87	3 1	2	5 0
5 1 - 7 0	17	1 3	5	3 1
7 1 - 9 0	4	0 2	0	0 0
9.1 - 13 0	14	0 6	9	4 5
13 1 - 19.0	4	0 4	0	0 0
19 1 or more	10	1 1	3	1 9

Four-Lane Roads, Divided

On four-lane divided roads without controlled access, the conclusion about cross traffic is again the same. High volume appears to increase the hazard somewhat.

Figure 15[20] presents the accident rates at intersections for all types of roadways combined. The evidence is overwhelming

[20]The bars in Figure 15 are of uniform width In all three volume groups, more than 85 percent of the exposure was at intersections with less than 10 percent cross traffic

that cross traffic in excess of 10 percent of the total traffic makes an intersection much more dangerous than if the cross traffic is less than 10 percent.

When all road types are combined, it appears that the accident rate goes up with increases in the total volume. But the exact opposite is the case for intersections on two-lane roads.

TABLE 31

ACCIDENT RATES (TYPE 3) AT BRIDGES AND OVERPASSES ON TWO - LANE ROADS LESS THAN 30 FEET WIDE, BY RELATIVE WIDTH OF BRIDGE ROADWAY AND ADJOINING PAVEMENT, AND ACTUAL WIDTH OF BRIDGE ROADWAY

Relative width	Width of roadway on bridge									
	Less than 20 feet		20 - 24 feet		25 - 29 feet		30 - 34 feet		35 feet or more	
	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles	Number	Per ten million vehicles
Feet										
Bridge narrower by more than 1 foot	17	8 1	4	2.5	0	-	0	-	0	-
From 1 foot narrower to 1 foot wider	28	5 6	27	2 7	1	0 9	0	-	0	-
Bridge wider by										
1 1 - 3 0	5	25 0	76	4 0	0	0 0	0	0 0	0	-
3 1 - 5 0	2	20 0	76	3 1	7	2 6	2	4 0	0	-
5.1 - 7 0	0	-	13	1 6	2	0.5	2	2 0	0	-
more than 7	0	-	0	0 0	4	0 2	14	0.7	14	0.9
Total	52	7 2	196	3 1	14	0.4	18	0 8	14	0 9

TWO-LANE INTERSECTIONS: EFFECTS OF OTHER FEATURES

Intersection Type, Night Traffic, Cross Traffic, and Volume

Three-way intersections are much safer than four-way intersections, according to Table 28. The angle at which the roads intersect does not make any appreciable difference. Increasing the percentage of night traffic reduces the accident rate, as with two-lane tangents.

Commercial Traffic, Cross Traffic, and Volume

This breakdown is given in Table 29. There is some tendency for the accident rate to increase with increasing commercial traffic, but it is not statistically significant.

Summary

The percentage of cross traffic is important, and so is the number of approaches to the intersection. Night traffic reduces the accident rate, while the effect of commercial traffic is not clear.

It would be of interest to know how the accident rate is affected by the type of traffic control (stop signs, traffic signals, etc.) The question cannot be answered from the data in the present study, because there is too little variety in traffic control at the intersections on the study routes.

STRUCTURES

Structures have been classified according to the relative width of the roadway at the structure, on the bridge or in the underpass, as compared with the adjoining pavement. Table 30 presents the accident rates on this basis. The table is restricted to two-lane roads with pavements less than 30 ft. wide.

Extra width in relation to the approach pavement definitely reduces the accident hazard on bridges. Table 31 shows that for bridges having the same relative roadway width, the actual width of the bridge pavement also contributes to the safety of the bridge.

There were not enough underpasses in the study to warrant any conclusions about the effect of roadway width in them. Such evidence as there is, based on a total of 28 accidents, indicates that underpasses are considerably more dangerous than overpasses, even though the average extra width of the underpasses in this study is about 2 ft. more than that of the bridges.

CONCLUSIONS

The conclusions fall under two headings: (1) a brief summary of the findings and (2) a critique of the study itself. The latter is as important as the former in guiding future research into the causes of accidents.

A summary of the findings was given near the beginning of this report and will not be repeated here. A number of significant relations were discovered, while others that had been expected to be clear did not turn out as expected.

