HIGHWAY RESEARCH RECORD

Number 188

Traffic Accident Research

10 Reports

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Foreword

The lowering of accident and fatality rates on our highway system has become a national goal. Despite the expenditure of millions of dollars for corrective features and the application of so-called safety measures, the rate and total number of accidents have risen greatly in the past few years. Perhaps one reason for this mounting toll is the absence of research that conclusively pinpoints causation of accidents. Researchers have continued to attack this tremendously complex problem, and the nine papers and two abridgments of papers presented in this RECORD present additional findings of value, application of which will help to utilimately reduce the highway toll.

Because of the high involvement that safety has with people in all walks of life, this RECORD should be of more than passing interest to a large audience. Administrators at all levels of government will find the research to be of significance; those responsible for the day-to-day provision of highway facility design, construction, operations and maintenance can utilize much of the work; and researchers of all disciplines in all aspects of traffic and safety will find much to draw upon. The research is especially useful to those having to do with accident record systems.

A Bureau of Public Roads researcher has related accident experience on the Interstate highway system to various geometric design characteristics in the first paper. This study investigates the accident severity effects of guardrails placed at bridge structures and signposts as well as the lateral clearance effects of bridge structures on accidents. The results show that accident rates and property damage costs are reduced by the presence of guardrails at these locations and that increased minimum lateral clearances of bridges are beneficial in reduction of accident severity.

In the second paper, three researchers using North Carolina data attempted to correlate eight selected site characteristics (such as volume, speed, median width) of multi-lane highways with injury accidents. Prediction equations that could be used to measure the effects of variables on accidents for a new site were developed. The research also investigated the effects of selected roadway characteristics on median-opening accidents and developed information useful to highway planners in decision-making and policy-formulation stages.

Aspects of the comprehensive safety study made on US Route 66 a few years ago are reported by an Illinois researcher in the next report. Some 850 single-vehicle accidents were investigated and analyzed. It was found that "risks" for compact cars were 2.23 and for sports cars 3.49 times as great as "risks" for standard-size cars. Some 15 percent of drivers involved in accidents were exceeding the speed limit at the time; other factors were, for the road, 13 percent for slipperiness, and for the driver, sleep, 25 percent and distraction, 9 percent. One unique finding was that the addition of a trailer to any vehicle multiplied the risk by a factor of 400 percent.

Three California researchers have applied statistical quality control techniques to traffic accident information and adopted these techniques to the decision-making process. A system of control chart computer programs was developed and applied to accident data. The report presents key conclusions and suggests the need for further inquiry. A discussion by an experienced researcher of accident data is included.

The next report, again by a BPR researcher, studies the application of statistical concepts to accident data. It describes statistical procedures that can be employed for three situations including minimum accident rate, highways with differing vehicle-miles of travel and amount of reduction needed to establish statistical significance and the conclusion that a safety program was effective.

The growth of motorcycle accidents is portrayed by an Iowa researcher in the sixth paper. Due to the nature of the vehicle, twice as many injuries and four times as many deaths compared to other vehicles were experienced in 1965. The paper points out that a cyclist's chances of being killed (on a vehicle-mile basis) are 20 times greater than a car driver's, and a passenger's chances even greater. The author suggests the establishment of more stringent engineering safety standards as a partial means of reducing the death and injury toll.

New and improved accident data utilization has been studied by a California engineer in the next report. Three types of tabulations for an accident surveillance system are set forth and systems diagrams for the entire system and accident concentrations were developed.

An elaborate study reported by two consultants has determined direct accident costs for a major metropolitan area. The comprehensive cost data developed will permit more objective interpretation of accident data for highway design and traffic control. Findings should be applicable to economic analyses of route improvements, accident location studies, sufficiency ratings and programs for enforcement and safety education.

Four North Carolina researchers have studied the effect of median openings on four-lane noncontrolled-access highways in terms of accident rates and levels of service. Their paper indicates that as volumes and development increase, the frequency of median openings has a significant effect on the accident rate. The authors suggest rigid control of median opening with minimum spacings in the 1,200- to 1,800-foot range.

The last two items in this RECORD are abridgments by two Cornell Aeronautical Laboratory researchers based on NCHRP projects. Both deal with the relationship between motor vehicle accident rates and geometric design elements and point out findings that, if applied in design or redesign, could reduce highway accident potentials.

Contents

Interstate System Accident Research—Study II

JULIE ANNA CIRILLO, Office of Research and Development, U.S. Bureau of Public Roads

This is an interim report on a long-term accident study designed to relate accident experience on the Interstate System to its various geometric design characteristics. The study investigates the effect of guardrails on accident severity at bridge structures and signposts and the effect of lateral clearance at bridge structures on accident occurrence and severity. Data used in these analyses were collected by 16 state highway departments and represent approximately 2,000 miles of interstate highway. Mileage was computed for both directions of travel. The results of a statistical analysis of property damage costs indicate that the presence of guardrails at overpasses, bridges, underpasses, and signposts reduces the property damage costs of single-vehicle accidents and that increased minimum lateral clearances at overpasses and bridges reduce accident rates and property damage costs.

•IN 1961, Interstate System accident research began as a joint effort of the several state highway departments and the U.S. Bureau of Public Roads. The research encompasses two studies: Study I, a general evaluative study comparing the safety record of the Interstate System with older existing highways that formerly accommodated interstate traffic, and Study II, the present study. The objective of Study II is to relate accident experience on the Interstate System to its geometric design characteristics.

A report on Study I by S. R. Byington has been published (1) and a second report on Study I will be available in the near future. This report presents the results of the initial analysis of data collected for Study II. More specifically, this report contains an analysis of the effectiveness of guardrails at bridge structures and signposts on accident severity, and the effectiveness of lateral clearance at bridge structures on accident incidence and severity.

Traffic, geometric, and accident data used in these analyses were collected by 16 state highway departments (Fig. 1). Only data available prior to February 1, 1965 were used. Other data submitted had not been processed prior to this date. These data represent approximately 2000 miles of the Interstate System. Mileage was computed for both directions of travel with no distinction being made between urban and rural sections, or year of data. The majority of data submitted was for years 1961, 1962 and 1963. However, small portions were also submitted for 1959, 1960 and 1964. The number of years of data available varied from state to state.

In both analyses only main-line Interstate study units were used. For this study, a main-line study unit is defined as any section on the Interstate highway less than 10,000 ft long and homogeneous throughout with respect to its geometric characteristics. Speed change lanes, although classified as separate units, are included in this category. All other units, such as ramps, collector-distributor roadways, and crossroads were not included in these analyses in an effort to reduce the variability in study section type and data.

All accident data on main-line units were utilized. To obtain the largest possible sample size, no distinction was made between daytime or nighttime accidents. For the

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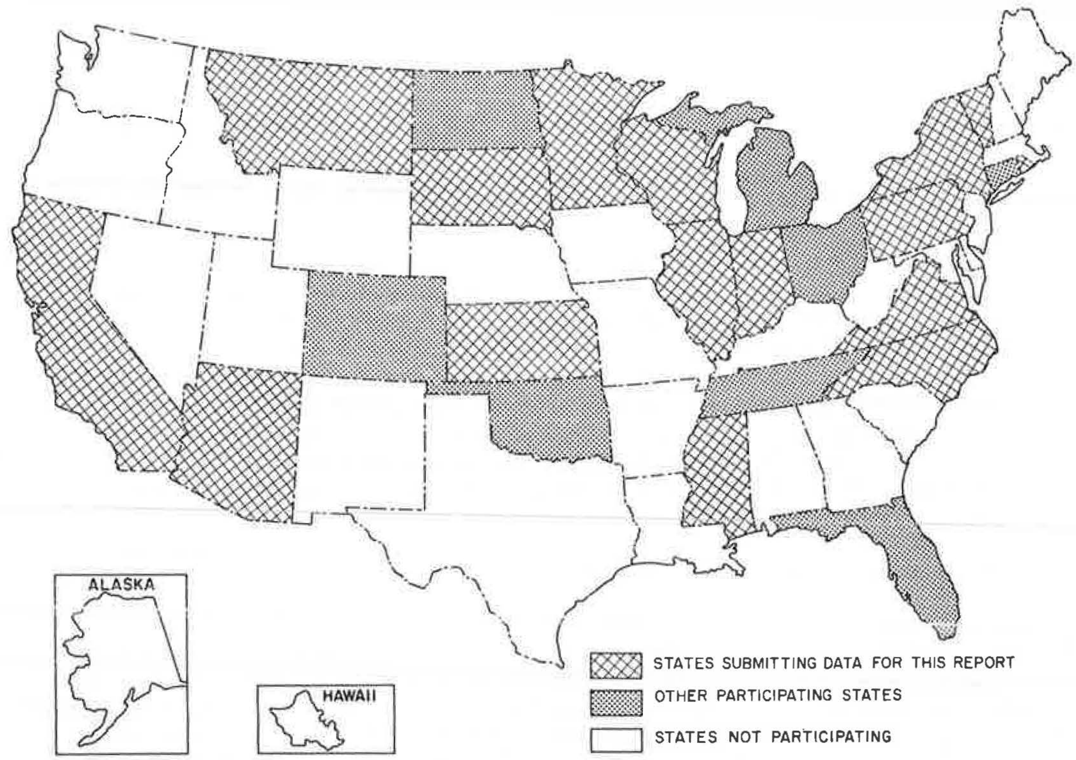

Figure 1. States participating in Interstate System Accident Research Study II, Jan. 1, 1966.

guardrail analysis only single-vehicle accidents were utilized, but for the minimum lateral clearance analysis both single and multivehicle accidents were considered.

A measure of the severity of collisions with fixed objects in terms of property damage costs was found to be useful in these analyses. Property damage costs include damage to vehicles, contents, and other objects damaged in the collision. An attempt to use the number of injuries and/or fatalities proved to be infeasible since the number of such occurrences in the available data was scant.

The results reported for minimum lateral clearance are limited to clearances less than 13 ft and structures shorter than 500 ft. In this analysis, structures were defined as bridges or overpasses; in the guardrail analysis, structures encompass overpasses or bridges and underpasses.

GUARDRAILS REDUCE ACCIDENT SEVERITY

The results of the analysis on the effectiveness of protective guardrail indicate that with regard to structures the presence of guardrail is beneficial in terms of accident costs.

Speed as a Factor

Where data on the speed of the vehicle just prior to collision were available, all single-vehicle accidents were grouped as (a) less than 40 mph, (b) 40 to 60 mph, and (c) over 60 mph. Due to the small sample size, a finer subgrouping was not possible.

Within each speed group, accidents were classified according to the object hit, with emphasis on the absence or presence of protective guardrail. Overpass or bridge and underpass accident data were combined into one group. Speed data were lacking in many of the accident records and this combination was necessary to have a meaningful

TABLE 1

COST PER ACCIDENT BY SPEED AND OBJECT HIT, SINGLE-VEHICLE ACCIDENTS

Object Hit	Speed (mph)	Number of Accidents	Total Cost ($)	Cost per Accident ($)
End of overpass or underpass pier or abutment not protected by guardrail	Less Than 40	10	8,500	850
	40-60	48	66,550	1,390
	Over 60	15	21,300	1,420
	Total	73	96,350	1,320
Guardrail protecting end of overpass or underpass pier of abutment	Less Than 40	7	3,490	500
	40-60	39	21,380	550
	Over 60	13	13,190	1,020
	Total	59	38,060	650
End of overpass or underpass pier of abutment, although protected by guardrail[a]	Less Than 40	2[b]	2,250	1,130[b]
	40-60	10	5,900	590
	Over 60	4	2,950	740

[a]Guardrail was penetrated and protected object was hit.
[b]One accident involved a 3-axle truck accounting for $1500 property damage.

sample size. Table 1 gives the cost per accident by speed and object hit. As expected, results show for each different object hit that increased speed increases the severity of the accident. In the under 40 mph category where the vehicle penetrated the guardrail and hit the protected object, the cost per accident is higher than in other speed categories. However, one accident involved a truck and accounted for $1500 property damage and the sample size (two accidents) is so small that this result is meaningless. In every other category, however, the cost per accident increases with speed.

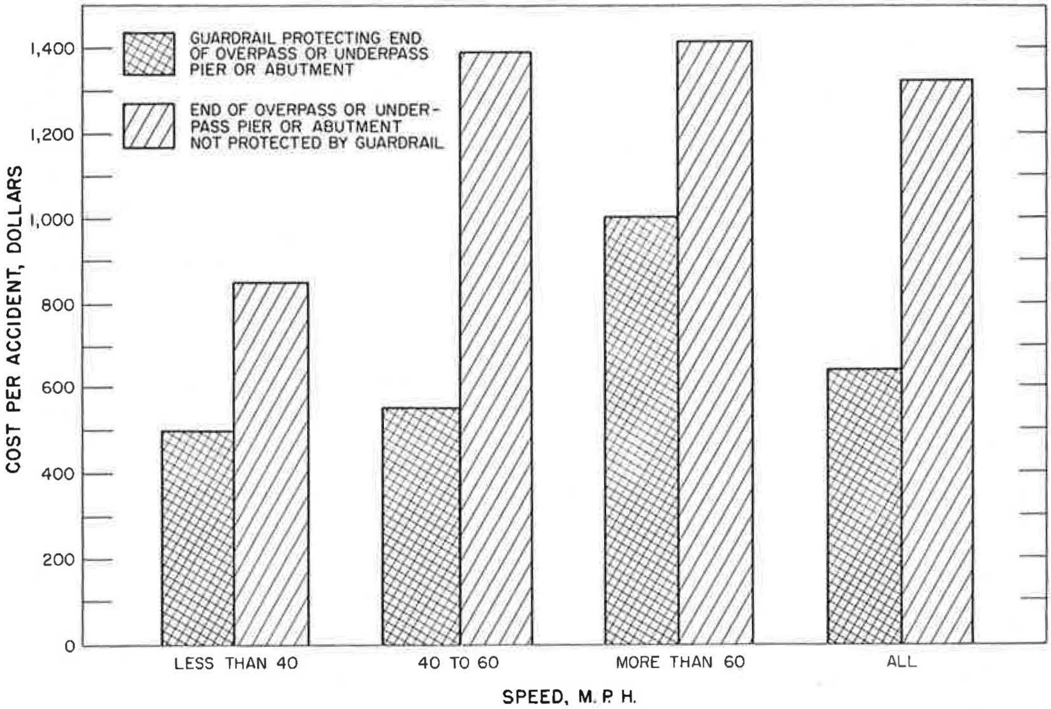

Figure 2. Cost per accident by speed and object hit for single-vehicle accidents.

For any one speed group (Fig. 2), the results indicate that protective guardrails decrease the severity of accidents. Because of the small sample size, these results could have been due to chance alone. To elicit trends and learn from the data how the chance factors may be operating, various levels at which the observed differences were significant were computed. The difference in average cost between accidents involving the protective guardrail and accidents involving an unprotected object was tested by means of a "t test." Due to small sample size, accidents where the guardrail was penetrated were not considered. The null hypothesis $H_o : U_1 - U_2 = d$ was compared against the alternate hypothesis $H_a : U_1 - U_2 \neq d$ where U_1 = average cost per accident without guardrail, U_2 = average cost per accident with guardrail, and $d = 0$.

If the null hypothesis is accepted, we can conclude that there is no difference in average accident costs between single-vehicle accidents with unprotected structures and single-vehicle accidents with structures protected by guardrail. However, if the null hypothesis is rejected, then the alternate hypothesis is accepted, and we can conclude that there is a difference between the two categories being tested (3) (i. e., protected structures vs unprotected structures).

In the less than 40 mph group the null hypothesis must be rejected at the 0.20 level of significance; in the 40 to 60 mph group at the 0.01 level of significance, and in the over 60 mph group at the 0.10 to 0.15 level of significance. If a vehicle is traveling under 40 mph prior to a collision with a structure, 80 percent of the time protective guardrail will help to reduce property damage costs of the accident. Similarly, at 40 to 60 mph 99 percent of the time, and over 60 mph 85 to 90 percent of the time protective guardrail will help reduce property damage costs of the accident.

The null hypothesis is rejected at the 0.05 level when all accidents are grouped regardless of prior speed for both accidents involving protective guardrail and accidents where no guardrail was present; i. e., 95 percent of the time guardrail reduces the severity of a single-vehicle accident with a structure. Thus, we can conclude that protective guardrail helps to reduce accident severity. These results demonstrate that there is a significant difference between the average property damage costs for accidents involving protective guardrail and accidents with no guardrail present. We cannot, however, conclude that this difference will offset the cost of the guardrail.

Although the findings of this analysis show that the presence of guardrails significantly reduces the cost of accidents in terms of property damage, it is not possible, due to the scarcity of data on injuries and fatalities, to infer a comparable reduction of injures and/or fatalities. Although injuries and fatalities account for approximately half of the total accident cost (2), the lack of data prohibits a benefit-cost analysis at this time. In the event larger samples become available, the reduction in total accident costs can be compared to costs of installing and maintaining guardrail. At that time, it should also be possible to analyze the number and cost of injuries and fatalities which occurred in those accidents where guardrails failed to prevent the vehicle from hitting the protected objects. Although in most cases these accidents are less costly in terms of property damage, they might be more costly in terms of lives lost.

Speed Data Not Considered

A direct comparison was made for all single-vehicle accidents regardless of speed prior to collision considering the cost per accident with regard to object hit and the presence or absence of guardrail protecting the object. This comparison eliminated consideration of the speed of the vehicle prior to collision, which was considered in the previous analysis. Since a much larger sample was available than when speed prior to collision was considered, the combination of overpasses or bridges and underpasses into one category was not necessary. It can be seen in Table 2 that accidents where no guardrail was present were more costly than accidents where guardrail was present. Thus, in terms of property damage savings per accident, guardrails appear to be beneficial regardless of whether the guardrail is protecting a bridge structure or a signpost.

Again a t test was performed to determine if any significant differences exist between the mean cost of the two accident categories shown in Figure 3 (i. e., object hit not protected by a guardrail vs guardrail protecting object). With regard to overpasses or

TABLE 2

COST PER ACCIDENT BY OBJECT HIT, SINGLE-VEHICLE ACCIDENTS

Object Hit	Number of Accidents	Total Cost ($)	Cost per Accident ($)
Guardrail protecting end of overpass structure	146	128,540	880
End of overpass structure, although protected by guardrail	16	16,960	1,060
End of overpass structure not protected by guardrail	36	56,840	1,580
Guardrail protecting underpass pier or abutment	17	12,560	580
Underpass pier or abutment not protected by guardrail	135	133,500	990
Underpass pier or abutment, although protected by guardrail	18	21,700	1,210
Guardrail protecting highway post	24	8,380	350
Highway signpost although protected by guardrail	6	2,500	420
Highway signpost not protected by guardrail	115	69,810	610

bridges and underpasses, the mean cost of accidents with guardrail is significantly different from the mean cost of accidents without guardrail at the 0.05 level. For highway signposts, the differences are significant at the 0.10 level. In general, when guard-

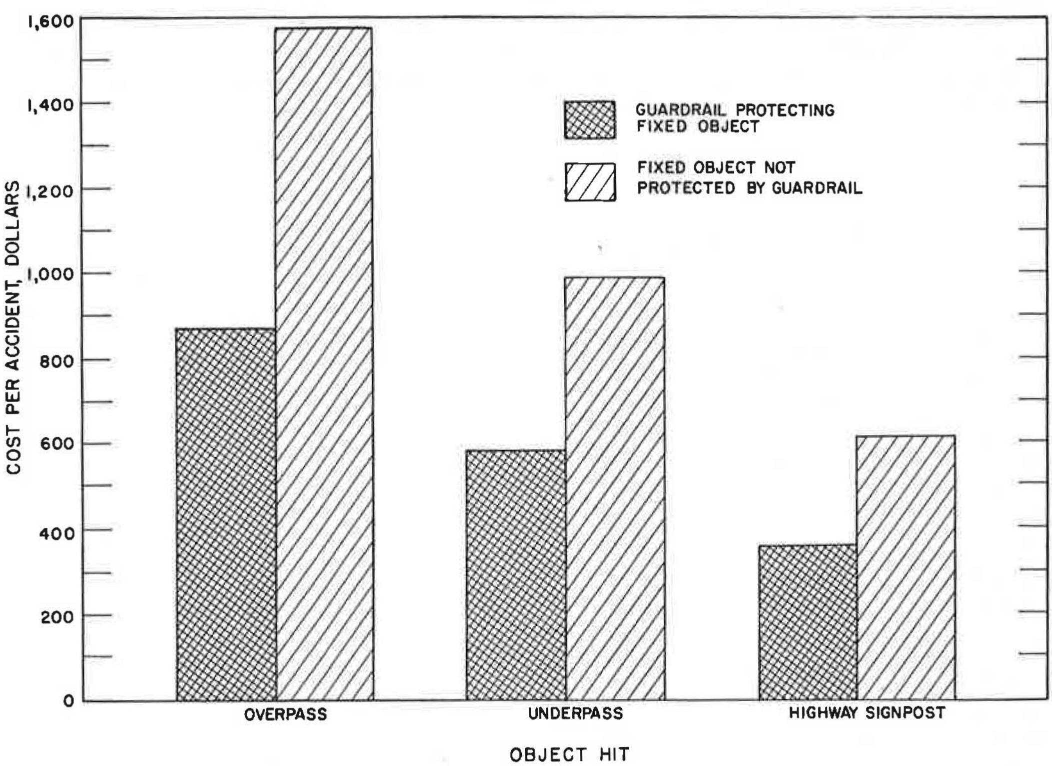

Figure 3. Cost per accident by object hit for single-vehicle accidents.

rails are protecting structures, accidents will be less serious 95 percent of the time than if no guardrail were present. In cases involving signposts, this figure becomes 90 percent. Thus, again we can infer that protective guardrail will reduce the severity of a single-vehicle accident with a fixed object.

INCREASED LATERAL CLEARANCE AND SAFETY

Although the sample size in some structure length and lateral clearance categories is relatively small, the results of this analysis indicate, from a safety viewpoint, a need for wider minimum lateral clearances. This need particularly applies where the length of the structure exceeds 250 ft.

Data were submitted in coded form. Each code represented an interval for structure length and minimum lateral clearance. Due to the smallness of the sample size, minimum lateral clearances of less than 6 ft were combined into one category and only one case was reported for minimum lateral clearance greater than 12.9 ft. In addition, very few Interstate sections with structures longer than 500 ft are presently under study. Because section length is used as the independent variable, the accident rate was computed for 100 million vehicles rather than the conventional 100 million vehicle-mile base.

The results given in Table 3 indicate that for structures 150 to 199 ft long, the accident rate is similar for all minimum lateral clearances. As structure length increases, the need for larger minimum lateral clearances is indicated by the increase in accident rate. For structures 200 ft or longer, the accident rate increases more rapidly for lower minimum lateral clearances. In fact, at lengths of 300 to 499 ft, the difference in accident rate between clearances less than 6 ft and clearances 9 to 12.9 ft is statistically significant at the 0.10 level. Ninety percent of the time a bridge 300 to 499 ft long will experience a lower accident rate if the minimum lateral clearance is 9 to 12.9 ft as opposed to a clearance of less than 6 ft. These results indicate that wider minimum lateral clearances reduce accident rates.

In addition, in most cases the cost per accident for any one structure length increases as the minimum lateral clearance decreases. However, the difference in cost between any two minimum lateral clearance categories for any structure length is not statistically significant.

TABLE 3

ACCIDENT RATE BY LENGTH OF STRUCTURE (OVERPASS AND BRIDGE) AND MINIMUM LATERAL CLEARANCE

Structure Length (ft)	Minimum Lateral Clearance (ft)	Number of Accidents	Number of Vehicles	Accident Rate per 100 Million Vehicles	Cost per Accident ($)
Less than 50	Less than 6	15	54,016,350	27.77	115
Less than 50	6-8.9	14	33,090,900	42.31	185
Less than 50	9-12.9	5	57,845,200	8.64	64
50-99	Less than 6	12	56,702,750	21.16	955
50-99	6-8.9	22	132,856,350	16.56	749
50-99	9-12.9	25	79,683,150	31.37	573
100-149	Less than 6	115	220,548,650	52.14	985
100-149	6-8.9	18	126,315,550	14.25	403
100-149	9-12.9	11	44,197,850	24.89	492
150-199	Less than 6	101	307,976,050	32.79	796
150-199	6-8.9	28	77,639,153	36.06	588
150-199	9-12.9	12	34,050,850	35.24	588
200-299	Less than 6	129	255,835,800	50.42	969
200-299	6-8.9	21	83,503,350	25.15	915
200-299	9-12.9	17	56,038,450	30.34	828
300-499	Less than 6	185	172,645,000	107.16	820
300-499	6-8.9	26	38,398,000	67.71	759
300-499	9-12.9	12	34,463,300	34.82	728

CONCLUSIONS

The results reported demonstrate that the installation of guardrail at fixed objects, namely overpasses, bridges, underpasses, and signposts is beneficial in terms of property damage savings for single-vehicle accidents. Also, increased minimum lateral clearances at overpasses and bridges reduce accident rates and property damage costs.

As more data become available, more extensive analyses will be performed. We do feel, however, that the results reported here are important and could be of interest in the field.

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Effects of Selected Roadway and Operational Characteristics on Accidents on Multilane Highways

P. D. CRIBBINS, Professor of Civil Engineering, North Carolina State University, Raleigh;
J. M. AREY, Altus Air Force Base, Oklahoma; and
J. K. DONALDSON, Highway Planner, Harland Bartholomew and Associates, Raleigh

The purpose of this investigation was to determine the effects of selected roadway and operational characteristics on accidents on multilane highways. Field data for 92 highway sites were collected and records of over 6000 accidents that occurred on these sites during a 21-month period in 1963 and 1964 were evaluated.

Eight selected highway characteristics—median width, speed limit, volume, level of service, access point index, intersection openings per mile, signalized openings per mile, and median openings per mile—were correlated with all injury accidents. A multiple-regression analysis was performed so that the effects on the accident frequency of all of the site characteristics could be examined simultaneously. By combining the five significant highway characteristics, a prediction equation to estimate injury accidents per mile was derived.

An adjunct objective of determining the effects of the highway characteristics on the median opening accident rate was also considered. The Student's t value which was calculated for each regression coefficient indicated whether the variable corresponding to the coefficient had a significant effect on the accident rate being examined. The predominance of positive coefficients throughout the analysis indicates that, generally, as the magnitude of the variable increases, the median-opening accident rate increases. However, when storage lanes are installed at openings, the median-opening accident rate is no longer significantly affected by the number of openings excluding intersections, the median width, the speed limit, or the traffic volume.

•SINCE the invention of the automobile and its subsequent widespread use in the movement of people and goods, the number of fatalities attributable to the motor vehicle has continued to increase. In fact, 49,000 people were killed and 1,800,000 people were injured in motor vehicle accidents in 1965 (6). Fortunately, however, the deaths per mile of travel have decreased over the past 20 years. Despite incorporation of new safety features in the many miles of roadway constructed each year, installation of safety equipment in the motor vehicle, and numerous safety campaigns aimed at the careless driver, the decreasing trend in the fatality rate is apparently leveling off.

Improvements in highway design and motor vehicle reliability have contributed significantly to the reduction in the accident rate, but efforts directed towards decreasing the fallibility of the driver have met with less success. Thus, the problem of reduction of the motor vehicle accident rate is extremely complex and even experts disagree as to the proper approach to its solution, if indeed there is a solution.

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In 1963, researchers in the Civil Engineering Department at North Carolina State University initiated an investigation concerning the effects of median-opening spacing on the number of accidents on multilane divided highways. The purpose of that two-year investigation was the formulation of a policy on spacing of median openings so as to minimize the median-opening accident rate while providing sufficient access to adjacent property. The research reported here is an extension of the investigation.

Specific objectives of this additional investigation are (a) to correlate certain site characteristics such as ADT, speed limit, median width, and the number of openings with all injury accidents on the site; (b) to develop prediction equations for the effects of these characteristics on injury accidents; (c) to test the hypothesis that the total number of accidents involved with or attributable to the median opening decreases as the median width increases; and (d) to investigate the effects of the facility's characteristics on the frequency of median-opening accidents. For purposes of this study an injury accident is defined as an accident, either fatal or nonfatal, in which at least one individual was injured.

If the facility's characteristics adversely affect the accident frequency, the characteristics can be controlled during design to insure a minimum accident rate. Any findings indicating that future controls would eliminate even a small percentage of the accidents could conceivably save many lives while reducing injuries and property damage.

SELECTION OF STUDY AREA

After establishing certain site criteria, 92 sections, both rural and urban, of multilane divided highway were selected for study. The sites were selected on the basis of homogeneity with respect to roadside development, median width, speed limit and average daily traffic (ADT) throughout the length of the site. Information on 6417 accidents which occurred on the sites during a 639-day period (Jan. 1, 1963 to Sept. 30, 1964) was obtained from files of the North Carolina Department of Motor Vehicles. During the summers of 1964 and 1965, each of these sites was visited by a field survey team to collect data to be used in the investigation. The results of an inventory of 92 sites totaling 388 miles in length are given in Table 1.

Sites with lengths shorter than the arbitrarily selected one-half mile were automatically excluded from the study. Such sites appear to function more as channelized intersections than as multilane divided highways. Sites having painted or narrow medians traversable at any point were also excluded. This freedom of traversability causes the median to function as one continuous median opening. Inclusion of such median types would have prohibited analysis of median-opening accidents.

The accident characteristics given in Table 2 were obtained for each accident from the North Carolina Department of Motor Vehicles.

METHODOLOGY

Preliminary Analysis

From the inventory of each site the following characteristics were chosen as the variables to be used in the analysis:

1. Access-point index,
2. Intersection openings per mile,
3. Signalized openings per mile,
4. Median openings per mile,
5. Median width,
6. Speed limit,
7. Volume, and
8. Level of service

The access-point index and level of service were derived for each site while the other characteristics were quantitative values recorded during the inventory. In order

TABLE 1

SITE CHARACTERISTICS AND LOCATIONS

Site No.	Site Length (miles)	Access Point Index	Intersection Openings per Mile	Signalized Openings per Mile	Opening Excluding Intersections per Mile	Median Width	Speed Limit	ADT	Level of Service	Total Number of Accidents	Total Injury Accidents	Total Median Opening Accidents	Route Designation	County
1	2.5	19899	4.00	1.20	1.60	30	55	14500	1.58	138	38	53	U.S. 64	Wake
2	1.4	2380	7.14	0.73	0.72	6	55	7600	1.36	21	5	12	U.S. 64	Wake
3	1.4	25054	11.43	1.43		27	35	12000	1.66	115	18	15	Glenwood Ave.	Wake
4	3.3	27024	1.21	0.61	2.72	30	45	18000	1.43	157	42	56	U.S. 1	Wake
5	2.0	8523	3.00			30	55	9000	1.13	46	20	23	U.S. 1	Wake
6	2.6	25520	3.85	1.15	3.85	25	55	18000	1.27	166	50	60	U.S. 70 ¢ 401	Wake
7	1.5	6069	2.00		8.00	15	60	8000	1.18	17	11	11	U.S. 401	Wake
8	4.7	5747	1.06		0.21	30	60	10000	1.08	33	16	10	U.S. 70	Wake
9	2.1	14217	8.10		1.91	30	45	10500	1.36	67	19	33	U.S. 64	Wake
10	14.9	4404	1.48		2.42	30	60	11000	1.00	152	49	35	U.S. 70	Wake
11	1.1	31120	6.36	1.82	2.72	30	35	10300	2.00	15	3	10	U.S. 64	Nash
12	1.6	1250	6.63			40	60	10000	0.95	2	0	0	U.S. 64	Nash
13	14.1	2182	1.63	0.07	3.97	35	60	6500	0.95	109	42	30	U.S. 301	Nash
14	4.2	23927	4.29	0.48	5.47	15	45	14400	1.36	189	41	83	U.S. 301	Wilson
15	12.4	20262	1.69		1.61	40	60	7200	0.95	73	31	—	U.S. 301	Wilson
16	0.8	15100	7.50	1.25	3.75	2	45	7200	1.62	8	1	3	U.S. 301	Johnston
18	5.7	2200	2.63		13.51	15	45	2400	1.50	7	4	0	N.C. 2	Moore
19	2.6	1015	1.54		3.85	35	60	3500	0.98	12	3	4	U.S. 1	Moore
20	3.1	181	0.65		2.26	40	60	2450	0.97	4	2	0	U.S. 1	Moore
21	4.6	4223	1.74	0.22	2.61	15	45	6000	1.28	37	13	14	U.S. 74	Richmond
22	1.6	2349	1.88			30	60	3400	0.97	7	4	2	U.S. 74	Anson
23	21.6	4913	1.53	0.09	1.71	30	60	8000	1.03	33	15	8	U.S. 74	Union
24	1.4	13559	4.29	0.72	1.43	30	45	3350	1.20	12	6	4	N.C. 54	Orange
25	5.9	2235	1.86		0.51	25	60	6500	1.04	66	20	41	U.S. 15 ¢ 501	Durham
26	3.2	650	1.88		2.81	30	60	1600	1.00	5	1	1	U.S. 29	Cleveland
27	11.3	4293	1.68	0.27	0.36	30	60	6500	1.15	103	37	55	U.S. 74	Cleveland
28	6.2	2761	1.13		2.90	50	60	11000	1.00	66	26	27	U.S. 74 ¢ 29	Gaston
29	7.5	24588	4.27	0.93	2.14	14	45	18000	1.43	270	85	106	U.S. 74	Mecklenburg
30	6.5	53077	4.15	3.08	0.31	2	45	25000	1.77	698	256	222	U.S. 74	Mecklenburg
31	2.2	37637	8.64	1.82	2.73	25	35	11000	1.94	73	20	35	Queens Rd.	Mecklenburg
32	1.4	11754	9.29	1.43		35	45	11000	1.15	52	23	24	N.C. 16	Mecklenburg
34	2.0	9975	5.00	0.50		3	55	7000	1.09	13	7	8	N.C. 273	Gaston
35	1.6	132000	4.38	1.88	0.63	30	45	17000	1.50	111	36	34	U.S. 74	Mecklenburg
36	4.2	11067	7.62	0.48	1.91	12	55	9000	1.50	60	27	29	N.C. 16	Mecklenburg

TABLE 1 (Continued)

Site No.	Site Length (miles)	Access Point Index	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT	Level of Service	Total Number of Accidents	Total Injury Accidents	Total Median Opening Accidents	Route Designation	County
37	15.2	4350	2.11	0.06	3.03	20	60	13000	0.97	358	100	136	U.S. 29	Mecklenburg
38	6.6	22375	4.09	0.46	1.97	15	45	15000	1.46	299	82	104	U.S. 29	Cabarrus
39	2.7	1549	1.11		1.85	30	60	2800	1.09	4	1	1	U.S. 1	Franklin
40	1.1	5700	4.55		3.63	15	45	8300	1.33	15	1	—	U.S. 158	Halifax
42	2.1	540	1.43		0.95	30	55	2650	1.00	11	2	3	U.S. 421	Chatham
43	0.8	1854	2.50			30	45	7200	1.28	9	2	0	U.S. 401 ¢ 421	Harnett
44	3.3	6815	2.12		2.12	30	60	3500	0.97	47	19	29	U.S. 421	Harnett
45	4.7	48290	4.68	0.43	5.74	30	45	20000	1.43	321	93	126	Bragg Blvd.	Cumberland
46	3.4	7566	2.65	0.59		30	45	22000	1.43	31	12	14	Bragg Blvd.	Cumberland
47	0.7	104111	10.00		1.43	25	35	22000	1.29	43	7	27	N.C. 87 ¢ 24	Cumberland
48	8.1	8286	3.46	0.12	0.12	30	55	12000	1.00	166	2	59	U.S. 301	Cumberland
49	2.4	50	1.25		2.50	30	60	2300	0.95	7	3	1	U.S. 117	Duplin
50	7.6	4250	2.24		1.97	30	60	6100	0.92	120	40	43	U.S. 117 ¢ 13	Wayne
51	4.7	2495	2.98		0.64	30	60	5700	1.00	33	9	17	U.S. 70	Wayne
53	0.7	8090	5.71		2.86	30	45	5600	1.25	3	0	2	U.S. 70	Johnston
54	2.5	8684	6.80	1.20		30	35	18000	1.88	58	11	28	U.S. 421	Guilford
55	3.1	17306	4.52	1.29	0.65	20	35	11000	1.71	35	17	21	Benjamin Pky.	Guilford
56	11.6	2069	0.43		0.86	30	60	8000	0.92	61	27	12	U.S. 29	Guilford
57	1.2	1853	1.67		0.83	25	60	4200	1.00	6	2	4	N.C. 158	Forsyth
58	5.6	1606	0.89		3.04	35	55	2200	1.00	10	5	3	N.C. 49	Randolph
59	1.5	26030	4.67	1.33	5.33	20	45	6500	1.20	40	18	21	U.S. 13 ¢ N.C. 11 ¢ 43	Pitt
60	2.8	9.75	0.72	0.36	2.14	20	60	3700	1.00	3	1	0	U.S. 13	Martin
61	3.1	3747	0.97		2.26	25	55	3800	1.00	12	7	2	U.S. 13 ¢ 17	Bertie
62	1.1	5430	3.64		1.82	30	60	3800	0.95	12	3	7	U.S. 13	Bertie
63	0.7	7323	4.29		2.86	30	60	4600	1.09	5	0	4	U.S. 70	Lenoir
64	0.9	18680	3.33		6.68	25	45	7580	1.33	17	4	10	U.S. 70	Lenoir
65	8.3	3357	1.56	0.12	1.69	20	60	5000	0.92	30	15	11		
66	16.2	1425	2.10		0.34	20	60	6000	0.93	56	21	14	U.S. 70	Craven
67	2.2	32048	0.91	0.46	0.45	10	35	9000	1.72	3	2	1	U.S. 70	Craven
68	0.9	201	1.11		2.22	25	55	5500	1.05	2	2	0	U.S. 70	Craven
69	2.3	9409	2.61		3.05	20	45	6500	1.20	26	9	10	U.S. 70	Carteret
70	3.6	9487	6.64	0.56	0.84	40	35	6250	1.50	68	16	30	U.S. 70	Carteret
71	3.9	8971	2.31	0.26	2.57	100	45	6000	1.20	113	29	35	U.S. 17 ¢ 258	Onslow
72	9.3	1035	0.97		2.48	30	60	3800	1.02	63	24	12	U.S. 421	New Hanover

TABLE 1 (Continued)

Site No.	Site Length (miles)	Access Point Index	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT	Level of Service	Total Number of Accidents	Total Injury Accidents	Total Median Opening Accidents	Route Designation	County
73	0.9	19069	6.67	1.11	3.34	20	45	2000	1.50	8	2	2	Shipyard Blvd	New Hanover
74	1.3	31406	10.77	1.54		6	35	15500	2.40	120	45		U.S. 421	New Hanover
75	1.0	50018	14.00	3.00		10	35	12000	2.20	94	30	40	U.S. 17, 74, 76	New Hanover
76	2.3	22000	10.87	2.61	0.87	20	35	8500	2.22	128	39	73	5th St.	New Hanover
77	0.8	33171	6.25	3.75	2.50	15	35	10200	2.40	23	8	13	U.S. 70	Alamance
78	32.8	1390	1.13		0.49	30	60	11000	0.95	278	96	82	U.S. 29 ¢ 70	Davidson
79	4.2	8211	2.38		0.72	25	55	15500	1.00	89	31	27	U.S. 29 ¢ 601	Rowan
80	1.6	63226	8.13	1.25		10	35	19000	1.56	49	10	26	U.S. 29 ¢ 601	Rowan
81	0.9	20377	7.78	2.22		10	45	5100	1.33	32	10	20	U.S. 321	Catawba
82	3.8	6054	2.37		1.31	30	60	55500	1.07	37	13	15	U.S. 321	Caldwell
83	2.6	898	3.08		0.77	33	55	7900	1.25	14	2	6	U.S. 70	Buncombe
84	1.9	99980	2.11	1.58	4.21	25	35	26000	2.40	240	76	90	U.S. 19	Buncombe
85	2.0	10685	2.00		3.50	30	55	5000	1.09	17	5	8	U.S. 64 ¢ N.C. 280	Transylvania
86	1.3	295	0.77		3.85	3	60	8500	1.11	21	1	11	U.S. 19 ¢ 23	Haywood
87	1.5	655			3.34	15	60	8000	1.09	7	2	2	U.S. 19 ¢ 23	Haywood
88	2.9	5386	1.03		2.41	18	60	7700	1.15	24	4	4	U.S. 19 ¢ 23	Haywood
89	2.7	2480	2.59			30	55	4100	1.05	20	10	5	U.S. 52	Surry
90	2.0	2664	2.00		3.50	30	60	5550	1.00	18	6	5	U.S. 401	Wake
91	0.7	28293	7.14	1.43		30	35	3200	1.72	7	2	2	Holden Rd.	Guilford
92	0.7	17535	7.14	1.43	1.43	30	35	17000	2.00	21	5	8	Summit Ave.	Guilford
93	0.9	1464	2.22		2.22	30	55	3500	1.09	7	2	3	U.S. 29 ¢ 70	Davidson
94	0.7	2900			5.62	10	60	5800	1.09	13	6	3	U.S. 29 ¢ 70	Davidson
95	9.5	5819	0.53		2.95	35	60	7200	0.92	1.26	45	35	U.S. 1	Moore
96	0.8	18500	3.75	1.25	1.25	70	35	2835	1.71	7	2		Cone Blvd.	Guilford

TABLE 2

ACCIDENT CHARACTERISTICS

(a) Location Type
1. Involving median but not at an opening
2. Intersection of four-lane with primary highway
3. Intersection of four-lane with secondary highway
4. At a median opening serving private drive
5. At a median opening serving a public drive
6. At an opening with no roadside access
7. At a signalized intersection
8. Median openings with storage lane serving public drive
9. Intersection with storage lane
10. Signalized intersection with storage lanes
11. Other
(b) Vehicles Involved in the Initial Impact
1. One utility vehicle (two axles)
2. One commercial vehicle (more than two axles)
3. Two utility vehicles
4. Two commercial vehicles
5. One utility, one commercial vehicle
6. Other
(c) Light Condition
1. Darkness (lighted)
2. Darkness
3. Daylight
(d) Accident Type
1. Vehicle hit from rear while attempting a left turn through an opening
2. Vehicle hit from the front while turning through an opening
3. Vehicle hit from rear after making turn through an opening
4. Vehicle hit from rear while turning from outside lane through opening
5. Vehicle hit by oncoming traffic while attempting to cross four lanes
6. Head-on collision whithin an opening by opposing traffic
7. Vehicle struck from rear while using left turn storage lane at an opening
8. Head-on collision within opening by vehicles crossing four lanes
9. Vehicle crossed median and collided with traffic in opposite lane
10. One vehicle striking object off road
11. Rear-end collision
(e) Personal Injury
1. Fatal injury
2. Nonfatal injury

to determine the potential points of conflict of traffic moving on, across and from a site, and thereby obtain an estimate of accident potential, an access-point index was computed for each site. The access-point index is the estimated total of all movements entering or leaving the site from commercial and industrial roadside development, private drives, and intersecting roadways expressed on a per-mile basis. Procedures for determining this index were evaluated in previous studies (4, 5). The average travel time for the entire site, divided by the site length, produced a minute-per-mile value which was used as the level of service for the site.