At the beginning of the analysis, the question was raised as to which type of accident rate would prove most reliable.[21] The Type 3 rate makes the best showing. Of the first 32 analyses to be made, e.g., two-lane tangents by grade, two-lane tangents by volume, the Type 3 rate behaves credibly in 30 of them and is not seriously misleading in any, (though it fails to bring out the effect of traffic volume on two-lane curves). The Type 1 rate, in contrast, is reasonable in only 25 of the analyses, and in two cases gives results which are significant by statistical tests and yet are seriously misleading. The Type 2 rate is misleading in only one case, but there are nine cases in which it is excessively irregular or else contains too little data to give useful results. It would seem that, with the present data at least, one can probably do no better than simply to use all the reported accidents at face value.

The most striking feature of the study is the amount of irregularity in most of the results. Few of the data which have been presented in tables and graphs can be fitted by really smooth curves. There is considerable scatter about the over-all trends, and it is quite likely that some subtle relationships have been masked by these irregularities.

The fluctuations are much larger than one would expect from considerations of the theory of sampling. They may be due, in part, to errors in the data, such as the failure of the original accident reports to specify the accident locations with sufficient accuracy.

But their principal cause is probably the tremendous complexity of the problem itself. Accidents are associated with so many factors, in such a multitude of combinations, that one has to resort to drastic oversimplifications in order to make any kind of order out of a chaotic mass of material. The remarkable thing is not the irregularities in the tabulations but the number of useful conclusions which do emerge. Most of these conclusions were suspected before the present study was begun, but the statistical analyses give them a broader foundation in hard facts than they ever had before.

However, the foundation is not as broad as it ought to be. Too many of the states were unable to provide information of sufficient accuracy and detail for use in this study. While there has been some improvement in this regard since 1941, the situation is still far from satisfactory. If further progress is to be made in understanding the causes of accidents, many of our states will have to make substantial improvements in the quality of their accident reporting.

[21] The three types use (1) adjusted accidents (based on total-to-fatal ratio), all states, (2) actual accidents, selected states (selected for their presumed completeness of reporting), (3) actual accidents, all states

Appendix

OUTLINE OF CARD-PUNCHING CODE

All types of cards (highway, accident, summary)

Cols. 1-2:	State
" 3-4:	County
" 5-8:	Route number
" 9-12:	Section number
" 13:	Terrain (flat, rolling, mountainous)
" 14:	Roadway type (2-lane, 3-lane, etc.)
" 15:	Pavement material
" 16-17:	Pavement width
" 18:	Shoulder material
" 19:	Shoulder width
" 20:	Median type
" 21:	Median width
" 22:	Type of curb
" 23:	Type of sidewalks
" 24:	Type of lighting
" 25:	85-percentile speed
" 26:	Traffic-control devices (reduced speed zone, no-passing zone, signalized intersection, stop sign, etc.)
" 27:	Speed limit
" 28:	Frequency of curves
" 29:	Frequency of intersections
" 30:	" " structures
" 31:	" " railroad crossings at grade
" 32:	" " sight restrictions
" 33:	" " roadside establishments, including dwellings
" 34-36:	Average daily traffic volume
" 37-38:	Percentage of night traffic
" 39:	" " commercial traffic
" 40:	" " cross-road traffic
" 41:	Grade
" 42:	Type element (tangent, curve, intersection, structure, railroad crossing, transition, toll booth)
" 43:	Length of entire tangent of which highway card may be only a part
" 44:	Curvature
" 45:	Superelevation
" 46:	Locality of curve (adjacent to a tangent, part of a compound curve, part of a reverse curve)
" 47:	Type of intersection (right-angled crossing, skew crossing, tee, rotary, etc.)
" 48:	Type of structure (bridge, underpass with center pier, underpass without center pier, tunnel)
" 49:	Length of structure
" 50-51:	Width of roadway on structure
" 52:	Relative width of structure roadway and adjoining pavement
" 53:	Type of railroad grade crossing (single or multiple track, right-angle or skew)
" 54:	Type of protection at railroad crossing
" 55:	Type of transition (in number of lanes, in width of median)
" 56:	Location of transition (at or near structures, on grades with extra truck lane).

The codes given so far apply to all kinds of cards. The identical punching is used in the first 56 columns for (1) the highway card designating a section, (2) each accident card representing an accident on the section, and (3) the summary card representing the section. From here on, however, the coding is different for different types of cards.

Highway cards

Cols.	57:	Type of card (highway card, accident card, summary card)
"	58-59:	Length of section
"	60-64:	Annual vehicle-miles on section

Cols. 65-80 are left blank.