Once the site characteristics had been identified, a mathematical relationship between the accident rate and each characteristic was investigated. The method of least squares was used to determine the existence of any linear relationship of the form

$$Y = A + BX$$

where

Y = accidents per mile,
A = constant,
B = coefficient, and
X = site variable.

After processing on an IBM 1620 computer the following information was also computed and printed out:

SSYX = sum square of Y deviation given an X,
r^2 = the dependence of Y on X, and
σ_y = standard error Y.

Once the r^2 and σ_y values for each characteristic were known, it could immediately be determined if further analyses were warranted. If these values were high enough to give some indication of linear dependence, a multiple regression would be attempted. By using a multiple-regression analysis, the effect of each of the characteristics would be measured and only the most important would remain in the equation. The form of the multiple-regression equation was

$$Y = b_0 + b_1x_1 + \ . \ . \ . \ + b_nx_n$$

where

Y = dependent variable,
b_0 = constant,
b_n = correlation coefficients,
x_n = independent variables, and
n = number of variables.

The R^2 and σ_y values were also computed and printed out so that some degrees of confidence could be placed in the final equation. Once the equation had been derived, the results could be checked against the actual site values by substituting the appropriate variables.

Injury Accidents

The first objective of this research was to examine the effects of eight site characteristics on the frequency of injury-producing accidents. The technique of multiple-regression analysis was chosen so that the effects of all of the site characteristics (independent variables) could be examined simultaneously. The regression analysis was run on an IBM 1410 computer using a pre-written program. Results of this analysis would also provide an equation which could be used with any new set of independent variables (in the range of the values used in this investigation) as a prediction equation for injury accidents on new or reconstructed sites. Thus the second objective of developing a prediction equation would be met.

Five of the initial eight independent variables remained in the equation after a stepwise regression analysis was performed. These variables, which are given in Table 3, include:

1. X_1 = access-point index,
2. X_3 = signalized openings per mile,
3. X_6 = speed limit (posted),
4. X_7 = volume, and
5. X_8 = level of service.

Results of preliminary analysis indicated that the frequency of injury accidents is directly proportional to total accidents. These variables and their corresponding coefficients are given in the following equation:

TABLE 3

STEPWISE MULTIPLE LINEAR REGRESSION VALUES

Characteristic	Variable	Coefficient	Student t	R^2	y	b_o
Step 1						
Access-point index	X_1	0.00010	3.26360	0.6944	4.6516	-32.51427
Intersection openings per mile	X_2	0.34746	1.31177			
Signalized openings per mile	X_3	3.29036	2.78540			
Median openings per mile	X_4	0.29792	1.14784			
Median Width	X_5	0.01826	0.42493			
Speed limit	X_6	0.39081	3.51030			
Volume	X_7	0.00053	4.48190			
Level of service	X_8	6.67571	1.98287			
Step 2						
Access-point index	X_1	0.00010	3.30603	0.6937	4.6290	-31.30565
Intersection openings per mile	X_2	0.32287	1.25525			
Signalized openings per mile	X_3	3.21666	2.76637			
Median openings per mile	X_4	0.27958	1.09775			
Speed limit	X_6	0.38225	3.50820			
Volume	X_7	0.00053	4.48372			
Level of service	X_8	6.58890	1.97033			
Step 3						
Access-point index	X_1	0.00011	3.45872	0.6894	4.6345	-31.53670
Intersection openings per mile	X_2	0.26823	1.06164			
Signalized openings per mile	X_3	2.91715	2.57774			
Speed limit	X_6	0.38590	3.53900			
Volume	X_7	0.00051	4.35639			
Level of service	X_8	7.45310	2.29046			
Step 4						
Access-point index	X_1	0.00011	3.43833	0.6852	4.6379	-28.34191
Signalized openings	X_3	3.28169	3.04109			
Speed limit	X_6	0.34218	3.38655			
Volume	X_7	0.00050	4.31364			
Level of service	X_8	7.34777	2.25747			

$$Y = -28.34191 + 0.00011X_1 + 3.28169X_3 + 0.34218X_6 + 0.00050X_7 + 7.34777X_8$$

A positive sign for the coefficient indicates that the number of accidents increases as the magnitude of the corresponding independent variable increases. The difference in the magnitude of the coefficient can be partially explained by the order of magnitude of the variables. The equation has a coefficient of determination (R^2) of 0.69, indicating that approximately 6 percent of the variance can be explained by the regression line.

The value of any prediction equation is its ability to predict accurate results. Using this equation and the given data, the predicted value is within $\pm 2\sigma_y$ of the actual value 94 percent of the time and within $\pm\sigma_y$ of the actual value 77 percent ot the time.

TABLE 4

FREQUENCY TABULATION OF MEDIAN-OPENING ACCIDENTS

Classification	Accident Type					Total
	1	2	3	4	5	
All	297	589	88	445	889	2308
Commercial	40	65	10	70	80	265
Utility	256	524	79	375	809	2043
Night (darkness)	74	61	28	93	143	399
Night (lighted)	27	101	15	30	120	293
Daylight	196	427	45	322	626	1615

The reader is cautioned that the apparent effect of the variables in the prediction equation is the effect when all of the variables are examined simultaneously and this apparent effect could be entirely different if the variables were examined independently.

Median-Opening Accidents

Intuitively, the investigators felt that roadways with medians narrower than one car length would have a higher accident rate than medians which provide storage protection for at least one vehicle. To test this hypothesis, a detailed study was made of accidents involved with or attributable to the median opening. Preliminary analysis indicated that 37 percent of all accidents could be classified as median-opening accidents. Also, information on the effects of seven site characteristics on the median-opening accidents was desirable to determine if any one or any combination of these characteristics was a significant factor associated with median-opening accidents.

Five different types of accidents are classified as median-opening accidents:

1. Vehicle hit from rear while turning through an opening,
2. Vehicle hit from front while turning through an opening,
3. Vehicle hit from rear after turning through an opening,
4. Vehicle hit from rear while turning from outside lane through an opening, and
5. Vehicle hit while attempting to cross four lanes.

The median-opening accidents were grouped into six classifications:

1. All opening accidents,
2. Commercial vehicle opening accidents (at least one commercial vehicle),
3. Utility vehicle opening accidents,
4. Night (darkness) opening accidents,
5. Night (lighted) opening accidents, and
6. Daylight opening accidents.

Each of the accident types is tabulated by accident classifications in Table 4.

Once again the method of regression analysis was employed to determine the effects of the site characteristics on the median-opening accidents. A detailed analytical procedure to detect any relationship between the site characteristics and the accident rate or between the site characteristics and the five accident types was utilized. With this procedure a separate regression run was made for each accident type under each classification and also for accidents occurring at openings with storage lanes, without storage lanes, and for their combinations.

The output from the regression program includes Student's t values for each regression coefficient. The Student's t can be compared to standard Student's t tables for a given α level to test the statistical significance of the regression coefficient. This test can be used to select variables which significantly affect the accident rate.

The Student's t comparison in the procedure can be used to test the hypothesis that the median width decreases as the median-opening accident rate increases. If the regression coefficient corresponding to median width is found to be statistically significant, and if the sign of this coefficient is negative, the hypothesis can be accepted. If the coefficient is positive or if the coefficent is statistically insignificant, the hypothesis must be rejected.

Roadway Characteristics

In addition to the objective of determining the effect of median width on the median-opening accident rate, the broader objective of determining the effects of other physical features of the roadway on the median-opening accident rate was also considered. Knowledge of the effects of the physical features of the roadway on the median-opening accident rate is valuable to the roadway designer in making decisions and formulating policy, although the effects are difficult to quantify.

TABLE 5

REGRESSION COEFFICIENTS FOR ALL MEDIAN-OPENING ACCIDENTS

Accident Variable	Dependent Variable	Storage Lanes		Independent Variable						
		With	Without	Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening		x	—	—	—	0.20678(H)	—	—	0.14(H)
x_{10}	Vehicle hit from front while turning through opening		x	—	0.27268(H)	1.112(H)	—	—	—	—
x_{11}	Vehicle hit from rear after turning through opening		x	—	—	0.1226(S)	0.05690(S)	0.00794(S)	—	0.03(H)
x_{12}	Vehicle hit from rear while turning from outside lane		x	—	0.16801(S)	—	0.20981(S)	—	—	0.20(H)
x_{13}	Vehicle hit while attempting to cross site		x	—	0.74902(H)	—	—	0.05571(S)	—	0.18(S)
x_{14}	Summation of 9, 10, 11, 12, 13		x	—	1.24629(H)	2.56531(S)	0.83988(S)	—	0.22353(S)	0.64(H)
x_{15}	Vehicle hit from rear while turning through opening	x		—	—	—	—	—	—	0.10(H)
x_{16}	Vehicle hit from front while turning through opening	x		0 30(H)	-1.56509(S)	13.4408(H)	—	—	—	—
x_{17}	Vehicle hit from rear after turning through opening	x		—	-0.17984(H)	1.0097(H)	—	—	—	—
x_{18}	Vehicle hit from rear while turning from outside lane	x		0.22(H)	0.54627(S)	-4.4653(H)	—	—	—	—
x_{19}	Vehicle hit while attempting to cross site	x		0.09(H)	—	—	—	—	—	—
x_{20}	Summation of 15, 16, 17, 18, 19	x		0.62(H)	—	9.7715(H)	—	—	0.68048(S)	—
x_{21}	Vehicle hit from rear while turning through opening	x	x	—	—	—	0.22438(S)	—	—	0.26(H)
x_{22}	Vehicle hit from front while turning through opening	x	x	0.30(H)	-1.18190(S)	15.1261(H)	—	—	0.44029(S)	—
x_{23}	Vehicle hit from rear after turning through opening	x	x	—	-0.18281(H)	1.15757(H)	—	—	—	0.04(S)
x_{24}	Vehicle hit from rear while turning from outside lane	x	x	0.23(H)	0.82626(H)	-3.92511(H)	—	—	—	0.22(S)
x_{25}	Vehicle hit while attempting to cross site	x	x	0.11(H)	0.84360(H)	—	—	—	0.10662(S)	0.20(S)
x_{26}	Summation of 21, 22, 23, 24, 25	x	x	0.67(H)	—	12.71571(H)	—	—	0.69409(S)	1.11(H)

TABLE 6

REGRESSION COEFFICIENTS FOR MEDIAN OPENING ACCIDENTS INVOLVING UTILITY VEHICLES

Accident Variable	Dependent Variable	Independent Variable						
		Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening	–	–	–	0.21159(H)	–	–	–
x_{10}	Vehicle hit from front while turning through opening	–	0.28422(H)	1.12340(H)	–	–	–	–
x_{11}	Vehicle hit from rear after turning through opening	–	–	0.15445(S)	0.06352(H)	0.06699(S)	–	0.02(H)
x_{12}	Vehicle hit from rear while turning from outside lane	–	–	–	0.18920(S)	–	–	0.15(H)
x_{13}	Vehicle hit while attempting to cross site	–	0.65441(H)	–	–	0.05167(S)	–	0.16(S)
x_{14}	Summation of 9, 10, 11, 12, 13	–	1.13725(H)	2.36625(S)	0.81433(H)	0.07959(S)	0.17669(S)	0.55(H)
x_{15}	Vehicle hit from rear while turning through opening	–	–	–	–	–	–	0.08(H)
x_{16}	Vehicle hit from front while turning through opening	0.32(H)	–	7.66502(H)	–	–	–	–
x_{17}	Vehicle hit from rear after turning through opening	0.01(S)	-0.11818(S)	0.92223(H)	–	–	–	–
x_{18}	Vehicle hit from rear while turning from outside lane	0.20(H)	0.65335(H)	-4.37884(H)	–	–	–	–
x_{19}	Vehicle hit while attempting to cross site	0.19(H)	0.17542(S)	-1.05945(H)	–	–	–	–
x_{20}	Summation of 15, 16, 17, 18, 19	0.65(H)	–	–	–	–	–	–
x_{21}	Vehicle hit from rear while turning through opening	–	–	–	0.22358(S)	–	–	0.20(H)
x_{22}	Vehicle hit from front while turning through opening	0.34(H)	–	8.03356(H)	–	–	0.30710(S)	–
x_{23}	Vehicle hit from rear after turning through opening	0.01(S)	-0.16911(S)	1.02717(H)	–	–	–	–
x_{24}	Vehicle hit from rear while turning from out side lane	0.21(H)	0.83382(H)	-4.32328(H)	–	–	–	0.21(S)
x_{25}	Vehicle hit while attempting to cross site	0.11(H)	0.79208(H)	–	–	0.04553(S)	0.08770(S)	0.13(S)
x_{26}	Summation of 21, 22, 23, 24, 25	0.67(H)	–	4.70448(S)	–	–	0.40757(S)	0.59(S)

TABLE 7

REGRESSION COEFFICIENTS FOR MEDIAN OPENING ACCIDENTS INVOLVING COMMERCIAL VEHICLES

Accident Variable	Dependent Variable	Independent Variable: Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening	—	—	—	—	—	—	0.01(H)
x_{10}	Vehicle hit from front while turning through opening	—	0.08913(S)	—	0.02794(S)	—	—	0.00(H)
x_{11}	Vehicle hit from rear after turning through opening	—	0.01261(S)	-0.05026(S)	—	—	—	—
x_{12}	Vehicle hit from rear while turning from outside lane	—	0.03297(S)	—	0.07707(S)	—	—	0.01(S)
x_{13}	Vehicle hit while attempting to cross site	0.00(S)	0.07885(H)	—	—	0.00585(S)	—	—
x_{14}	Summation of 9, 10, 11, 12, 13	—	0.15515(S)	—	0.15477(S)	—	—	0.06(H)
x_{15}	Vehicle hit from rear while turning through opening	—	No significant variables			—	—	—
x_{16}	Vehicle hit from front while turning through opening	—	-0.24287(S)	1.91872(H)	—	-0.03912(S)	—	—
x_{17}	Vehicle hit from rear after turning through opening	—	-0.02708	—	—	-0.00289(S)	-0.00982(S)	—
x_{18}	Vehicle hit from rear while turning from outside lane	0.02(S)	—	—	—	—	—	—
x_{19}	Vehicle hit while attempting to cross site	—	—	—	0.15385(H)	—	—	0.00(S)
x_{20}	Summation of 15, 16, 17, 18, 19	—	—	2.14703(H)	—	—	—	—
x_{21}	Vehicle hit from rear while turning through opening	—	—	—	—	—	—	0.02(S)
x_{22}	Vehicle hit from front while turning through opening	—	-0.24873(S)	—	1.98444(H)	-0.04095(S)	—	—
x_{23}	Vehicle hit from rear after turning through opening	—	—	—	—	—	-0.00686(S)	—
x_{24}	Vehicle hit from rear while turning from outside lane	—	No significant variables		—	—	—	—
x_{25}	Vehicle hit while attempting to cross site	—	0.06525(H)	—	—	—	—	0.02(S)
x_{26}	Summation of 21, 22, 23, 24, 25	—	—	1.66365(H)	—	—	—	—

TABLE 8

REGRESSION COEFFICIENTS FOR MEDIAN OPENING ACCIDENTS WHICH OCCUR UNDER NIGHT (LIGHTED) CONDITIONS

Accident Variable	Dependent Variable	Independent Variable						
		Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening	0.00(S)	—	—	0.07102(S)	—	—	—
x_{10}	Vehicle hit from front while turning through opening	0.00(S)	—	—	0.08413(S)	—	—	—
x_{11}	Vehicle hit from rear after turning through opening	—	—	—	—	—	-0.01432(S)	—
x_{12}	Vehicle hit from rear while turning from outside lane	—	0.00646(S)	—	—	—	—	—
x_{13}	Vehicle hit while attempting to cross site	0.13(S)	—	—	—	—	—	—
x_{14}	Summation of 9, 10, 11, 12, 13	—	—	0.90315(S)	—	—	—	0.00011(S)
x_{15}	Vehicle hit from rear while turning through opening	—	—	—	—	—	—	0.00003(S)
x_{16}	Vehicle hit from front while turning through opening	0.11(H)	-0.56925(S)	2.29801(H)	—	—	—	—
x_{17}	Vehicle hit from rear after turning through opening	—	-0.12352(S)	0.83667(H)	—	—	—	—
x_{18}	Vehicle hit from rear while turning from outside lane	0.08	—	-0.87142(H)	-0.13651(S)	—	—	0.00006(S)
x_{19}	Vehicle hit while attempting to cross site	0.10(H)	—	1.05463(S)	—	—	—	—
x_{20}	Summation of 15, 16, 17, 18, 19	0.28(H)	-0.65463(S)	3.32038(H)	—	—	—	—
x_{21}	Vehicle hit from rear while turning through opening	0.01(S)	—	—	0.11982(S)	—	—	—
x_{22}	Vehicle hit from front while turning through opening	0.11(H)	-0.61668(S)	2.36844(H)	—	—	—	—
x_{23}	Vehicle hit from rear after turning through opening	—	-0.13809(S)	0.98329(H)	—	—	—	—
x_{24}	Vehicle hit from rear while turning from outside lane	0.06(H)	-0.69221(S)	—	-0.21829(S)	—	—	—
x_{25}	Vehicle hit while attempting to cross site	—	—	—	—	—	—	—
x_{26}	Summation of 21, 22, 23, 24, 25,	0.66(S)	-0.54066(S)	4.10008(H)	—	—	—	—

TABLE 9

REGRESSION COEFFICIENTS FOR MEDIAN OPENING ACCIDENTS WHICH OCCUR UNDER NIGHT (DARKNESS) CONDITIONS

Accident Variable	Dependent Variable	Independent Variable: Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening	—	—	-0.20492(S)	0.06419(S)	—	—	0.03(H)
x_{10}	Vehicle hit from front while turning through opening	—	—	—	0.02942(S)	—	0.00782(S)	0.01(S)
x_{11}	Vehicle hit from rear after turning through opening	—	—	—	0.03389(H)	—	0.00538(S)	0.00(S)
x_{12}	Vehicle hit from rear while turning from outside lane	-0.00(S)	—	—	0.08788(H)	0.00757(S)	—	0.05(H)
x_{13}	Vehicle hit while attempting to cross site	7.33(S)	—	—	0.04585(S)	0.01767(H)	—	0.02(S)
x_{14}	Summation of 9, 10, 11, 12, 13	—	—	—	0.25274(H)	0.03380(H)	—	0.10(H)
x_{15}	Vehicle hit from rear while turning through opening		No significant variables					
x_{16}	Vehicle hit from front while turning through opening	—	—	—	—	—	-0.05256(S)	—
x_{17}	Vehicle hit from rear after turning through opening		No significant variables					
x_{18}	Vehicle hit from rear while turning from outside lane		No significant variables					
x_{19}	Vehicle hit while attempting to cross site	0.17(H)	0.53931(H)	-4.29234(H)	-0.39403(S)	—	—	—
x_{20}	Summation of 15, 16, 17, 18, 19	0.18(H)	0.78972(H)	-5.25988(H)	—	—	—	—
x_{21}	Vehicle hit from rear while turning through opening	—	—	-0.35201(S)	—	—	—	0.04(S)
x_{22}	Vehicle hit from front while turning through opening		No significant variables					
x_{23}	Vehicle hit from rear after turning through opening	—	—	—	0.05359(S)	—	—	—
x_{24}	Vehicle hit from rear while turning from outside lane		No significant variables					
x_{25}	Vehicle hit while attempting to cross site	0.17(H)	0.57286(H)	-4.47781(H)	-0.37540(S)	—	—	—
x_{26}	Summation of 21, 22, 23, 24, 25	0.16(H)	0.86043(H)	-6.28257(H)	—			0.24(S)

TABLE 10

REGRESSION COEFFICIENTS FOR MEDIAN OPENING ACCIDENTS WHICH OCCUR DURING DAYLIGHT HOURS

Accident Variable	Dependent Variable	Independent Variable: Access-Point Index (1×10^{-3})	Intersection Openings per Mile	Signalized Openings per Mile	Openings Excluding Intersections per Mile	Median Width	Speed Limit	ADT (1×10^{-3})
x_9	Vehicle hit from rear while turning through opening	—	—	—	0.10848(S)	—	—	0.10(H)
x_{10}	Vehicle hit from front while turning through opening	—	0.23121(H)	0.84348(H)	—	—	—	—
x_{11}	Vehicle hit from rear after turning through opening	—	—	—	—	0.00513(S)	—	0.01(H)
x_{12}	Vehicle hit from rear while turning from outside lane	0.02(S)	—	—	0.13296(S)	—	—	0.11(H)
x_{13}	Vehicle hit while attempting to cross site	—	0.48987(H)	—	—	—	—	0.12(S)
x_{14}	Summation of 9, 10, 11, 12, 13	—	0.73260(H)	1.33861(S)	0.37942(S)	—	—	0.37(H)
x_{15}	Vehicle hit from rear while turning through opening	-0.01(S)	—	—	—	—	—	0.09(H)
x_{16}	Vehicle hit from front while turning through opening	0.19(H)	-1.29450(S)	9.98349(H)	—	—	—	—
x_{17}	Vehicle hit from rear after turning through opening	0.01(H)	-0.06260(S)	—	-0.04747(S)	-0.00812(S)	—	—
x_{18}	Vehicle hit from rear while turning from outside lane	0.15(H)	0.53824(S)	-3.23945(H)	—	—	—	—
x_{19}	Vehicle hit while attempting to cross site	0.47(H)	—	—	—	—	—	—
x_{20}	Summation of 15, 16, 17, 18, 19	0.92(H)	—	—	—	—	—	—
x_{21}	Vehicle hit from rear while turning through opening	—	—	—	0.11959(S)	—	—	0.16(H)
x_{22}	Vehicle hit from front while turning through opening	0.19(H)	-1.16407(S)	10.8562(H)	—	—	—	—
x_{23}	Vehicle hit from rear after turning through opening	0.01(H)	—	—	—	—	0.01453(S)	—
x_{24}	Vehicle hit from rear while turning from outside lane	0.19(H)	0.50181(H)	-3.09566(H)	—	—	—	—
x_{25}	Vehicle hit while attempting to cross site	0.54(H)	0.82278(S)	—	—	—	0.29706(S)	—
x_{26}	Summation of 21, 22, 23, 24, 25	0.88(H)	—	8.98627(S)	—	—	0.53289(S)	—

Independent variables other than median width are examined for significance as a contributor to the median-opening accident rate using the Student's t test in the same manner as for median width. For the respective classifications, Tables 5 through 10 give the order of magnitude for the independent variable regression coefficients corresponding to the dependent variables used for the regression analysis. Any coefficient with a negative sign indicates that the accident rate decreases as the magnitude of the corresponding variable increases, and conversely a positive sign indicates that the accident rate increases as the magnitude of the variable increases. Caution must be exercised, once again, in interpreting the sign of the coefficient. This is the sign of the contribution of the variable when examined in the presence of the other independent variables, but this sign may change when the variable is examined alone.