Accident cards

Cols.	57:	Type of card (highway, accident, summary)
"	58:	Month of accident
"	59:	Day of week
"	60-61:	Hour of day
"	62:	Light condition
"	63:	Weather
"	64:	Condition of surface (wet, dry, muddy, etc.)
"	65:	Road defects, if any
"	66:	Traffic control operation (policeman, automatic control operating, automatic control not operating)
"	67:	Severity (fatal, injury, property damage)
"	68:	Location (at intersection, at median opening, between intersections)
"	69:	Type of collision (with pedestrian, with other motor vehicle, with fixed object, ran off roadway, etc.)
"	70-71:	Description of vehicle maneuvers
"	72-73:	Miscellaneous actions (avoiding object in roadway, avoiding other vehicle not involved in collision, etc.) Coded for first two vehicles to collide.
"	74:	Pedestrian's actions
"	75:	Type of fixed object involved (bridge rail, guard rail, trees or shrubs, utility pole, etc.)
"	76-80:	Types of vehicles involved

Summary cards

Cols.	57:	Type of card (highway, accident, summary)
"	58-59:	Length of section
"	60-64:	Annual vehicle-miles on section
"	65-66:	Number of fatal accidents in study year
"	67-68:	Number of injury accidents
"	69-70:	Number of property-damage accidents
"	71-72:	Number of fatal and injury accidents combined
"	73-74:	Total number of accidents in study year
"	75-77:	"Adjusted" number of accidents, using total-to-fatal ratio
"	78-80:	"Adjusted" number of accidents, using total-to-fatal-and-injury ratio

The meaning of the adjustment used in Columns 75 to 80 of the summary cards is explained in the main body of the report.

Relation of Traffic Signals to Intersection Accidents

CASE HISTORIES FROM MICHIGAN SIGNALIZATION EXPERIENCE

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● THE unprecedented expansion of vehicular volumes since the war is putting the existing highway structure to a tremendous test and is revealing glaring deficiencies created by enforced neglect during the war years. The public is clamoring for relief and its demands can be met only by the construction of new facilities and by improving the operation of the old.

The traffic engineer has the responsibility for operating traffic on the plant as it exists. Regardless of the inadequacies, he must keep traffic moving as efficiently and safely as possible. In view of the importance and difficulty of his job, he not only must analyze his problems thoroughly but must examine the tools of his trade continuously and critically. This paper presents early results of some investigations in Michigan of one class of these tools — traffic control signals.

The conditions demanding rural traffic regulation and protection are, for the most part, concentrated in and about intersections. A recent study of accident experience on a heavily traveled suburban trunkline in Michigan revealed that 70 percent of all the accidents occurred on the 30 percent of the route in intersection areas. This study had particular reference to the influence of roadside features in accident causation, but since roadside establishments cluster about practically every important intersection, the results are entirely characteristic.

It appears, then, that the requirements for the operation of traffic between intersections are understood and are not too hard to provide. But where traffic streams intersect, the problems of efficient, safe movement are multiplied. The difficulties inherent in this situation have long been recognized, and certain standard methods of intersection traffic regulations and protection have been developed and used.

Where traffic volumes are low, stop signs halt entering traffic for a convenient opportunity to cross or turn onto the main highway. Where both traffic streams are extremely heavy, grade separations permit uninterrputed movement on and interchange between both routes. But the real problems arise at intersections with volumes too large for stop signs to be effective, and yet not large enough to warrant a costly separation structure.

These intermediate locations constitute a twilight zone in which opinions as to proper traffic-engineering procedures jostle as violently as the vehicles themselves and sometimes quite as unreasonably. Stop-and-go signals and flashers are the accepted means of traffic control at these intersections. The basic cause of the conflicts of opinion is a widespread confusion, and even ignorance, regarding the function and proper use of the first of these signals.

The signal salesman of the past offered the stop-go signal as a panacea for all traffic ills, and since safety was a condition sought by his customer, he labelled it a safety device. The public generally still holds to this belief.

As a matter of fact, the stop-go signal is nothing more than a regulator valve. Properly applied and operated, it can produce orderly flow in two intersecting traffic streams, and traffic safety is an important by-product of traffic order. But order, and not safety, is the functional purpose of signalization; neither orderly movement or its byproduct, safe movement, will be obtained unless the signal is applied to the right conditions in the right way.

Some years ago the Michigan State Highway Department began to suspect that signal installations do not necessarily end accidents. It appeared that what they really do is to alter traffic behavior and, for that reason, produce a different accident pattern. It was noted, moreover, that often accidents actually increased after signalization. In view of these experiences, it was deemed necessary to conduct a probing study of the whys and wherefores of accidents as pertaining to traffic signals.

Figure 1.

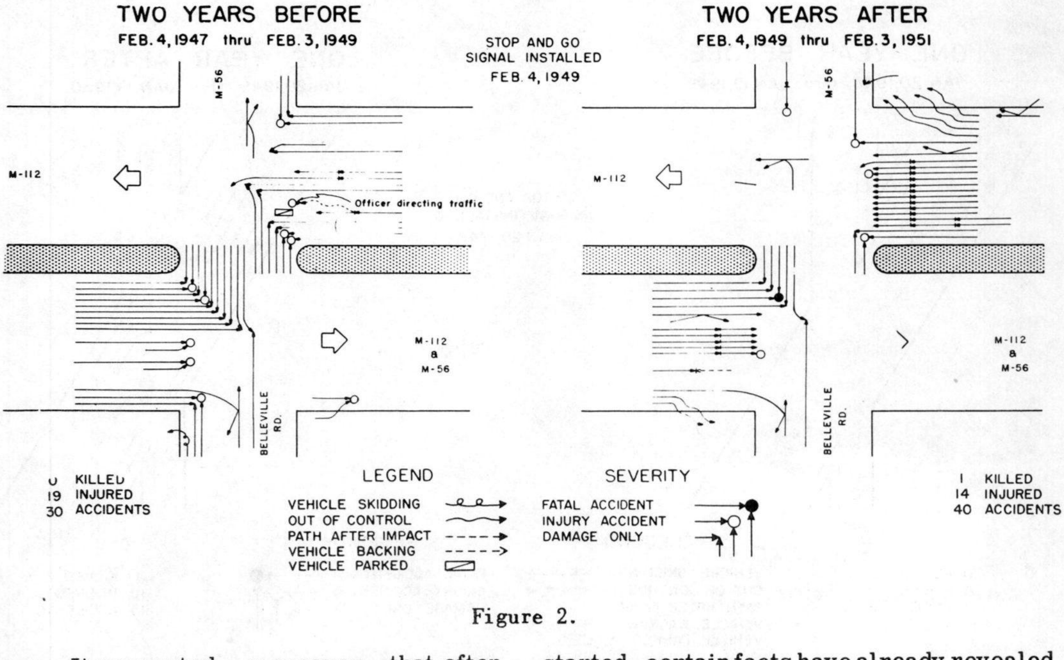

Figure 2.

With this thought in mind, a Traffic Analysis Section has recently been established in the Planning and Traffic Division. In addition to its function of determining needs for various types of traffic control and design, the new section also evaluates the efficiency and safety of such controls after placement. Although its work is only started, certain facts have already revealed themselves.

In the first place, it has become apparent that composite or mass grouping of accident data from many locations means little or nothing when applied to traffic-signal problems, because each location has individual conditions and characteristics which are basically important to an understanding and solution of its particular traffic problem. It was finally decided to isolate each case and diagnose each new signal installation by a before-and-after study of its accident experience. Michigan hopes, by this process, to establish a trend which may be used in the future to predict accident potential and to gain information helpful in determining the type of signal installation most conducive to safety.