The data in Table 5 include the coefficients of the variables that were significant at least at the 0.10 α level for all median-opening accidents. The S and H shown in parentheses after the coefficient indicate whether the coefficient is significant at the 0.10 α and the 0.005 α level respectively. It is not recommended that these coefficients be used with their corresponding variables to form prediction equations. The coefficient is presented here only to show the order of magnitude and relationship for the different dependent variables. Large differences in the order of magnitude of the coefficients of the independent variables for a given dependent variable are possibly due to units of the independent variable. Any differences in the coefficient that are unexplained by the magnitude of the variable are differences due to the contribution of that variable to the accident rate.

SUMMARY

1. No one highway characteristic showed enough relationship to injury accidents to be called the primal cause.

2. An equation relating total accidents to injury accidents had a high level of predictability ($Y = -0.02216 + 0.30227X$).

3. By combining the five significant highway characteristics (X_1 = access-point index, X_3 = signalized openings per mile, X_6 = speed limit, X_7 = volume, X_8 = level of service) and using a multiple-regression analysis, an equation was derived to predict the injury accidents per mile of highway ($Y = -28.3419 + 0.00011X_1 + 3.28169X_3 + 0.34218X_6 + 0.00050X_7 + 7.34777X_8$).

4.. The Student's t value computed for each regression coefficient indicated whether the variable corresponding to the coefficient had a significant effect on the accident rate being examined. From a tabulation of the regression coefficients for each of the independent variables corresponding to a specific accident type, it was observed that the roadway characteristics do influence the median-opening accident rate. More specifically it was observed that:

(a) The access-point index was significantly related to four of the six accident classifications. The index showed little effect, however, on commercial accidents and on darkness accidents.

(b) The number of intersections contribute significantly for all accident classifications. This contribution was negative for some of the accidents within a given classification.

(c) The number of signalized intersections has a highly significant influence on the accident rate, although significant for a slightly lower number of the accident types than the number of intersections. With the exception of the darkness classification, the effects of this variable were generally to increase the accident rate as the magnitude of the variable increased.

(d) The number of median openings excluding intersections also had a significant effect on the accident rate. For almost all of the accident types, the coefficient remained positive, indicating that the accident rate tends to increase as the number of median openings excluding intersections increases.

(e) The two roadway characteristics having the least effect on the accident rate were median width and speed limit. As the width of the median increases, the accident rate (with the exception of the commercial classification) increases. The commercial accident rate decreased generally with increasing median width. These same relationships hold for speed limit within the commercial classification.

(f) Accident frequency is highly influenced by the ADT for most of the accident classifications. The classification for which ADT is least significant is darkness and most significant is all accidents. In virtually every classification the ADT has a positive influence on the accident rate.

CONCLUSIONS

1. It is apparent that further research concerning the effect of individual highway characteristics on accidents will be less fruitful than research relating the effect of combinations of highway characteristics on the same accidents.
2. Injury accidents and total accidents are closely related and can be predicted from each other.
3. Accidents per mile can be predicted with confidence by using actual or estimated values (new facility) for the access-point index, signalized openings per mile and speed limit.
4. Due to the generally small number of accident types for which the median width is significant and the predominant number of positive coefficients for this variable when it is significant, the hypothesis that the median-opening accident rate decreases as the median width increases must be rejected.
5. Also, due to the low coefficients of determination and relatively high standard errors for prediction, the objective of developing realistic prediction equations for median-opening accidents could not be met.
6. The predominance of positive coefficients throughout the analysis indicates that, generally, as the magnitude of the variable increases, the median-opening accident rate increases. This information tends to support the belief of many traffic engineers that the number of median openings of all types should be kept to a minimum.
7. From the pattern of influence of the independent variables on the accident types, it can be concluded that whenever storage lanes are installed at openings the median-opening accident rate is no longer significantly affected by (a) the number of openings excluding intersections, (b) median width, (c) speed limit or (d) ADT.

In conclusion, it is apparent that additional theoretical research is essential if a more complete understanding of the effects of roadway characteristics on accidents is to be provided. However, the results of this investigation suggest various ways in which accidents associated with median openings can be affected by roadway and operational characteristics, and how many of the undesirable characteristics can be corrected. Knowledge of these effects by the highway designer should foster improved design of multilane divided highways, which in turn should reduce the deaths, injuries, and property damage resulting from median-opening accidents.

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Single-Vehicle Accidents on Route 66

J. STANNARD BAKER, Traffic Institute, Northwestern University

•THIS study was part of the Operation 66 Joint Engineering Enforcement Project conducted in the summer of 1964 by the Office of Highway Safety, U. S. Bureau of Public Roads and the seven states on Route 66 between Chicago and Los Angeles (Fig. 1).

To gather information, the highway patrols of the seven states used a special form to supplement each state's official accident report. A copy of the official highway patrol report for each accident was also obtained, except for Texas accidents.

Qualifying accidents outside of incorporated places between San Bernardino, California, and Joliet, Illinois, were reported. Most of the route was on sections of I-15, 40, 44 and 55. The remainder was on US 66. Accident data were collected between June 1 and October 31, 1964. Traffic volumes by hour and type of vehicle were counted during one or more week days, at intervals of approximately 150 miles.

Except for completing the supplementary report, each highway patrol followed its usual reporting procedure for the single-vehicle accidents. The procedures were not exactly the same. It may be, therefore, that some states reported a greater proportion of minor accidents than others.

Data collection was planned to require no more than an additional hour for the investigator to record the supplementary single-vehicle accident information. Hence, no claim can be made that accidents were investigated in depth. A 37-page instruction manual was provided for the supplementary form. Each reporting officer was supposed to receive from a supervisor a day's instruction in this special work.

There have been other studies of single-vehicle accidents, notably a continuing one by the California Highway Patrol (1). It is mainly a statistical treatment of biographical data, accumulated violations and accident experience of involved drivers. Contributing factors are listed.

ACCIDENTS REPORTED

For the purpose of this study, supplementary reports were required for four standard types of motor-vehicle traffic accidents:

1. Collision on road with parked motor vehicle,
2. Collision on road with fixed object,
3. Overturned on road, and
4. Ran off road.

For this study, the road was defined as including both pavement and shoulder.

From the four types of accidents reported, those in which there was a supported claim that a non-contact motor vehicle encroached on the path of the vehicle directly involved or otherwise clearly influenced its behavior were eliminated.

A total of 951 accident reports was received. Of these, 12 were not used because they were other than the specified four types; 89 more were eliminated because non-contact vehicle involvement was well supported. This left exactly 850 reports to be tabulated.

Of the 850 single-vehicle accidents, only 17 or 2.0 percent were fatal (Table 1). This gives a severity ratio of 21.8 injury and 26.3 damage-only accidents for each fatal

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TABLE 1

SEVERITY OF ACCIDENTS

Severity	Number		Percent	
Fatal		17		2.0
Class A injury	164		19.3	
Class B injury	141		16.6	
Class C injury	66		7.7	
Total injury		371		43.6
No injury		447		52.7
Injuries not known		15		1.7
Total accidents		850		100.0

accident. The National Safety Council's estimate (2) for all "reportable" traffic accidents in 1964 gives a ratio of 34.8 injury and 348 damage-only accidents per fatal accident. Thus, single-vehicle accidents on Route 66 appear much more severe than traffic accidents as a whole. But this would be expected because of the generally high operating speeds on Route 66.

The types of vehicles involved are given in Table 2. Note that 105 out of 735 or one car in seven in a single-vehicle accident had a trailer. Of these, 57 percent were cargo trailers; 30 percent were house trailers; 11 percent were other motor vehicles; and 3 percent were boat trailers. Of the 20 trailers towed by trucks (not including semitrailers), 35 percent were other motor vehicles; 30 percent were cargo trailers; 30 percent were house trailers; and 5 percent were boat trailers.

Three kinds of special data were sought in this study: (a) factual (objective) information about the circumstances of the accidents; (b) opinions (subjective) about contributing

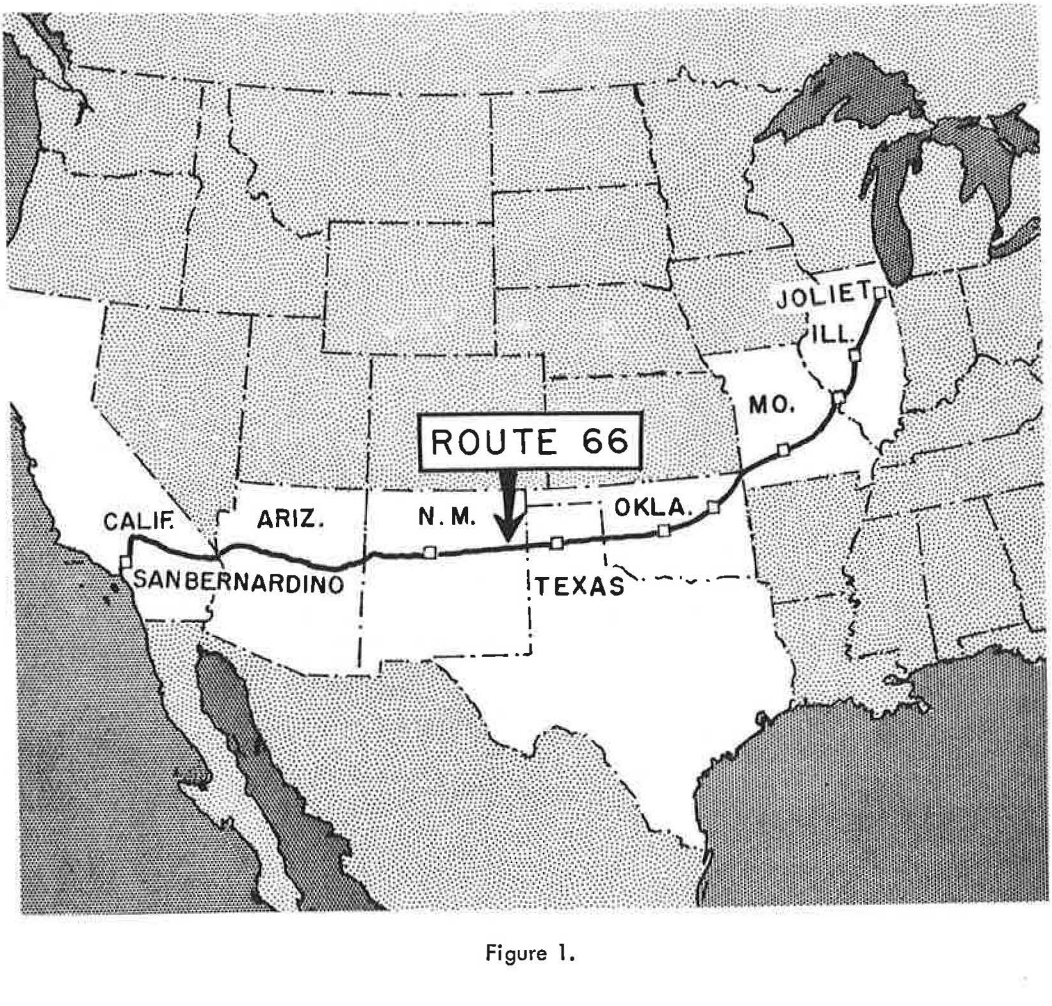

Figure 1.

TABLE 2

VEHICLES INVOLVED

Types	Total Vehicles		With Trailer	
	Number	Percent	Number	Percent
Standard cars	519		88	17.0
Compact cars	141		13	9.2
Small and sports cars	75		3	4.0
Total cars	735	86.5	105	14.3
Tractors and semitrailers	47		47	100.0
Trucks	63		20	31.8
Total trucks	110	12.9	64	59.1
Motorcycles	5	0.6	0	0.0
Buses	0	0.0	0	0.0
Total vehicles	850	100.0	169	19.9

factors; and (c) comparisons which help evaluate the reliability of police inferences in accident reporting.

Factual Information About Circumstances

Time of Accidents—Because of the character of the route studied, distribution of accidents differs somewhat from usual countrywide figures (2). Morning and evening peaks are less pronounced (Table 3).

Most accidents, 18.7 percent, occurred on Friday, followed closely by Saturday with 18.0 percent. Tuesday had the fewest, 10.7 percent. The modal hour of the day, without regard to day of week, was 1 to 2 p.m. with 6.4 percent of the total 24-hour accidents; the minimum hour was midnight to 1 a.m. with 2.5 percent.

These values largely reflect traffic volumes. Therefore, risk indexes were computed by dividing the percentage of accidents in each hour by the percentage of traffic counted in that hour. The lowest index, 0.57, was from 9 to 10 p.m. and the highest, 3.43, was from 3 to 4 a.m. (Fig. 2). Darkness is probably a factor in the risk index because most of the high-risk hours are dark. But if darkness is the only factor, the index should be one value for all hours of darkness and another for all daylight hours. But this is not the case. Thus, there are probably differences in quality of driving at different hours of the day for single-vehicle accidents. The hours with high-risk indexes are those during which one would expect to find more drivers who had been drinking, and those in which drivers would probably be most likely to fall asleep.

Seat-Belt Usage—The easiest route from Chicago to Los Angeles obviously carries an unusually high percentage of long-trip vehicles. It is believed that people are more likely to use seat belts on long trips. Therefore, experience on this route should represent maximum use of seat belts for 1964.

Of 2,050 occupants in single-vehicle accidents, only 472 or 23.0 percent were in seats equipped with belts. Of the occupied seats with belts, only 48.3 percent of the occupants had their belts fastened (Fig. 3). Compare this with the 1963-1964 seat-belt usage reports from Automotive Crash Injury Research (3) where 33 percent of occupants were in seats with belts, and 27.6 percent of these were wearing them. The ACIR data were for rural accidents in selected areas but not necessarily on through routes. The much higher percentage of those having belts and who were wearing them on Route 66 suggests that long-trippers are more likely to use available belts.

TABLE 3

PERCENTAGE OF ACCIDENTS IN PEAK HOURS, MONDAY THROUGH THURSDAY

Peak	Countrywide[a]	Route 66
Morning (7 to 9 a.m.)	11.8	7.9
Evening (4 to 6 a.m.)	19.3	10.6
Total	31.1	18.5

[a]Accident Facts, 1965.

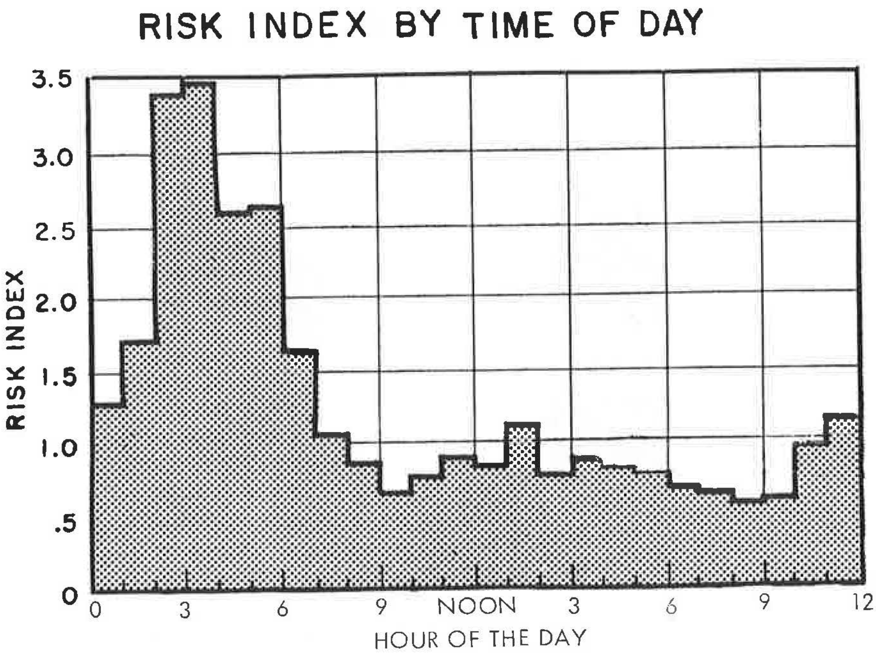

Figure 2.

Among drivers, 31 percent had belts available but only 50.2 percent were reported in use. Of right-front-seat passengers with belts, 43.3 percent had them fastened.

None of the 189 fastened seat belts was reported to have broken in an accident. One driver of a sports car said that his belt was fastened before the accident but unbuckled (without damage) when he turned over twice.

Men used their belts more than women, 51 percent compared to 43 percent (Fig. 4). In the 16 to 19 age group, 54 percent used their belts as contrasted to 43 percent for

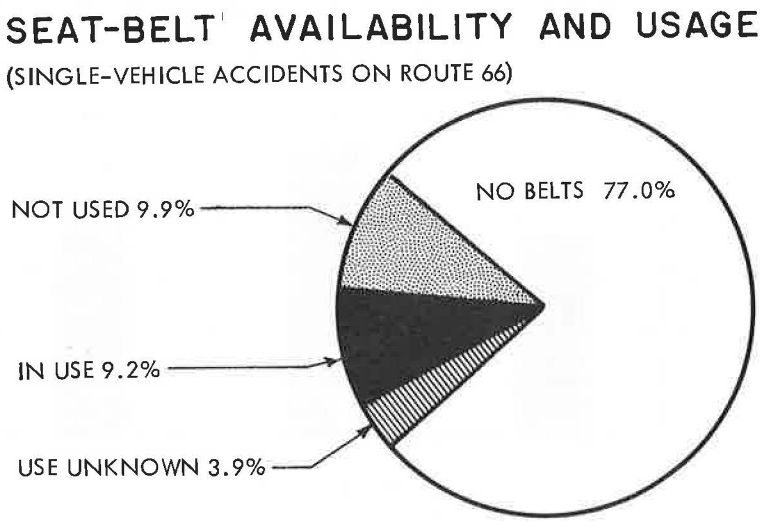

Figure 3.

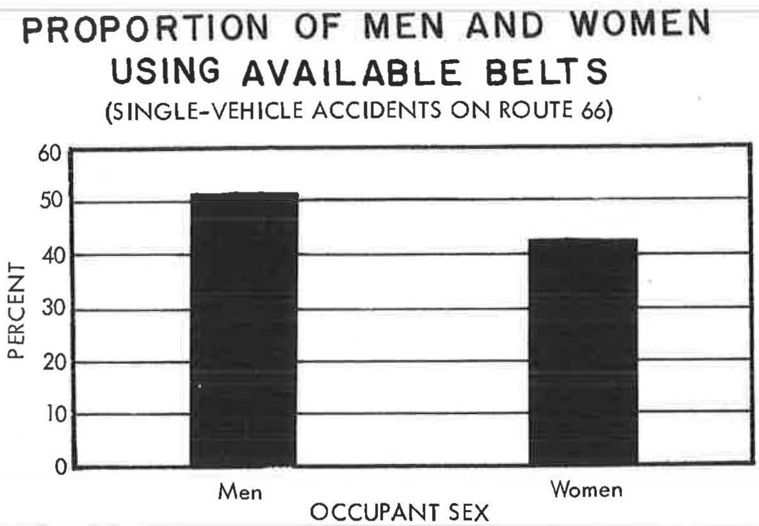

Figure 4.

older people and 38 percent for younger children (Fig. 5). The highest percentage, 60, of seat-belt users were male passengers less than 16 years old. The lowest percentage, 28, were male passengers 30 or more years old. Seat belts appear to be catching on with the younger generation.

Operational Failure—To escape accident, the road-vehicle-driver system must operate so as to avoid three principal hazards: (a) left roadway (jumped the track), (b) struck object while still on roadway, and (c) overturned before leaving roadway. If one of these hazards is not avoided, the car-driver-road system has failed in some operation required for safety. The operational failure describes the accident. Note that these operational failures differ from the four standard types of accidents which were required to be reported in this study. Leaving the roadway is leaving the pavement, not "running off the road," which includes shoulder; striking an object is "collision

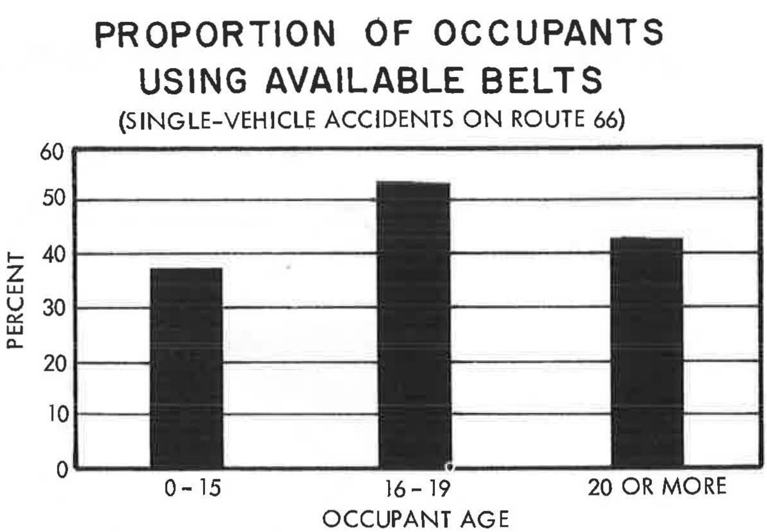

Figure 5.

Figure 6.

with parked motor vehicle" or "collision with fixed object," but only before the vehicle leaves the pavement. A vehicle is considered to have left the roadway when one wheel is off the pavement.

Operational failure No. 1, "left roadway," accounted for 781 or 91.9 percent of the accidents studied. It includes many accidents in which the vehicle overturned or struck an object on the shoulder or after running off the shoulder (Fig. 6). It does not include accidents in which vehicles overturned on the pavement after they had run off and come back on. The greatest part of these left-roadway accidents were on straight roads, mainly because Route 66 has so few curves. Road alignment was as follows: straight, 79.4 percent; moderate curve, 14.8 percent; sharp curve, 1.9 percent; ramps, channelization, etc., 3.9 percent.

Because vehicles drive on the right side, 1.38 times as many vehicles left the right side of the roadway compared to the left (Table 4). Of the 729 vehicles which left the roadway not at intersections, 231 or 31.7 percent managed to come back on again before they got into trouble (Table 5); of those which went off to the left first, 25.4 percent got back on again; of those which went off to the right first, 36.2 percent returned. However, the return was not successful in preventing the accident. Figures 7 and 8 show the off-roadway experience diagramatically. In Figure 8, data are shown for one-direction and two-direction roadways separately. Off the left in one-direction traffic would be into the median. Arrows with little bars across the tips indicate that the vehicle crossed the median into the opposite roadway. Arrows with dots at the end or angle indicate that a solid object such as a guardrail or embankment was struck.

TABLE 4

SIDE ON WHICH VEHICLE LEFT ROADWAY[a]

Road	Left	Right	Total
Curve to left	21	38	59
Curve to right	36	29	65
Straight 1-way (divided)	201	233	534
Straight 2-way (undivided)	48	123	171
Total	306	423	729

[a]Fifty-two vehicles left roadway at intersections.

The foregoing leads to a consideration of the attitude of the vehicle when it left the roadway. This is given in Table 6. In 56.8 percent of the left-road accidents, the car was sideslipping (yawing) or weaving; the driver was apparently out of control by some maneuver before he ran off the pavement.

From where the vehicle left the pavement to where it came to rest varied from a few feet to more than a thousand. Figures 9, 10 and 11 show the final positions for shoulder widths of less than 4 ft, from 4

TABLE 5

CARS RETURNING TO ROADWAY AFTER LEAVING IT

Road	Off Left		Off Right	
	Number	Percent	Number	Percent
Curve left	4	19.0	15	39.4
Curve right	11	30.5	8	27.6
Straight 1-way	50	24.8	87	37.3
Straight 2-way	13	27.1	43	35.0
Total	78	25.4	153	36.2

to 12 ft, and for more than 12 ft. The dashed line parallel to the roadway edge shows to scale the width of the shoulder. Without knowing how many vehicles left the roadway and did not have accidents, it is impossible to evaluate the effect of the width of shoulder as far as safety is concerned. Such additional data would be virtually impossible to obtain. Figure 12 shows the percentage of vehicles coming to rest more than the specified distance from the edge of the roadway. This corresponds reasonably well with data from other sources (4).

The object struck is of interest to those considering roadside improvements to reduce severity of single-vehicle accidents. The data apply to both struck-object-before-leaving-roadway and ran-off-the-road accidents (Table 7). These objects do not necessarily stop the vehicle or damage it severely, although it may roll over after striking.

Operational failure No. 2, "struck object while still on roadway," accounted for 38 or 4.5 percent of the single-vehicle accidents studied. Because the vehicle must have struck the object while all wheels were on the pavement, it follows that the object struck must have been on or very close to the pavement. In some cases, however, the vehicle was crosswise on the road when it struck the guardrail or other roadside object. The object could be as much as 5 ft from the pavement and be struck by rear-end overhang while the wheels were still on the pavement (Table 8). Guardrails were the most common objects struck.

Fifteen of the 38 struck-object accidents were in Arizona. This was the most conspicuous difference among states in the data gathered. The kinds of objects hit in Arizona were as varied as among the other states, so there seems to be no logical explanation for the larger number.

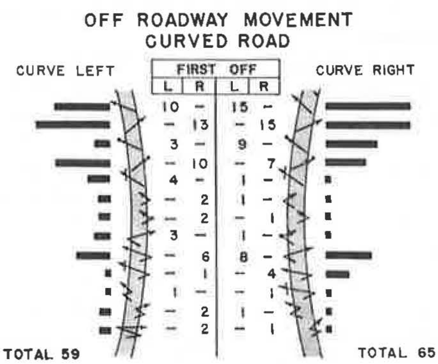

Figure 7.

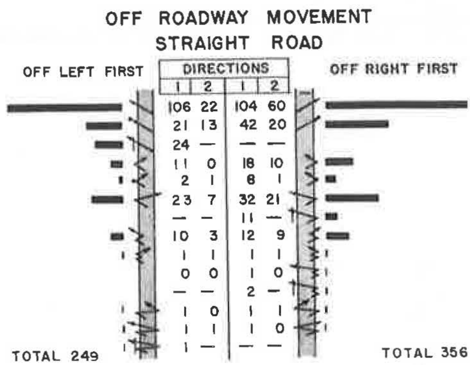

Figure 8.

TABLE 6

ATTITUDE OF VEHICLES LEAVING ROADWAY

Bearing	Percent
Going straight without yaw	41.2
Sideslipping in a sharp turn	47.9
Had been weaving side to side before leaving road	8.9
Unknown	2.0

Operational failure No. 3, "overturned before leaving roadway," accounted for 31 or 3.6 percent of the single-vehicle accidents studied. Straight or nearly straight and dry roads accounted for 64.4 percent; ramps, channelization, narrowing and driveways, 16.1 percent; slippery pavement (2 accidents), 6.5 percent; high wind (2 accidents), 6.5 percent; and unknown, 6.5 percent.

Vehicles which overturned after leaving roadway were classified as left-roadway operational failures. The percentage which overturned-on-roadway varies greatly with the type of vehicle (Table 9).

Of the 630 cars without trailers, the small percentage which overturned before leaving the roadway is due to the predominance of standard vehicles, none of which over-

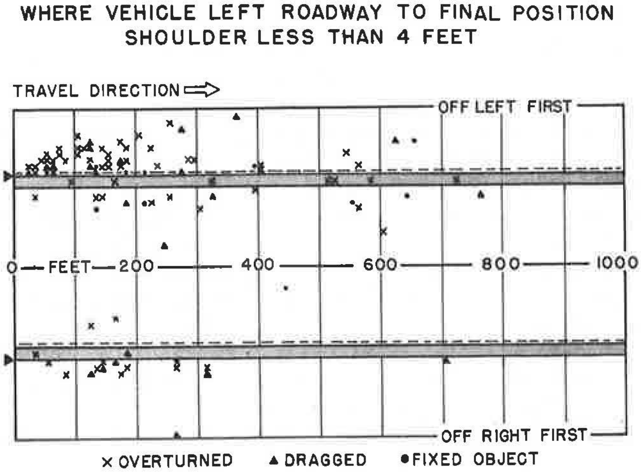

Figure 9.

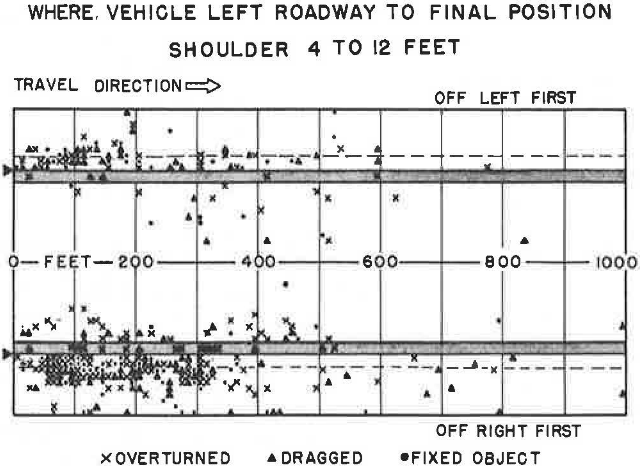

Figure 10.

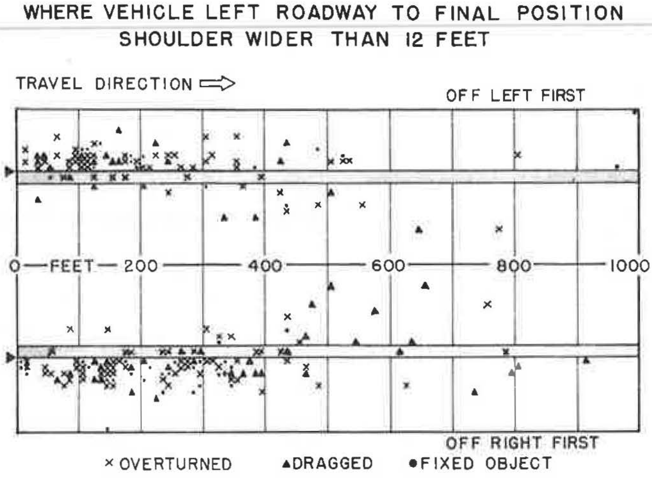

Figure 11.

turned (Fig. 13). Of the five small cars which overturned before leaving the pavement, four were Volkswagens and one was a Renault Dauphine.

Age and Sex of Driver—There is nothing unusual about the distribution of single-vehicle accidents according to sex of driver: 71.6 percent were male and 28.4 percent female. For both male and female drivers, those 20 to 25 years of age were involved in more single-vehicle accidents than any other five-year age group—23.6 percent for males and 16.7 percent for females. For both sexes the number of accidents diminished steadily with age. The distribution of those accidents doubtless reflects to a large extent differences in miles driven by the age and sex groups. Unfortunately, exposure data on which risk indexes could be computed were obtained only in Arizona. If the percentage of drivers of each age using Route 66 was the same in all states as in Arizona, the risk index by age would be about as given in Table 10. The risk index for the average driver would be 1.00. Drivers 30 years old and 65 years old are about average.

Risk Index by Type of Vehicle—Types of vehicles involved have been enumerated in the discussion of the accidents reported and in connection with overturning accidents. Counts were made in each state to determine the proportion of each type of vehicle using Route 66. From these data it was possible to compute a risk index by major types of vehicles. The risk of a standard car without trailer was established at 1.00 as the base for this index. Values for vehicles of other kinds are given in Table 11.

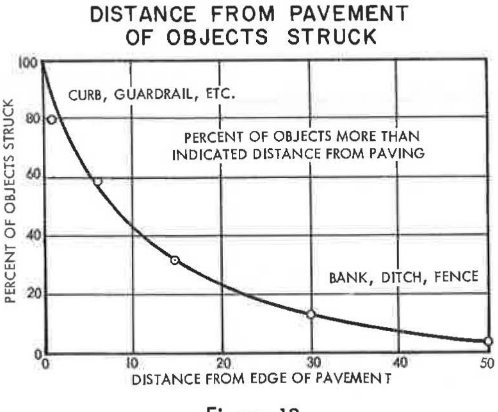

Figure 12.

In general, compact cars are $2\frac{1}{4}$ and small cars $3\frac{1}{2}$ times as risky as standard cars. Adding a trailer multiplies the risk by approximately four. Actually, there were only four small cars with trailers in accidents so that the risk index for this type is not statistically significant, but it is compatible with the other indexes. Because no bus had a single-vehicle accident during the study period, the index for buses is zero. Buses probably do have the lowest risk index but an index based on a sample large enough to show some bus accidents would obviously not be zero.

The considerable differences in risk indexes of the three classes of passenger cars are paralleled by the differences in percentage of those cars that overturn on the road as mentioned earlier, but the total number

TABLE 7

DISTANCE FROM ROADWAY OF OBJECT STRUCK

Distance (ft)	Percentage	Principal Objects Hit
Less than 1	20.1	Curb, guardrail, barricade
1 to 6	21.2	Guardpost, delineator, guardrail
7 to 14	26.8	Bank or ditch, guardrail, information sign
15 to 29	18.3	Bank or ditch, fence, culvert
30 to 49	9.9	Bank or ditch, fence
50 or more	3.7	Bank or ditch, fence

of overturning accidents is so small that overturning cannot alone explain the differences in risk indexes.

Indeed, nothing in the data collected explains the risk-index differences among the three groups of passenger cars without trailers. Because guesses will inevitably be made to explain this phenomenon, three different, speculative possibilities are mentioned here.

One possible explanation might be the least speculative. The much higher risk index of young drivers has been noted. For economic and cultural reasons, young drivers seem to be much more likely than older drivers to be on long, fast trips in small and compact cars. Thus a difference in driver skills or attitudes may also explain the difference in risk indexes of the three classes of cars.

Second, there is a substantial proportion of rear-engine cars among the compacts and a large proportion of rear-engine cars among the small cars. No standard cars have rear engines. Thus there is a correlation between rear-engine construction and risk index. However, from these data, one cannot justifiably reach the conclusion that this correlation indicates any cause-and-effect relationship.

A third inference may also be made. Many parts of Route 66 are exposed to areas where high winds are common. Wind was suggested as a contributing factor in a number of the accidents reported. Generally, the area of a car exposed to wind pressure varies as the square of its linear dimension; doubling car size would quadruple surface area. But weight varies as the cube of linear dimension; doubling the linear dimensions will multiply the weight by eight. Therefore, the ratio of weight to wind pressure area varies as the $^3/_2$ power of car length. In other words, the larger the car is, the greater its road friction resistance will be compared to its wind area. Large cars will be deflected or buffeted less by sudden gusts of wind or air blasts from passing trucks. Thus, wind will trigger fewer drivers of large than of small cars into losing control.

TABLE 8

OBJECTS STRUCK WHILE VEHICLE STILL ON ROADWAY

Guardrails	8
Bridge rails or structures	7
Traffic control devices	7
Barricades	5
Culverts	2
Information signs	2
Railroad crossing gates	2
Rock slides	2
Guard post	1
Divider reflector	1
Parked car	1
Total	38

Opinions About Contributing Factors

The circumstances which are thought of as contributing factors in traffic accidents are, unfortunately, rarely conditions which can be objectively observed or which leave unmistakable signs after the accident. Therefore, determination of causative factors is largely a matter of inference. Conclusions concerning such factors are consequently opinions of those making the inferences and must be evaluated accordingly.

Information about causative factors solicited by the supplementary report form for this study inevitably reflects stereotypes or common patterns of the investigator's beliefs, lack of time to seek further proof (for example, by disassembling the

TABLE 9

VEHICLES OVERTURNING
BEFORE LEAVING ROADWAY

Type	Number	Percent
Motorcycle	2	40.0
Truck and trailer	3	13.1
Car with trailer	13	12.3
Truck without trailer	3	7.0
Tractor with semitrailer	3	6.8
Car without trailer	7	1.1
Total	31	3.6

PROPORTION OF CARS WITHOUT TRAILERS OVERTURNING ON PAVEMENT

AS PERCENTAGE OF ALL IN SINGLE-VEHICLE ACCIDENTS

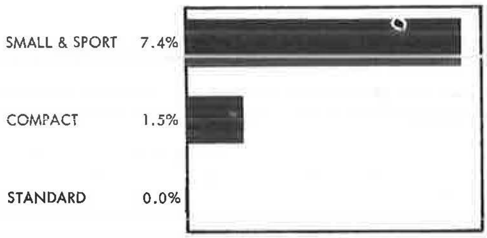

Figure 13.

vehicle), and the limitations of investigators' scientific training. Nevertheless, highway patrol officers attending the accident are in the best position to make inferences relating to contributing factors. Therefore, until better procedures are available, cautious consideration must be given to their opinions as expressed in special schedules on the supplementary report form. This part of the study, therefore, has many characteristics of an opinion poll.

Speed—The supplementary report called for a "best estimate" of speed and also a possible minimum and maximum value. In two-thirds of the reports, the minimum estimate was given as 5 mph less and the maximum estimate as 5 mph more than the best estimate. With such uniformity of range, only the best estimates are shown in Table 12 and Figure 14. Almost half of the accidents occurred where the speed limit is 70 mph because most of the route is posted for that speed.

Note in Figure 15 that the percentage of accidents at more than the speed limit diminishes steadily as speed limits increase. Most of the investigators' speed estimates of more than 75 mph were substantiated by witnesses. Some occurred while the violator was actually being pursued.

Contributing Factors—In the supplementary report, the investigator could mark on a list to indicate his opinion relating to contributing factors. The list was subdivided into groups for road, driver, and vehicle. Space was provided in each group to write in other factors than those specifically listed. More than one factor could be listed and the investigator could indicate his degree of certainty by marking yes or possibly. If an investigator listed more than one factor (which investigators did for only 16.5 percent of the accidents), only that one which seemed to be best substantiated by circumstances described or reasoning expressed was tabulated.

The five most frequently mentioned factors were (a) driver asleep, 24.1 percent; (b) slippery road, 13.0 percent; (c) tire failure, 11.9 percent; (d) distractions, 8.7 percent; and (e) alcohol, 8.1 percent. A more detailed listing appears in Table 13.

Examples of other road factors include: pavement narrows suddenly, soft shoulders, drop-off to shoulder; of other driver factors: drag racing, headstrong, blacked out, confused by traffic; of other vehicle factors: overloaded, shifting load, wipers quit in heavy rain, axle or spindle broke, accelerator stuck, smooth tires, trailer collapsed.

Driver factors are more frequent than car and road factors combined. Because most of the investigators' information about contributing factors comes from the drivers, it may be surmised that, if anything, driver factors are under-reported and vehicle and road factors are over-reported.