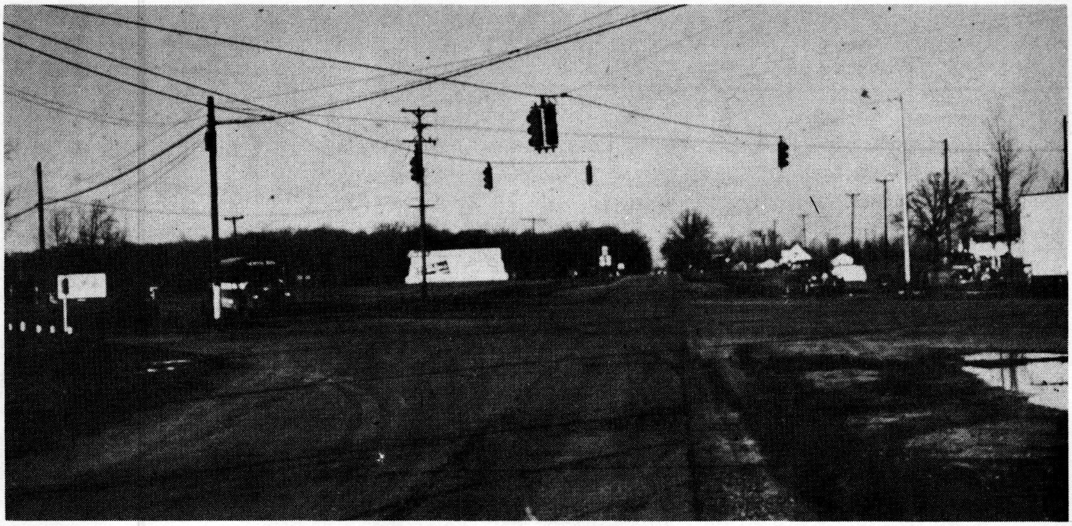

Figure 3.

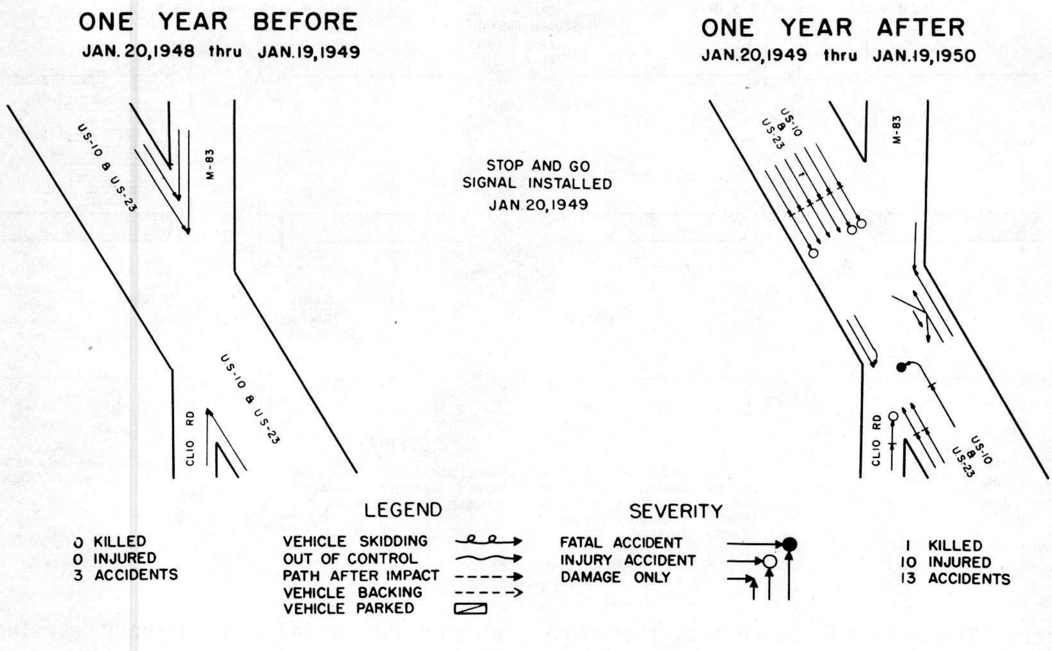

Figure 4.

The examples below are drawn exclusively from rural or suburban areas, because the conditions for which signals are used and under which they operate are radically different on congested city arteries from those that exist on isolated trunkline intersections in relatively open country. For one thing, signal control is a part of the process of movement through a crowded city district and drivers are conditioned to it. But usually the signal at a rural intersection is an exceptional feature of the rural trunkline and, as such, is often dangerously inconsistent with the driver's expectation of an unobstructed roadway for high-speed travel.

The remainder of this discourse will be centered on pictures and charts of carefully selected intersections. They were selected to prove that stop-go signals are not cure-alls. They are not presented as damning evidence against all such signals but as contributions to a record which, it is hoped, will grow in usefulness as it becomes more complete. The figures include a view and a before-and-after collision idagram of each intersection.

The first case (Fig. 1) is the intersection of M 112 with M 56, commonly known as Belleville Road. M 112 is the Detroit Industrial Expressway, but in this particular area it has lost its expressway characteristics and has intersections at grade, even though it remains a divided highway with controlled access.