Drivers tend to explain accidents by circumstances which have least culpability compatible with credibility. Drivers may sometimes tell investigators that they fell asleep when actually they were intoxicated. Driving under the influence is illegal and, therefore, more culpable than falling asleep while driving, which is not specifically unlawful. Likewise, when a driver falls asleep, he may be happy to explain the accident by some road or vehicle condition. In this connection, it is interesting to note

TABLE 10

RISK INDEX BY AGE

Age	Approximate Risk Index	Age	Approximate Risk Index
20	2.4	55	0.7
25	1.7	60	0.8
30	1.0	65	1.0
35	0.7	70	1.3
40	0.6	75	1.7
45	0.5	80	2.2
50	0.6		

TABLE 11

RISK INDEX BY TYPE OF VEHICLE

Vehicle	Without Trailer	With Trailer
Standard car	1.00	4.57
Compact car	2.23	8.48
Small car	3.49	14.47
Truck	0.69	4.33
Tractor and semitrailer	—	1.21
Bus	0.00	—
All types	1.17	2.67

what drivers said when they did not concur with investigators with respect to being asleep or under the influence of alcohol. In 11 (5.4 percent) of the accidents investigators believed falling asleep was a factor, 4 drivers claimed tire failures, 2 claimed distractions, and 1 each claimed confusing road situation, wind blast, sun glare, alcoholic influence, and other driver's condition. In 10 (14.5 percent) of the accidents

TABLE 12

INVESTIGATORS' BEST ESTIMATE OF APPROACH SPEED

Speed Limit	Number of Accidents	Approach Speed				Percentage Over Limit
		Mean	Mode	Lowest	Highest	
30	4	46.3	40	15	85	75.0
35	6	44.2	35	85	55	75.0
40	6	45.0	—	20	65	50.0
45	13	46,2	45	25	65	38.0
50	35	49.3	50	10	85	31.2
55	82	56.2	50	40	80	30.3
60	131	54.7	60	25	75	19.1
65	127	57.3	65	10	85	11.8
70	417	61.1	65	10	110	8.9
75	1	45.0	45	45	45	0.0
Total	822	57.3	65	10	110	15.5

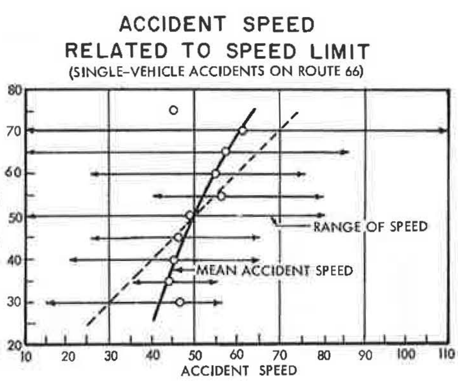

Figure 14.

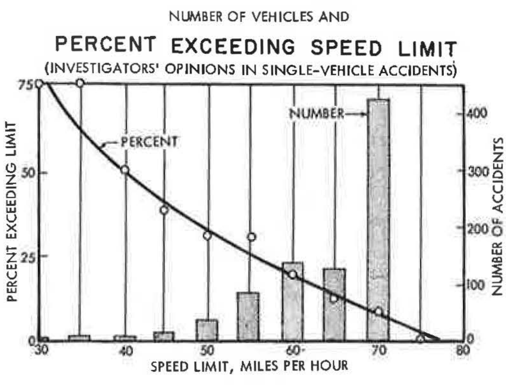

Figure 15.

TABLE 13

INVESTIGATORS' OPINIONS ABOUT CONTRIBUTING FACTORS

Factor	Number		Percent
Road factors, total		155	18.3
Confused by road situation or signs		18	2.1
Unexpected road surface condition		111	13.1
Wet, slippery	110		
Hole, bump	1		
Other		26	3.1
Wind	12		
Sun glare	2		
Object in road	2		
Other	10		
Driver factors, total		378	44.5
Driver asleep or dozed		205	24.1
Alcohol or drugs		69	8.1
Illness		3	0.4
Distraction		74	8.7
In car	49		
Outside of car	25		
Other		27	3.2
Inattention	7		
Lack of skill	6		
Other	14		
Vehicle factors, total		169	19.9
Brake failure		9	1.1
Steering gear failure		12	1.4
Light failure		0	0.0
Tire failure		101	11.9
Other		47	5.5
Trailer hitch	21		
Other	26		
No factor mentioned		148	17.3

listed by investigators with alcoholic influence as a factor, 3 drivers indicated confusing road situations, 2 indicated distractions, and 1 each indicated tire failure, steering gear failure, driver asleep, and illness.

POSITION OF TIRE BLAMED RELATED TO VEHICLE DAMAGE

Figure 16.

PRINCIPAL CONTRIBUTING FACTORS BY SEX OF DRIVER

(INVESTIGATORS' OPINIONS)

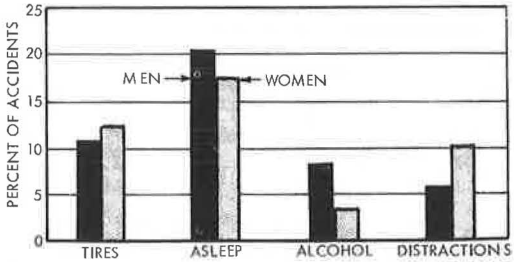

Figure 17.

TABLE 14

PERCENTAGE OF ACCIDENTS BY SEX AND AGE GROUP BELIEVED TO HAVE SELECTED FACTORS CONTRIBUTING

Age	Tire Failure	Driver Asleep	Driver Under Influence	Distraction
Less than 20	13.7	29.4	4.9	9.8
20 to 29	11.4	30.2	8.1	7.1
30 to 39	15.7	18.6	8.1	8.1
40 to 49	12.3	18.4	12.3	7.0
50 to 59	16.0	20.4	9.6	4.2
60 or more	14.3	16.4	3.6	16.4
Males	12.9	24.5	9.9	6.4
Females	14.5	20.9	3.8	11.6

By the same principle, we may hypothesize that some drivers may have suggested tire failure as a factor when, in fact, the driver had been drinking, had fallen asleep, or had otherwise been responsible. Such an explanation might be credible if a tire was, indeed, disabled after the accident. Even had the tire been damaged by collision or furrowing in, the investigator would not have at his disposal facilities for removing and examining the tire to determine the nature and probable cause of its disablement. Because tires would most likely be disabled by the accident if they were in the vehicle's most heavily damaged area, the position of the tire which was supposed to have failed was tabulated (Fig. 16). If approximately three times as many tires which were claimed to have failed were in the heavily damaged part as in other parts, it was reasonable to assume that some of these were improperly considered to be a factor in the accident.

The positions on vehicles of tires which investigators believed to have contributed to accidents are (a) rear right, 36.8 percent; (b) rear left, 26.6 percent; (c) front right, 19.3 percent; and (d) front left, 17.3 percent. With front-tire failure, the vehicle went off the roadway much more often on the side on which the tire failed. With rear-tire failure, the reverse seems to be true, but the difference between rear tires is small and probably not significant.

Age and Sex Related to Contributing Factors—The percentage of drivers in each age group believed by the investigator to have been connected with accidents having major contributing factors is given in Table 14. It appears that men are more troubled by falling asleep and drinking, women by tire failure distractions (Fig. 17). Differences for tire failure are probably too small to be significant, but the other factors show interesting variations.

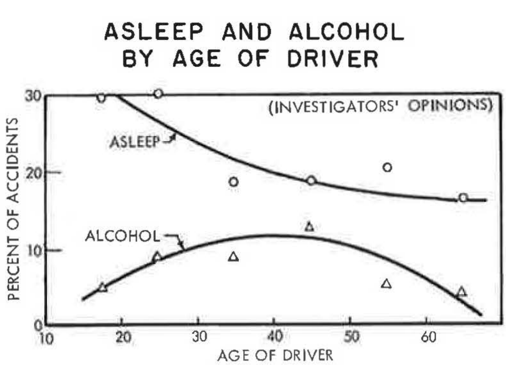

Figure 18.

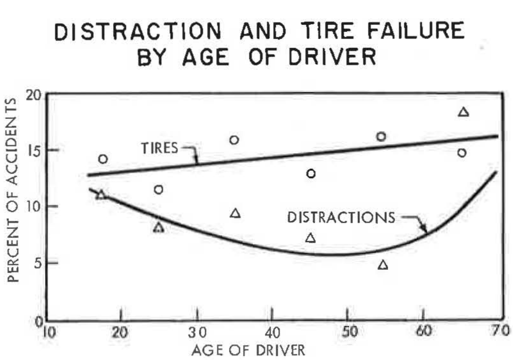

Figure 19.

The variation with age in percentage of accidents believed to have been contributed to by alcohol and sleep is shown in Figure 18. For young drivers, alcohol is conspicuously low and sleep is high One wonders whether the opinions on which these curves are based represent reality or whether young drivers who have been drinking successfully explain their accidents to investigators by claiming to have fallen asleep—and if this is true for young drivers, could it not be true throughout the whole range of ages?

Frequencies of tires and distractions believed to contribute to single-vehicle accidents according to age of driver are shown in Figure 19. Tires appear not to be importantly related to age, unless there is a slight increase in risk with age. Distractions, on the other hand, are high for young and old drivers—a condition which might be expected. The number of these is small so the figure for greater ages is undoubtedly not reliable.

Distractions are generally believed to be important contributing factors to accidents but they are difficult to detect. After the accident, either the driver has forgotten all about the distraction, or he sees no reason to mention it. Distractions are extremely varied, but they separate into two major categories—those within the vehicle and those outside of the vehicle. In this study of 850 single-vehicle accidents, 74 were believed by the investigator to have involved driver distractions. In 49 accidents the distraction was inside the car and outside in 25.

A list of the inside distractions will illustrate their great variety:

1. Children	
Turned to cover or attend baby behind	6
Child alongside driver	3
Looking at child or baby	2
Turned to talk to children	1
Child's balloon blew in driver's face	1
Child pulled shift lever back	1
2. Other passengers	
Talking to driver	5
"Back-seat driving"	2
Watching passenger	2
Trying to awaken wife	1
Horseplay in car	1
3. Smoking and eating	
Dropped lighted cigarette or lighter	4
Reaching for cigarette, food, or water	3
Lighting cigarette	2
Eating	1
4. Adjusting car equipment	
Tuning radio	2
Adjusting sun visor	1
5. Miscellaneous	
Kleenex blew in driver's face	1
Suitcase fell off seat	1
Wasp in car	1
Particle in driver's eye	1
Reaching in car	1
Emotionally upset	1
6. Unspecified in car	5

Perhaps the fact that children are the most common distraction is related to the fact that distractions appear as contributing factors in a greater percentage of accidents involving women drivers than men drivers.

Distractions outside the vehicle are probably less likely to be remembered and reported than distractions inside. Some of the outside distractions may be problems of proper distribution of attention among competing hazards rather than true extraneous distractions. The list follows:

1. Other vehicles
   - Vehicle alongside or ahead 4
   - Vehicle behind 2
   - Gesturing at overtaken driver 1
2. Looking at scenery 6
3. Problems with own vehicle
   - Luggage on roof came loose 1
   - Trailer acted up 1
   - Steering gear seemed wrong 1
4. Road construction
   - Watching road grader 1
   - Observing barricades 1
5. Unspecified, probably speculative 7

The unspecified distractions both inside and outside the vehicle may be speculative. Not having other specific, logical contributing factors to explain the accident, the driver and the investigator may have surmised that it was some kind of a distraction but without any idea of exactly what.

How would the driver avoid a similar accident? This question was asked investigators. No specific list of possibilities was provided for checking. For 40 accidents the reply to this question was indeterminate. The 12 ideas offered by investigators are shown in Figure 20. These generally correspond with opinions concerning contributing factors. · Driver asleep heads the list in both cases. Speed is prominent—slower for conditions perhaps reflects a tendency of police to explain accidents by "too fast for conditions" when nothing more specific comes to mind. Attention is high on this list but not among the contributing factors, probably because it was not specifically mentioned in the driver-factor check list.

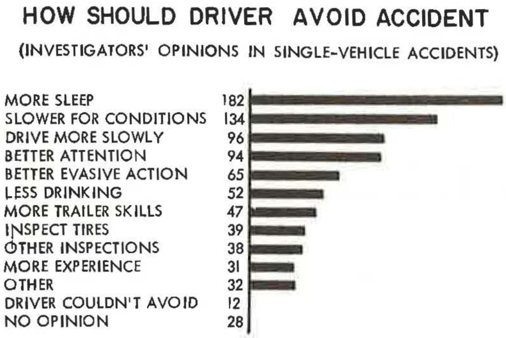

Figure 20.

Comparisons to Evaluate Reliability of Opinions

In this study, a crude effort was made to gain some idea of how highway patrol officers arrive at conclusions in usual working situations. Some of this evaluation has already been suggested in connection with tabulating their conclusions.

For comparison purposes, in addition to reporting their own conclusions, investigators were also asked to report conclusions of drivers. Admittedly this is no elegant research technique, but it does give some tentative insights which might not otherwise be available.

In general, investigators appear to accept drivers' versions of how and why the accident occurred, but they may disagree in a few instances, especially where observable conditions contradict drivers' statements.

Speed—Police estimates of speeds are consistently higher than drivers' estimates, especially above the speed limit. Drivers average speed estimate was 54.8 mph, that of police 57.3 mph. The difference seemed to be about the same for all speed limits at which there were enough accidents to give reliable figures. Police believed 128 drivers were exceeding the speed limit as opposed to 50 drivers who admitted to more than the limit. For the most common speed limit, 70 mph, only four drivers admitted going faster. None of these acknowledged more than 75 mph. Police, on the other hand, considered 37 to have been exceeding 70 mph. Only 17 exceeded that limit by as little as 5 mph. One driver was reported at 95 mph, one at 100 mph, and one at 110 mph. Perhaps drivers would have admitted higher speeds to others than police, but this is doubtful.

Contributing Factors—In general, investigators and drivers agree remarkably on contributing factors. Of 573 cases for which both driver and investigator offered an opinion, there were 537 in which they agreed and 36 in which they disagreed. In other words, the investigator differed from the driver in only 6.3 percent of the cases. This probably means that in a large number of cases the investigator accepts the driver's opinion. Perhaps in many cases the driver's statement is the only information on which he can base an opinion. But the inference can also be made that practically the same results would be obtained by having drivers themselves report the contributing factor as by having the investigators do it, at least in single-vehicle accidents.

The most common disagreements were 21 accidents in which police considered sleep or alcohol to have been a factor, whereas drivers offered less culpable explanations.

Skill—More than other kinds of accidents, single-vehicle accidents suggest a failure of the driver to control his vehicle. That would generally mean lack of skill either in driving strategy in anticipation of possible hazards or in tactics in coping with actual hazards. Yet among the 850 single-vehicle accidents, investigators indicated only six in which lack of skill was a contributing factor and in only four cases did drivers suggest lack of skill. But lack of skill was not specifically listed to be checked in the supplementary report. As an unquestionably prominent factor in single-vehicle accidents, it was purposely omitted to determine to what extent investigators or drivers might mention it as a factor in accidents without having it suggested by listing. Compare the few cases in which lack of skill was mentioned with the frequent occurrence of accidents which clearly appear to involve such lack of skill as steering too much, braking on slippery surfaces, and inability to cope with a trailer. The comparison strongly suggests that investigators try to use only the categories specifically called for on the report form and shun the opportunity to record "other." This means that to get more reliable analysis of contributing factors, report forms should either be elaborated to include very long lists of categories or should mention no specific categories. In the latter case, investigators would probably resort to stereotypes of their own or their department's, especially stereotypes which conform to classifications of law violations.

The California study (1) reported faulty driving as the second most common cause (after speed). It accounted for 25.0 percent of all single-car accidents. The difference between the Route 66 study and the California study suggests that opinion-gathering methods have a strong influence on determination of contributing factors. For example, as mentioned earlier, skill does appear more prominently in the opinions as to how the accident could have been prevented than in the contributing factors.

Combinations of Contributing Factors—Variation among states is considerable in the proportion of accidents in which investigators expressed no opinion about contributing factors. These variations are doubtless partly and perhaps largely accounted for by differences among investigators—differences mainly in training for investigating and forming opinions. That is, it is probable that two investigators with the same information about an accident would apply different techniques and standards and so come up with different conclusions about contributing factors.

The accidents for which no factor was named vary from 5.4 percent in Texas to 31.5 percent in Missouri. Accidents in which two or more are suggested vary from 10.3

percent in Oklahoma and New Mexico to 45.9 percent in Texas. In other words, Texas leaned toward multiple factors. Missouri investigators seemed reluctant to offer opinions.

Most accidents, when skillfully reconstructed and analyzed, appear to have numerous contributing factors which combine to cause them. Four or five factors are common and sometimes the number goes to a dozen. But in the investigators' reports of these accidents, a single factor seemed to be the rule. This suggests that these investigations are too brief and the investigators insufficiently trained to do more than a superficial job of determining the combinations of factors that cause accidents. The listing of factors in this study shows: no factor mentioned, 17.4 percent; one factor only, 66.1 percent; and more than one factor, 16.5 percent. In only a very few cases were three or four factors indicated. One accident was listed with five.

The most common combination is sleep and alcohol (23 accidents). It is, perhaps, logical that these might combine. For several reasons, people who had been drinking might be more likely than others to doze while driving.

The second most common combination, distraction and sleep (10 accidents), makes no sense. If a person is sleeping he is not subject to the usual distractions; conversely, if he actually was distracted he was probably not sleeping.

The next most common combination is sleep and tire failure followed by confusing situation combined with slippery road (each combination with six accidents). Neither of these is a very convincing combination. Certainly it seems unlikely that a driver would both doze and experience a tire failure, although it may be argued that the sleepy driver is less able to cope with a tire failure because he has to awaken first.

A considerable number of the combinations given are not complementary contributing factors. Complementary factors are those which go together like tire failure and lack of skill. This fact suggests that many of the reported combinations are actually speculative alternatives, not real complementary combinations. Thus the investigator could have meant that the accident might have been due to a slippery road or a tire failure rather than a slippery road and a tire failure.

The factor which most commonly combines with others is a wet or slippery roadway. It is combined with almost every other listed factor, especially with lack of skill, distractions, and driver asleep. It would be complementary to lack of skill, but probably an alternative to driver asleep.

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Statistical Analysis of Accident Data as a Basis for Planning Selective Enforcement

ROBERT BRENNER, GARY R. FISHER, and WALTER W. MOSHER, JR., Institute of Transportation and Traffic Engineering, University of California, Los Angeles

This paper deals with the application of quality control techniques to the analysis of traffic accident information, and the adaptation of the techniques to operational decision-making processes. The underlying theory of control charts and its application to motor vehicle accident data is presented in detail. Several new theoretical conclusions relating to the statistical sensitivity of accident control charts are presented.

A generalized system of control chart computer programs, designed to reduce the reported statistical techniques to operational practice, was developed and subsequently applied to a sample of accident data. Results suggest that for many accident data uses, a high alpha-error probability should be tolerated in order to realize a low beta-error probability concomitant with operationally defined lengths of roadway, realistic control chart time periods, and reasonable sensitivity to changes in accident-producing potential. Such control charts would rarely fail to detect a small change in accident potential at the cost of having many of these change indications be spurious. The principle is that for many accident data applications, it is appropriate to tolerate many false indications of change in order to reduce the likelihood of failing to detect a real change.

•THE overall accident information system is comprised of on-the-scene investigation, report preparation, encoding, and subsequent statistical analysis of the recorded data. The system potentially can yield important information for operational decision-making in engineering, enforcement, licensing, and other governmental functions directed toward controlling the motor vehicle accident problem.

The data may be utilized on a single accident basis, as in judging whether to issue a criminal complaint against an offending motorist, or on an aggregated basis as in calculating accident rates. The latter aspect is the subject of this work, with the presumption that information on the individual accident is complete and correct. The study is concerned with combining such information from a multiplicity of accidents, and making valid interpretations of the results.

The most difficult problem in interpreting such aggregated accident information is to identify stable patterns out of the continuing fluctuations in the data from day to day, week to week, month to month, and year to year. This inherent, seemingly unexplainable, fluctuation forces increasing levels of aggregation, such as combining daytime and nighttime accidents to obtain 24-hour totals, because with the resulting larger accident totals it generally becomes easier to extract a stable pattern out of fluctuations that otherwise could not be reliably interpreted.

Cursory examination, however, discloses that the simplest form of accident information aggregation, namely, raw tabulation of numbers of accidents, in itself can pose

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substantial questions in logic of interpretation. Should numbers of daytime accidents be combined with nighttime accidents? Winter with summer accidents? Good weather with bad weather accidents? Freeway with surface street accidents? Rural with urban accidents? There obviously is a point beyond which such aggregations no longer are useful or, at best, are of limited help in the specifics of allocation of enforcement manpower, selection of appropriate accident countermeasures, establishment of priorities for maintenance or capital improvements, or other operational purposes.

To be useful, sufficient accident data should be available to meet the needs of a given operational problem. Thus, for example, if a commander has to allocate his manpower between daytime and nighttime shifts, he requires data that are collected on a shift basis; he will not be materially helped by a 24-hour accident total. However, he also is not helped very much if the data collected on a shift basis do not include enough information to enable him to detect any stable pattern of differences between daytime and nighttime accident experience, since he does not wish to continuously respond to what might be random differences.

All uses of aggregated accident information for operational decision-making of one form or another pose the same problem of detecting stable patterns of accident experience out of a broad array of random fluctuations of statistical data.