The figure shows M 112 to be a four-lane divided highway with the medial divider having a width of 32 ft. at this point. Belleville Road is a well-developed asphalt-surfaced road. There are dual signal heads for both directions of M 112. Belleville Road has one signal head for both the near slab and far slab of M 112 in both directions. Signal head visibility is, therefore, better than average and not a contributing factor for the accident pattern to be discussed.

The volume of traffic on Belleville Road, plus a large number of angle collisions, indicated the need of a stop-and-go traffic signal installation. Consequently this project was completed on February 4, 1949. The accident study conducted over a 2-yr. period before and after the installation shows 30 accidents before and 40 accidents after the installation (see Fig. 2). Angle collisions were reduced from 16 to 8, while rear-end collisions were increased from 2 to 17. There are over twice as many rear-end collisions between westbound vehicles on M 112 as eastbound. An explanation is that motorists are coming out of the expressway section from this direction and are acclimated to high vehicle speeds and no cross traffic. Their time-speed sense apparently fails them when faced with the necessity of stopping for a red signal.

Another interesting fact to be noted is that most of the angle collisions in both the before and after periods occurred when vehicles from Belleville Road collided with vehicles on the far slab of M 112. This same condition has been observed at other locations, and we are running some observation and accident studies at certain selected intersections to determine a method of correcting this condition with signalization. We are providing a delayed far-side green, which means that a motorist can enter a divided highway and have a better than average chance of crossing both slabs, since the near signal will go red first, followed a short time thereafter by the far signal. We are doing this under the assumption that some drivers, when crossing a divided highway, will attempt to negotiate the entire crossing rather than store in the medial area in case the green interval expires.

Since we have only conducted tests on this particular operation for a short period, before-and-after accident experience is not available, but operational-wise the plans seem to be obtaining good results.

Figure 3 shows a view of US 10 and US 23 at the intersection of Clio Road, which is located in a rural area north of Flint. The view was taken looking north from Clio Road. The highway has dual signal heads, while Clio Road has single heads. The trunkline is a four-lane undivided highway, while Clio Road is a two-lane concrete pavement. Clio Road north of this location is also state trunkline highway M 83 which serves a prosperous agricultural area.

Vehicle volumes on US10, US23 were very high, while the Clio Road volumes were above signal requirements. The collision diagram shows 3 accidents before and 13 accidents after installation (see Fig. 4). The vehicle speeds are high throughout this area, which accounts for the increase in rear-end collisions.

Maple Road runs west from Birmingham and intersects US24 in a rural area although there is intersection development (Fig. 5). Maple Road carries considerable traffic. The view shows US24 as a four-lane highway, during the time covered in the accident study, US24 was a two-lane highway carrying near capacity vehicle volumes for such a roadway.

The collision diagram (Fig. 6) shows an increase in accidents from 7 to 13 after the installation of the traffic signal. Vehicle speeds are high on US24, which again accounts for the increase in rear-end collisions. The accident study will enter a third stage at this location, since we shall now be able to record the effects of the changing of the physical surface of US24 from a two-lane to a four-lane pavement.

Figure 7 shows the intersection of M59 with Milford Road. A small village named Highland lies to the south of this intersection on Milford Road. A number of angle collisions were occurring due to the suddenness with which motorists found themselves upon M59. It is a two-lane concrete pavement with moderate vehicle volumes traveling at a high average speed.

Figure 5.

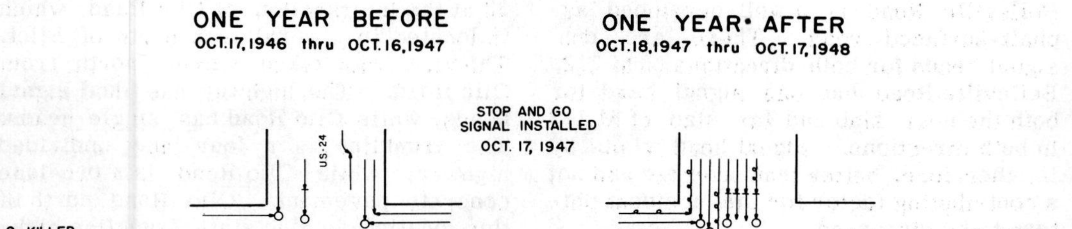

Figure 6.

The collision diagram (Fig. 8) shows that positive results were gained by the installation of a flasher, since accidents were reduced from 12 to 6, while injuries were cut from four to zero in the 2-yr. periods before and after installation.