SELECTED TOPICS ON CONTROL CHART THEORY

Several ways of adapting control chart techniques to accident information have been reported by a number of investigators [Mathewson, Brenner, and Hulbert (1954), Mathewson and Brenner (1956), Norden, Orlansky, and Jacobs (1956), Littauer (1957), Blindauer and Michael (1959), Rudy (1962)].* All are essentially variations of the classical Shewhart quality control chart techniques originally designed to assist in maintaining product quality during the course of manufacture [Shewhart (1931), Grant (1952)]. The Shewhart control charts, in turn, are based on well-known probability concepts and the associated theory of runs in sequential events.

When these control chart techniques are applied to accident data, a number of matters have to be considered more carefully than is usually necessary in the manufactured product applications for which they were originally conceived. To highlight some of these matters, a brief review is presented of overall control chart logic, starting with the statistical concept of control chart limits as applied to accident analysis. Formal derivations are in Appendix B. More detailed background information on probability theory and its applications to control charts can be found in the referenced works.

STATISTICAL CONTROL CHART LIMITS ON ACCIDENT EXPECTATION

The network of surface streets and freeways will be considered to be made up of a group of "elements," the definition of which is left open here. For enforcement purposes, the most convenient definition might be the beat. For traffic engineering, it might be the intersection as distinguished from the intervening mid-block lengths; for highway engineering, it might be design features such as a horizontal curve between the points of tangency.

Each element has an accident history. This history can be described in terms of the number of accident events without regard to the number of injuries or extent of property damage accompanying each event. Or it may be described in terms of the aggregated losses, such as the total number of fatalities, without regard to the number of events that produced the totals. Or it may be described in various combinations of events and accompanying severity, such as the total number of accidents in which one or more persons were killed. It is convenient at the outset to consider accident experience solely in the context of the number of accident events, although, with minor mathematical adjustments and assumptions, the same logic can be applied to the other definitions.

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*References are cited in Appendix A, Bibliography, under appropriate headings.

Implicit in all operational decisions directed toward the accident problem is some estimate of accident expectation, regardless of whether or not the estimate is explicitly identified. A decision to improve horizontal sight distance around a curve generally implies a judgment (by someone) of a high accident expectation for the unimproved roadway coupled with a reduction in expectation with the improvement. A decision to allocate additional enforcement manpower to a given beat implies a judgment of high expectation on that beat.

Underlying all statistical usage of accident data for operational decision-making is the assumption that these data reflect in some manner the accident causation process. The same assumption is explicitly employed here.

Another important assumption is the commonly accepted belief that even when all factors that conceivably could relate to accident causation remain unchanged (condition of the road surfaces, traffic control devices, weather, condition of vehicles, composition of motorists and their driving habits), accident experience will nonetheless vary. In some periods there will be no accidents, while in others the number will be high. Therefore, any observed deviation in accident experience from what it was expected to be might be reflecting nothing more than inherent variability of accident experience in an unchanging accident causation process. On the other hand, an observed deviation might be indicating some change in the accident causation process. Generally speaking, the closer accident experience is to what we expected it to be, the more likely are we to conclude that we correctly assessed the accident causation process. Similarly, with greater deviations we are more likely to conclude that there was some (unanticipated) change in the accident causation process.

In order to make such judgments more precise, it is necessary to express quantitatively the inherent variability of accident experience. The control chart technique is one statistical method for doing so. Specifically, it is a pair of accident values having a selected probability of bracketing the value of accident expectation. To cite one example, a two-sided 95 percent control chart interval, $\Pr\{A < \eta < B\} = 0.95$, is read as a 95 percent probability that the range between A and B will bracket the number of accidents.

Stated otherwise, we expect that in any 95 of 100 periods of observation in which the accident causation process remains unchanged, the number of accidents that occur will be bracketed within the range A to B. At the same time, we expect that in the remaining 5 observation periods the number of accidents will be greater than B or less than A. Depending on the application, broader or narrower control chart limits may be specified. A 90 percent control chart interval will be narrower than the 95 percent interval for the same expectation; a 99 percent interval will be broader. As shown in Figure 1, (a) when the observed accident losses fall within the 95 percent control chart interval, we are most indecisive as to the occurrence of a change in accident causation; (b) we are less indecisive when it falls outside the 95 percent interval, although still within the 99 percent interval; and (c) we are least indecisive when it falls outside the 99 percent interval.

Bearing in mind that the purpose in interpreting accident experience is to decide whether or not there has been some change in the underlying accident causation process, we "play the odds" and draw conclusions according to the following basic set of rules:

Rule 1. If the observed number of accidents falls outside the control chart interval, we conclude that there was a change in the underlying accident causation process (during the time period and on the road element for which the control chart interval was established).

Rule 2. If the observed number of accidents falls inside the control chart interval, we conclude that there was no change in the accident causation process.

For a 95 percent control chart interval, on the average 5 out of 100 (Rule 1) decisions that a change has occurred in accident causation, when in fact it has not, will be made. Or, the likelihood that Rule 1 will lead to an erroneous conclusion is 5 percent. We shall refer to this decision error as the Type I error, or the alpha (α) error, or the error of commission (stating that a process change occurred when in fact it did not).

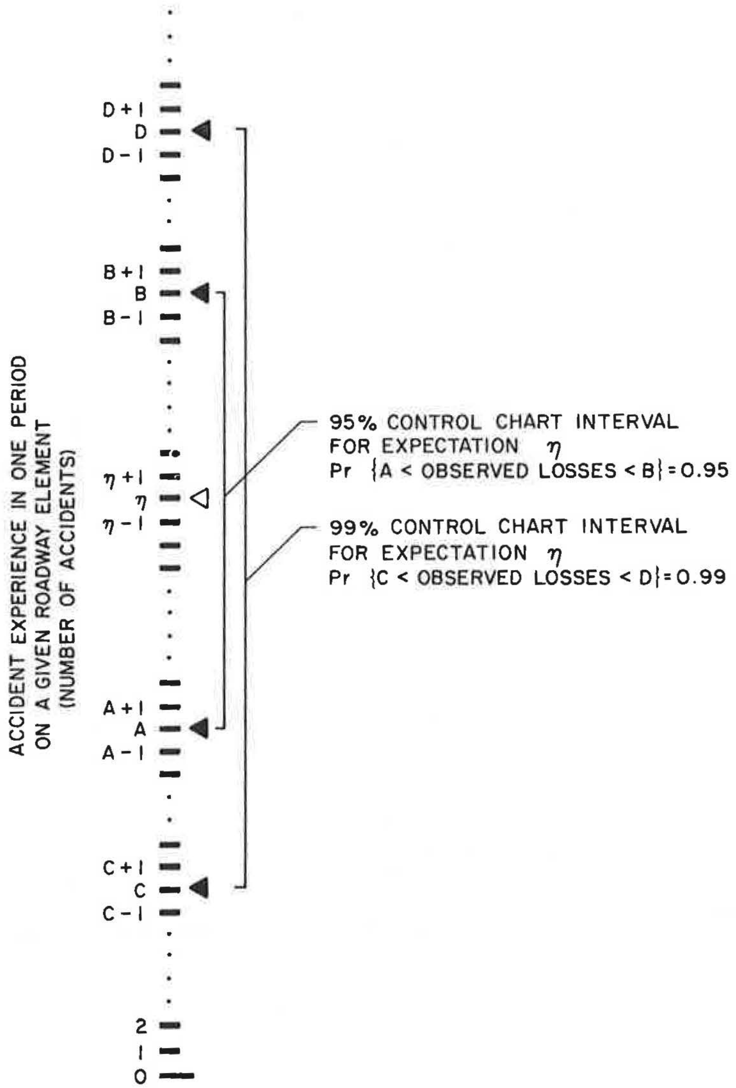

Figure 1. Representation of 95 percent and 99 percent control chart intervals for interpreting accident experience.

Rule 2 decisions as to no change in the accident causation process will also be correct most of the time, but nevertheless will be wrong occasionally. We shall refer to this error as the Type II error, or the beta (β) error, or the error of omission (failure to recognize that a process change occurred).

A method for establishing the magnitude of the beta error is described in Appendix B. It suffices here to state that it depends on the accident expectation.

The various possible decisions and decision errors in interpreting observed accident experience in relation to the control chart interval on its expectation are shown in Figure 2. The magnitudes of the Type I and Type II errors determine the sensitivity of the control chart interval for judging that changes in the accident causation process have or have not occurred. Operational personnel have to establish these values in advance, that is, to decide what chances they are willing to take on making the Type I error and

Event	Decision	Actual Status of Accident Causation Process	
		Changed	Unchanged
Value of observed losses is above upper bound of control chart interval	Accident causation has changed (i. e., worsened)	Decision is correct	Decision is Wrong Type I Error
Value of observed losses is within the control chart interval	No change in Accident Causation	Decision is Wrong Type II Error	Decision is Correct
Value of observed losses is below lower bound of control chart interval	Accident causation has changed (i. e., improved)	Decision is Correct	Decision is Wrong Type I Error

Figure 2. Correct and incorrect decisions inherent in use of control chart intervals.

Type II error. In general, this will depend on the operational problem itself. It will, however, also be linked to choices on other matters that have to be set properly to derive full benefit from the control chart logic, including (a) the length of the time period (should control chart intervals be established for daily losses? weekly? monthly?); and (b) the length of the roadway element (a one-mile length? five? ten?).

In addition to these matters relating to choice of the error probabilities and the domain (length of time period and length of roadway element) for the control chart interval, there is the all-important choice of how to estimate the expectation for which the control chart interval is to be computed. And when the expectation is estimated for the unchanging accident causation process, the choice has to be made as to the degree of change to which the control chart interval is to be sensitive. An interval that rarely will lead to the Type II error of failing to detect, say, a 10 percent change in accident causation, will frequently permit the Type I error of asserting that a change of this magnitude occurred when in fact it did not.

In effect, there is not any single optimum control chart interval for interpreting accident experience, but rather whole familes of intervals involving various combinations of (a) Type I error, (b) Type II error, (c) length of time period, (d) length of roadway element, (e) accident expectation, and (f) degree of sensitivity to process change. The optimum combination of these factors will depend on the particular application. Various criteria for selecting a combination will be discussed later. However, the underlying theory and interpretation procedures are the same for all combinations.

In the discussion so far, the control chart interval for each time period is developed around the expectation for that time period. The accidents in the period are then compared with the predetermined control chart interval, and a decision is made as to whether or not a process change occurred in that period. By combining this information (observed accidents in the present period in relation to the control chart interval around the expectation) with similar information for the prior observation periods, it becomes possible to establish the presence (or absence) of process changes extending over a sequence of observation periods. Up to the present time, the basis for combining successive sets of information in this manner has arisen from the theory of extreme runs (i.e., Grant, 1952).

An allowable rule for interpreting information in successive control chart intervals depends on the selected value for the Type I error associated with an arbitrary interval. However, for such rules to fit into the framework we are developing here, the Type I and Type II errors associated with the use of these rules must be known. To the authors' knowledge, there has been no systematic study performed to assess the magnitude of these errors. A more detailed discussion of methods of generating such rules and of assessing the magnitude of the Type I and Type II errors associated with their use is beyond the scope of this paper but is, nevertheless, mentioned as a possible avenue of future investigation.

SOME ISSUES RELATED TO ESTIMATING ACCIDENT EXPECTATION

The manner in which accident expectation is estimated can substantially alter the validity and effectiveness of control chart methods. Several matters related to this problem will be discussed.

Apart from its important role in accident control chart technology, the procedure for estimating accident expectation is of itself important for operational decision-making. Valid estimates of accident expectation may be of major operational importance even if control chart technology is not being used. For example, knowledge that the expected number of accidents on Saturdays is higher than on Mondays may be sufficient for a proportionately greater allocation of manpower to Saturday duty. The discussion here, however, will not treat this important use of accident expectation as an operational tool of itself, but instead is limited to its use in control charts.

As stated earlier, underlying all statistical usage of accident experience for operational decision-making is the assumption that accident data in some manner reflect the underlying accident causation process. For purposes of exposition, we shall define p^* as the measure of this accident causation process. Let us then posit that the accident expectation m is a barometer of p^*.

Accident expectation can be estimated in any number of different ways, each of which may produce a different value for m. However, since all are supposed to be barometers of the same accident causation process measure p^*, the question must be raised as to how good the selected value m is as a barometer of p^*.

It is convenient at this point to introduce the Poisson distribution for accidents which arises from the assumptions that (a) any given accident observed on a roadway is independent of any other traffic accident, and (b) as the length of the time period in which any given section of roadway is observed approaches zero, the probability of observing one or more accidents approaches zero. One property of the Poisson distribution is that its mean and variance are equal. Denoting by Y_t the number of accidents and by m the mean, then

$$P[Y_t = y_t] = \frac{e^{-m}\, m^{y_t}}{y_t!} \tag{1}$$

and an estimate $\hat{m}$ of m based on the accident data over the preceding N unit time periods is

$$\hat{m} = \frac{1}{N} \sum_{i=t-N}^{t-1} Y_i \tag{2}$$

The estimate (Eq. 2) assigns equal weights to the accident experiences of all of the preceding N unit time periods. In contrast to this, a variable weighting scheme could be used. For example, the scheme

$$\frac{Y_{t-3} + 2Y_{t-2} + 5Y_{t-1}}{8} \triangleq \hat{m}$$

assigns variable weighting 1:2:5 to the accident data of the third, second, and first periods, respectively, immediately preceding the period t. The general concept is that the longer away in time, the lower the correlation in accident losses. In the example, the losses in t - 1 carry 5 times the weight of those in t - 3 for estimating losses in period t. Of course, selecting the appropriate weights in schemes such as this also poses a problem. For the present, however, we shall consider only the equal weighting approach.

We can increase the inherent stability of our estimate $\hat{m}$ by increasing the number of data points in our sample. Stability of this nature makes $\hat{m}$ relatively insensitive to short-term transient changes in p*, and can be desirable for some applications, as, for example, in deciding whether or not to make some costly spot capital improvement, or in making some basic policy change in licensing. In these kinds of decisions, one would not wish to react to some transient change in the accident causation process which might readily correct itself.

On the other hand, other classes of operational decisions specifically require sensitivity to short-term transients in accident causation. Selective enforcement is in this category. One may even suspect that its primary use of control chart techniques would be only in response to short-term effects, although for some enforcement decisions more stable effects might be the important factors. Thus, a single method of estimating accident expectation will not be optimum for all uses of control charts.

SOME ISSUES RELATED TO THE CHOICE OF ONE-SIDED OR TWO-SIDED CONTROL CHART SYSTEMS

The preceding discussion of control charts has dealt with two-sided control chart limits. With no a priori information concerning the direction of change of the causation process, the two-sided limits are appropriate when we expect either an improvement or a worsening in the causation process. However, if we have a priori reasons to believe that the causation process will change in a particular direction (for instance, due to diurnal variation) it is wasteful of information to employ control charts based on two-sided control limits. We are thus led to propose three separate control chart systems: Control Chart System A based on an upper one-sided control chart limit, Control Chart System B based on a lower one-sided control chart limit, and Control Chart System C based on two-sided limits. The designation of A, B, and C for the three types of control charts is arbitrary, and is used solely to simplify the presentation, here and later in the report.

Control Chart System A

When on the basis of a priori information we expect the causation process to worsen, or when an operational decision is to be made only when the accident causation process appears to have worsened (based upon a measure of p*), it is appropriate to use a control chart based on an upper one-sided control limit. With such charts, a decision that a worsening in the causation process has occurred in time period t is reached only when the measure of p* falls above this limit. It is not possible with this type of control chart system to make any decisions regarding process improvement even if improvement actually occurs in period t.

Control Chart System B

When we expect the causation process to improve on a priori grounds, or when an operational decision is to be made only when the process appears to have improved, it is appropriate to use a lower one-sided control limit on the measure of p*. With these charts, the decision that an improvement has occurred in the causation process in period t is reached when the measure of p* falls below this limit. With this type of control chart system it is not possible to reach the conclusion that the process has worsened in period t even if in actuality it has.

Control Chart System C

When we have no a priori information concerning the direction of change of the causation process, or when operational decisions concerning improvement and worsening must be made, it is appropriate to use two-sided control limits on the measure of p^*.

A mathematical description of each of the three control chart systems together with their associated decision rules is presented in Appendix B, Topic 1.

Conceivably, an investigation might be initiated using Control Chart System C; when sufficient indication of direction of change of the causation process is available, the investigation might then be continued with System B or System A (whichever is appropriate). A complete discussion of interplay among the three control chart systems and guidelines for their choice will be postponed to future papers.

SOME ISSUES RELATED TO SPECIFYING CONTROL CHART PARAMETERS

Once a user has selected either an A, B, or C control chart system as the most appropriate for a particular operational problem, he must specify its relevant parameters, some of which relate to the nature of the application while others are largely statistical. The specification of the statistical parameters will be discussed here.

The statistical group of factors that must be taken into account in establishing a control chart system for a particular application relates to the property of "control chart sensitivity" and includes (a) the acceptable alpha (α), i.e., probability of the Type I error; and (b) the acceptable beta (β), i.e., probability of the Type II error pursuant to failing to detect a K percent change in expectation.

A control chart utilizing a low value for the alpha error will have correspondingly low probability of suggesting that a change in p^* took place when in fact there was no change. However, this kind of a chart might also have a correspondingly high beta error, i.e., a high probability of failing to suggest a change in p^* when such a change in fact occurred.

In effect, it is not possible to reduce the probability of making a Type I decision error without increasing the probability of making a Type II decision error. The user must accordingly decide, in establishing a control chart system, the kind of error that he is most anxious to avoid making. In some applications, it might be especially important to avoid the Type I error; in others, avoidance of the Type II error might dictate the choice. The following are examples of these situations:

1. Choose a low value of alpha (e.g., 0.01 instead of, say, 0.05). The decision on a proposed major expenditure for a given capital improvement is to be geared to a worsened accident causation process. Accordingly, one would wish to guard against concluding that a worsening had occurred when it did not, because such an erroneous conclusion would lead to the money being spent needlessly.

2. Choose a low value of beta (e.g., 0.60 instead of 0.90). A decision on a proposed operational practice is to be geared to correcting a worsening risk situation. Accordingly, one would wish to guard against not recognizing a high-risk situation, and having failed in this regard, thereby deciding against a needed operational practice. A control chart in this form would have reduced likelihood (i.e., 0.60 instead of 0.90) of failing to detect a bona fide worsening of risk, but would more often come up with a spurious indication of worsening risk.

The selected level of the beta error must be linked to a selected change in accident expectation. For example, with Control Chart System A and a fixed value of the alpha error of 0.05, a beta error of approximately 0.28 is associated with a failure to detect an 80 percent increase over an accident expectation of 10 accidents per time period. For the same control chart system and alpha error, a beta error of 0.16 is associated with failure to detect a 100 percent increase over an accident expectation of 10 accidents per time period. Stated otherwise, we may sizably decrease the beta error for fixed system, alpha error, and expectation if we are willing to sacrifice detection sensitivity.

A UNIFIED PROCEDURE FOR ESTABLISHING A CONTROL CHART SYSTEM FOR A PARTICULAR APPLICATION

In this section we shall be concerned with describing briefly the manner in which the parametric values of a control chart are specified once the choice of the control chart system has been made. This shall be illustrated with actual data.

Consider that a user decides that a particular control chart application requires an alpha error of magnitude α^*, and a beta error of magnitude β^* for (probability of failing to detect) a change of magnitude K^* (percent) of accident expectation. As derived theoretically in the Appendix, in order for this triplet to produce a reliable control chart system, the accident expectation must be as great as a mathematically calculable value that will be referred to as λ_0^*. If the estimate of the expectation is less than λ_0^*, a different control chart system must be designed according to one or more of the following alternatives: (a) change the value of the tolerable alpha error (α^*), (b) change the value of the tolerable beta error (β^*), or (c) change the value of K^*. Or, to maintain the desired α^*, β^*, K^* triplet, we have the following alternatives: (a) increase the period of measurement, e.g., from a one-week to a one-month period, as a means of increasing the accident expectation for the same roadway length up to λ_0^*; (b) increase the length of roadway, e.g., from a one-mile up to a five-mile length, as a means of increasing the accident expectation up to λ_0^* in the same period of measurement; or (c) increase both the period of measurement and roadway length so that accident expectation for the new combination is up to λ_0^*.

Guidelines for selecting the appropriate alpha error, beta error and associated K value have already been discussed. These decisions are common to all control chart designs. The new method, however, goes beyond the (α, β, K) choices, and deals as well with changing either or both the roadway lengths and the period of measurement, so that a control chart system of selected (α^*, β^*, K^*) sensitivity can be used.

The mathematical bases underlying the proposed method are presented in Appendix B, and deal with the following topics, under various assumed operational constraints:

1. Topic 2, determination of the control chart time period for a fixed length of roadway;
2. Topic 3, determination of roadway length for a fixed time period control chart; and
3. Topic 4, determination of optimum trade-offs between length of time period and length of roadway.