The intersection of US223 with US223

(Business Route) southeast of Adrian (Fig. 9) makes an interesting intersection to study, since it operates from a traffic standpoint like a T intersection, even though it has four approaching legs physically. US223 splits into a business route going north into Adrian, while the bypass route continues west from the intersection.

The collision diagram (Fig. 10) shows an identical pattern in both the before and the after patterns. The number of accidents was constant at eight, while the injuries were reduced from seven to one.

Figure 7.

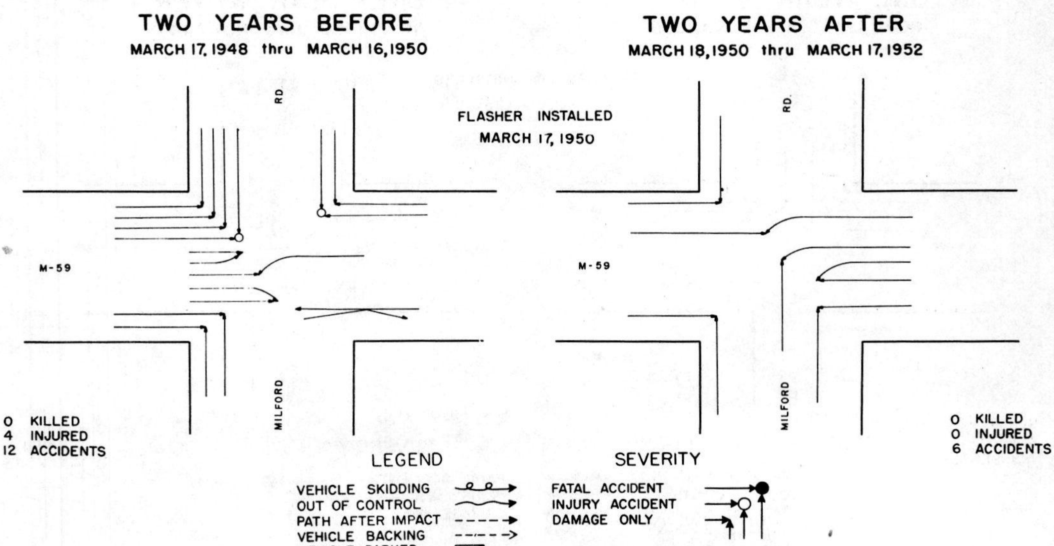

Figure 8.

SUMMARY

From the examples shown of accident experience before and after installations of stop-go and flasher signals, it might be concluded that we should either abandon the stop-go installations or else improve our installation methods. It might be concluded that flasher signals should be substituted for present equipment at the existing stop-go locations. But the problem is not that simple, and is not to be solved by any easy answers.

To begin with, abandoning use of the stop-go signal under existing conditions would leave a wide and dangerous gap in the traffic engineer's array of control devices. Also, we believe that Michigan standards of signal installation are fully in line with the best accepted modern practice. And finally, the flasher signal itself has its own limitations. But there are still other factors to be considered:

All of these selected intersections have traffic-volume characteristics which place them in that intermediate range referred to earlier in this paper; traffic is too heavy for stop signs but does not quite warrant a separation of grades. However, there is a wide variation of volumes represented by these 13 selected intersections, ranging all the way from 1,100 to more than 14,000 vehicles per day on the main highway. The four flasher-equipped locations had average traffic of 3,800 vehicles, or only half the average of 7,600 vehicles per day for the nine stop-go intersections. Performance of the two types of controls is not directly comparable under these widely differing conditions.

The stop-go intersections were selected

Figure 9.

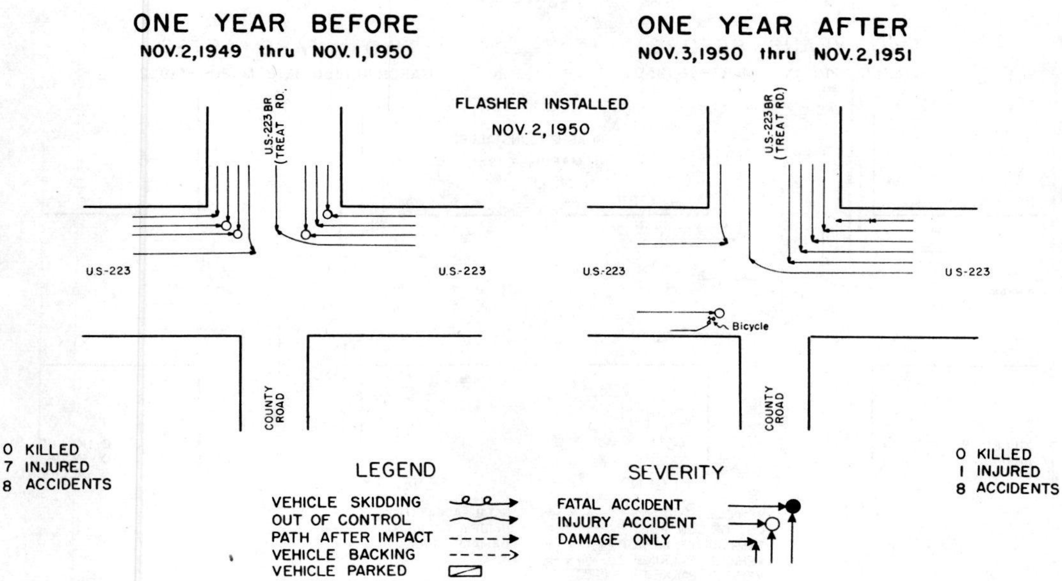

Figure 10.

to demonstrate that the stop-go signal is not a cure-all. They are only a few out of the 150 or 160 rural and suburban intersections in Michigan where similar control equipment is installed. While our analyses have not proceeded far enough to reveal the full performance record of these other locations, it is safe to say that a considerable number of them are operating with a fair degree of safety.

However, while the intersections shown may not be completely representative of Michigan's total experience with rural stop-go signals, they are thoroughly representative of the weakness of these devices in handling certain difficult conditions which are inherent in rural trunkline traffic operation. They clearly cannot be installed whenever and wherever public pressure dictates. They plainly show that we are playing with life and death when we place signals at locations to which they do not apply.

The figures reveal some of the conditions which render the operation of stop-go signals ineffective and dangerous. They suggest the probability that in some cases volumes are crowding the limit for this kind of control, and they show that most of the intersections are exposed to the hazards created by roadside mercantile development. But the most-important unfavorable condition indicated by the collision diagrams is that these are isolated controls and that they intrude unexpectedly into the high-speed characteristics of rural trunkline traffic. This latter fact is the message spelled out by the huge increases in rear-end and turning collisions at several of these intersections.

This latter effect can be expected in some degree whenever a stop-go signal is installed in an isolated location on a high-speed rural trunkline. It is apparent, at least, that the present signal installed according to the best currently approved methods, cannot be depended upon to command the attention of approaching drivers to a degree that assures consistent safety.

But even if the shortcomings of the stop-go signal were more glaring than is indicated by available experience, it does not mean that its use can be abandoned. Traffic must be regulated and protected at the many important rural intersections in this intermediate range. Flashers are unequal to the task of assigning use when volumes on the intersecting routes are in the upper brackets. It is totally unrealistic to dream that grades will be separated at any but the heaviest traveled of these locations—and at these not quickly.

It seems that the most practically constructive course is to focus some rather critical attention on this device whose operations we are analyzing. It is a highly standardized mechanism which has not been changed or improved in any basic way for at least 25 yr. Methods and procedures for using the stop-go signal have been developed and improved, and these also have become highly standardized.

Is it not possible that this standardization process has brought us to a dead end in the field of intersection control? It seems likely that what we are finding is that the same form of this device is not equally applicable to traffic conditions in both urban and rural areas. Do not all of the special conditions of rural trunkline traffic operation—higher speeds, isolated location, and intersections cluttered with roadside developments—point plainly to the need for signals specially designed for this service? It is even conceivable that further investigation, study and experiment might yield improvements in installation and operation methods.

These are some of the directions in which we believe our analyses of rural traffic signal operation are leading. With the alarming concentration of accidents at rural intersections, it is vital that highway and traffic engineers learn all they can about the conditions affecting intersection traffic design, operation and control.

Certain points have been soundly established. The stop-go signal, in spite of public confidence in its powers, is not primarily a safety device, it is not fool-proof, and it is not a cure-all. These findings indicate that to install one of these devices just because the public demands it, is like giving a child a loaded pistol just because he is crying for it.

Our investigations in this field will continue. The author strongly urges that other agencies undertake studies paralleling those reported in this paper. In the future we can unite our information and increase our understanding of these important phases of the traffic and safety problem.

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