In the interest of simplifying the presentation, the discussion-demonstration to follow is limited to the Topic 2 treatment, since a similar procedure could be followed in dealing with Topic 3. In dealing with the Topic 4 problem, graphical and/or computer techniques are required for determining optimum trade-offs between period length and roadway length. These trade-off procedures become necessary if, to realize a selected control chart sensitivity, either the required time period or roadway length turn out to be greater than would be useful for a given operational application. A demonstration of the Topic 4 problem will be deferred to future papers.

TABLE 1

MILEPOST DESIGNATIONS AND LENGTHS OF FIVE OCEANSIDE BEATS

Item	Beat 1	Beat 3	Beat 5	Beat 43	Beat 45
Length (miles)	17.93	5.28	4.84	4.35	2.85
Beginning milepost	53.65	40.68	35.84	45.96	32.99
End milepost	71.58	45.96	40.68	50.31	35.84

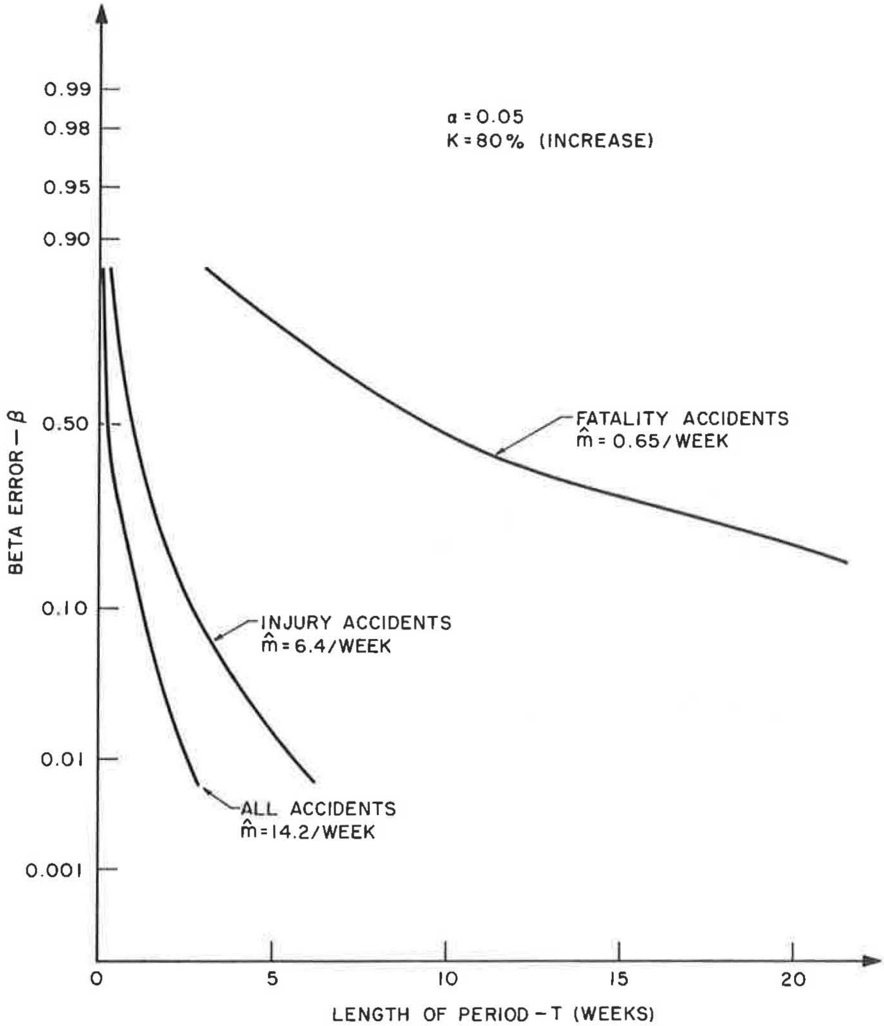

Figure 3. Control Chart System A: β vs T (based on 1962 Oceanside data).

In order to develop a demonstration of the overall method, actual accident data were used. These data were provided by the California Highway Patrol in an IBM tape data file for accidents that occurred on Highway 101 in the Oceanside area (near San Diego) between the years 1961 and 1964. This roadway is divided into five CHP line beats. The beginning and ending milepost designation, together with the length of each beat, are shown in Table 1.

The overall process is shown in Figures 3 and 4 in which the variation of β with control chart time period (T) is plotted for fixed values of α, K, and $\hat{m}$. Two grossly different values of α are used (α = 0.05 in Fig. 3, and α = 0.30 in Fig. 4) to demonstrate the effect that the choice of α has on control chart time period. Three values of $\hat{m}$ are used; the reasons for selecting these values will be explained presently. The value of K is arbitrarily set at 80 percent (increase). These figures apply to Control Chart System A.

A number of general properties of the mathematical formulation are directly illustrated. Some of these are:

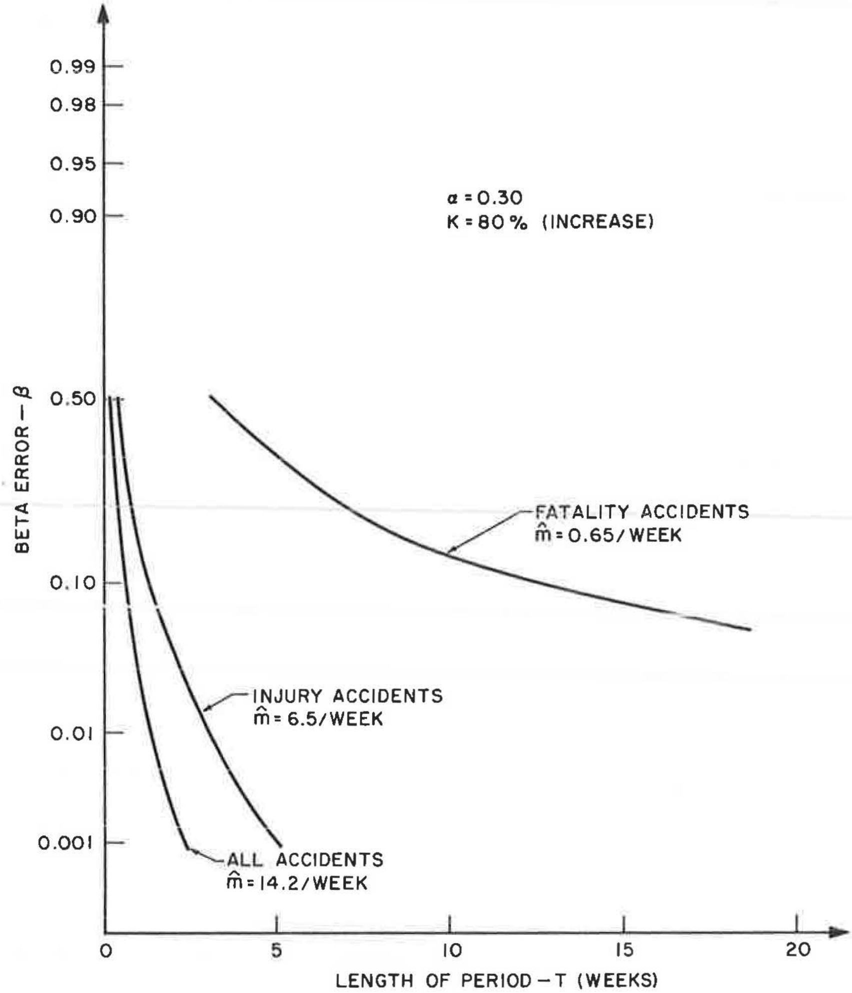

Figure 4. Control Chart System A: β vs T (based on 1962 Oceanside data).

1. By increasing the α error that we are willing to tolerate, we can reduce the control chart time period. For example, with β held constant at 0.3 for an $\hat{m}$ of 6.5 accidents/week, the control chart time period changes from 1.5 weeks to 0.8 weeks by increasing the α error probability from 0.05 to 0.30.

2. By increasing the β error that we are willing to tolerate, we can reduce the control chart time period. For example, with α held constant at 0.30, for an $\hat{m}$ of 6.5 accidents/week, the control chart period changes from 2.5 weeks to less than 3 days by increasing the β error from 0.02 to 0.50.

3. The control chart period varies sharply with changing values of accident expectation. For example, with β held constant at 0.1 and α held constant at 0.30, the control chart period is 12.5 weeks for an $\hat{m}$ of 0.65 accidents/week, and 4 days for an $\hat{m}$ of 14.2 accidents/week.

Figures 3 and 4 pertain only to the three selected values of $\hat{m}$ (0.65, 6.5 and 14.2) and the two arbitrarily chosen values of α (0.05 and 0.30). Similar functional plots, or other forms of nomographs, can be readily developed for the complete array of α and $\hat{m}$ values.

The $\hat{m}$ values in Figures 3 and 4 were deliberately selected to coincide with estimates of accident expectation on the Oceanside length of roadway. This is to say that, using the accident history of this roadway (the 1962 record in this case), estimates of $\hat{m}$ for the expected numbers of several categories of accidents were computed. The functional variations of β with the control chart period were then generated only for these values of $\hat{m}$, to satisfy the demonstration purposes of this work. In practice the user would estimate the accident expectation from past history and then, with these data, enter an array of ($\hat{m}$, α, K) charts to determine the smallest control chart period that he could use and still have the resulting control chart produce meaningful conclusions.

In the example illustrated in Figures 3 and 4, the $\hat{m}$ values for which the functions are plotted coincide with the following estimates of accident expectation for the full length of Oceanside roadway (the beat distinctions have been suppressed to facilitate the demonstration of the method):

1. $\hat{m}$ = 0.65 accidents/week coincides with fatality accidents,
2. $\hat{m}$ = 6.5 accidents/week coincides with personal injury accidents, and
3. $\hat{m}$ = 14.2 accidents/week coincides with total accidents.

A control chart on fatality experience having an α error probability of 30 percent and a 10 percent (β error) probability of failing to detect an 80 percent (K) increase in fatality-producing potential would require a control chart time period at least 12.5 weeks long. In other words, there would be one control chart point every 12.5 weeks. If the period were reduced to 3 weeks, the β error would be increased to about 50 percent. Thus, even a bimonthly control chart would be essentially insensitive to as much as an 80 percent shift in fatality-producing potential. The user would probably conclude that control charts on fatality experience would not be useful.

On the other hand, a control chart on total accident experience on this roadway could use a period as short as 4 days for β = 10 percent and α = 30 percent. With this degree of sensitivity, it would be a highly useful operational tool.

Several additional sets of α, β, T values for fixed K on the Oceanside roadway are given in Table 2. This illustrates the frame of reference within which a user could select a control chart system for this roadway. His choice of a particular α, β, T combination would depend almost entirely on his operational judgment as to how he might utilize control chart results.

TABLE 2

SELECTED RESULTS UNDER CONTROL CHART SYSTEM A USING TIME PERIOD, T, AS FUNCTION OF α, β, K = 80 PERCENT, AND ACCIDENT CLASSIFICATION FOR 1962 OCEANSIDE ACCIDENT EXPERIENCE

Alpha	Beta	Accident Classification: Total T (weeks)	Personal Injury T (weeks)	Fatal T (weeks)
0.05	0.80	0.20	0.50	4.5
	0.60	0.25	0.75	7.8
	0.50	0.30	0.90	8.8
	0.30	0.65	1.5	15.2
	0.20	0.85	2.0	20.0
	0.10	1.25	2.8	>20
	0.05	1.7	3.6	>20
	0.01	2.5	5.7	>20
0.30	0.50	0.12	0.37	3.2
	0.40	0.20	0.45	4.3
	0.20	0.32	0.80	7.8
	0.10	0.6	1.3	12.5
	0.05	0.8	1.8	18.8
	0.03	1.0	2.3	>20
	0.01	1.35	3.0	>20
	0.005	1.6	3.6	>20
	0.001	2.2	5.0	>20

To increase further the operational utility of these control chart systems, it undoubtedly would be desirable to reduce the K value as much as possible, i.e., to make the overall control chart process sensitive to as little as, say, a 10 percent increase in accident potential instead of the 80 percent value used in the Oceanside example. A good way of doing this would be to substantially increase the α error probability, possibly to as much as 40 percent. The resulting control chart would rarely fail to detect a small change in accident potential, but at the price of having its indications of changes be more frequently spurious.

The principle suggested here is that for certain applications of control chart techniques to accident data, it will be appropriate to tolerate more false indications of a change in accident-potential in order to reduce the likelihood of failing to detect a real change.

Each of the three variations of the method (fixed roadway length-minimum time period, fixed time period-minimum roadway length, trade-off between roadway length and time period) can be programmed for computer solution, either for weighted or unweighted estimates of accident expectation. It thereby would become practical to implement control chart techniques in which the control chart is continuously being adjusted to maintain a preset sensitivity. To the best knowledge of the authors, a dynamically adjusting control chart system of this nature has not as yet been applied to accident rate processes.

Computer solutions will also make practical another new and potentially important control chart methodology, namely, to maintain concurrently within the same enforcement or engineering jurisdiction a number of control charts of different sensitivities. One control chart of given sensitivity might be directed toward short-range operational decisions, another of different sensitivity might be for long-range decisions. In one sense, this is tantamount to treating continuing accident data from a number of different, although possibly overlapping, directions. Some of the resulting indications might be contradictory, but an overall gross indication should nonetheless emerge if there is some reason for such an indication. One must always bear in mind that control chart techniques serve virtually no useful purpose for sharply defined changes in accident causation processes. Instead, their primary justification is for hazy situations in which gradual changes in accident causation are suspected. In such hazy situations, with no sharply defined yeses or noes, it becomes necessary to glean hints and suggestions from as many directions as possible.

The authors would strongly emphasize here that any control chart system for interpreting successive variations in accident experience is, at best, an inexact process, although much more exacting than simple "seat of the pants" analyses of such data. In the same vein, it almost would be idle to hope that any kind of statistical treatment would come up with precise yes or no answers to specific operational problems. Instead, control charts will produce hints and indications of underlying changes in accident causation and the associated appropriateness or inappropriateness of given operational decision alternatives. They thereby produce additional inputs to operational decision-making, but nevertheless do not comprise the whole of the process.

CONTROL CHARTS ON ACCIDENT RATES

The discussion thus far has dealt with control charts based on raw numbers of accidents, and has not considered charts based on accident rates. The overall logic is essentially the same; nevertheless, several problems of control chart application arise according to the nature of the exposure and procedures used to estimate it.

Let us define an accident rate, R_t, in time period t as the number of observed accidents of a particular classification, Y_t, per unit of accident exposure, E_t:

$$R_t = Y_t/E_t \qquad (3)$$

When the exposure is constant from time period to time period, the distribution of R_t (when Y_t is Poisson) has mean m/e and variance m/e^2. When m is large (say, greater than 25 accidents/period), it is possible to approximate the rate control chart limits by asymptotic expressions. In virtually all prior applications of control chart techniques to accident data, asymptotic expressions have been used for both rate and raw accident limits. These expressions, however, do not hold for small m; in such cases in order to determine rate control limits, we must know the form of the distribution of R_t (which is not Poisson even when E_t is constant from period to period).

With E_t a random variable (i.e., traffic density, vehicle miles), we are faced with other problems. For instance, what is the distribution of E_t? Are Y_t and E_t statistically independent? What then is the distribution of R_t? For many of the widely used exposure measures, questions such as these are largely unanswered.

We ask these questions because it is our contention that in many selective enforcement problems operational constraints dictate that we deal with small expectations—thus precluding the use of asymptotic expressions for either rate or raw accident control limits. For example, with a desired (high) control chart sensitivity, we will usually find that in order to use such expressions to determine control limits, we need either inordinately long roadway sections, long control chart time periods, or both. Furthermore, the results from the ensuing analyses would prove virtually useless for basing operational decisions. These remarks become particularly pertinent in dealing with control charts based on finely classified accident data.

Remarks can also be made concerning the exposure measure itself. There still is no measure that cannot be validly criticized on some account. Even if mileage is obtained by direct odometer readings, one could question the absence of normative observations of the time of day or day of week in which the odometer values were generated. If these normative data were available, one could question the absence of additional descriptions of the type of driving, e.g., the relative demands on freeways vs surface streets.

Without deprecating the importance of detailed multidimensional descriptions of exposure data, a somewhat different point of view is suggested for operational purposes. This is to base all initial statistical descriptions of accident causation process on raw totals of the accident events, with no attempts to operate on these data with any form of randomly varying exposure information such as mileage. Subsequently, exposure information could be advanced as possible explanations of fluctuations of the raw accident data.

Several factors support this logic. First, the mathematical theory is clearly developed for treating raw accident data, but not for treating accident rates having exposure as a random variable. Second, manipulating relatively exact raw accident totals with less exact, if not totally spurious, exposure data can readily confound interpretations without producing any reliable new insights.

Finally, it appears that most operational countermeasures ultimately reduce to responses to raw accident experience anyway. Consider the example of a given enforcement beat on which the raw numbers of accidents are high. Even if the accompanying traffic volumes were also high, so that a low mileage-based rate resulted, substantial manpower would nonetheless be allocated to that beat. This is to say that high accident losses will produce operational action regardless of whether or not, with exposure manipulations, the losses are represented by statistically low rates.

This leads to the very challenging proposition that the "accident causation process" is the totality of all exposure. The raw accident losses should be considered as measuring the multidimensional quantity and quality of exposure. Personal characteristics of drivers as well as physical characteristics of vehicles using a roadway become a part of that roadway's exposure, along with the inventory of weather conditions encountered by the motorists. The amount of drunkenness in the set of drivers using a particular roadway is as much a part of that roadway's exposure measure as the raw volumes of vehicles. (It should be noted that Eq. 3 implies that the multidimensional space of factors which contribute to the exposure have been reduced to a single random variable E_t.)

A high accident experience becomes an indication of something amiss in the antecedent exposure hyperspace; a statistically significant change in accident experience is an indication of change in some aspect of the exposure hyperspace. The problem reduces to isolating where the exposure change is occurring and directing operational action to it. One may even argue that all operational actions can be considered to be directed toward influencing or changing some aspect of the exposure hyperspace.

The implications of this proposition are more far-reaching than may be immediately apparent. It leads to replacing present rate-based accident statistics with raw accident data, unmodified by any exposure data, as the primary statistical methodology for operational purposes. It precludes any deliberate or inadvertent overlooking of inherently dangerous environments as a result of operating on this accident data with sound or unsound exposure data. It identifies accident experience as such, clearly and unambiguously.

Speculations as to how these losses relate to the antecedent exposure base are a secondary aspect of the analytical process. Correlations between the losses and the exposure (hyperspace) presumably, of course, would strongly dictate appropriate operational measures. However, failure to isolate such correlations nonetheless would not preclude proper recognition of accident loss magnitudes as such, and changing patterns in these magnitudes.

In scientific history, many phenomena have been observed well before acceptable theories were developed to explain the phenomena. This is somewhat analogous to the situation here. Regardless of whether or not some exposure argument reduces a high accident loss experience to a low rate, operational personnel will take appropriate corrective actions. The proposition of developing raw accident data methods reflects this highly rational operational practice.

CONCLUSION

The use of control chart techniques for accident data is not new. Such usage has been suggested by a number of authors, and on the surface, is almost a natural for operational personnel whose decision-making requires them to be able to detect stable patterns—if such patterns exist—out of what otherwise are largely random fluctuations of accident experience from one period to the next, or from one roadway length to the next. This is precisely the primary purpose of control charts.

However, these techniques are not in widespread use today, if they are being used at all. We may offer several possible explanations. One is that the underlying mathematical logic has not been fully translated into the rather immediate operational needs, such as how the user should select the length of roadway and the period of time of his control chart system.

A more important reason is that the precise rules of the α and β errors in accident control chart applications have never been fully enunciated. In fact, at the outset of this effort we were utilizing the conventional 5 percent α error, and were finding that the resulting control chart systems were virtually worthless for the roadway under study. The charts would show the obvious, sharp changes in accident experience, but would be insensitive to the more subtle changes. Clearly, operational personnel do not need, nor have the time to bother with, statistical methods that do no better than they can do by simple examination.

The key to practical usefulness of these techniques for accident data analysis is, in our opinion, the β error. Conventional statistical experiments with low α error generally must have large sample sizes to realize low β error. Economic constraints will generally dictate the sample size and in most cases rule out the experiment with low β error. As a result, it is rather common for the scientist, rather than reporting a spurious discovery, to say that he has discovered nothing. This approach is questionable in many areas of accident data analysis where the cost of false detection is relatively insignificant when compared to the cost of failing to detect a problem. Our work to date strongly suggests that for many accident data uses a high α error probability, even 40 percent or larger, should be tolerated, if necessary, to realize a low β error concomitant with realistic values of T, L, and K.

The question of optimum trade-off between α and β error leads directly into another important area of inquiry, namely, that of determination of the value or cost associated with making each type of error. An accompanying issue is the value or cost of each possible countermeasure that might be implemented following a (control chart) indication of need. Combining such value systems with the statistical measure implicit in the α, β, K choice is immediately suggested as the next major area of study. This combination can lead to important new cost/effectiveness methods.

Another related line of inquiry is illustrated in this example: A unit commander has to allocate his manpower to the beats and shifts under his jurisdiction, regardless of whether or not stable statistical patterns can be discovered. At present, he does this without the benefit of control chart methods. When he starts to use control chart methods, he undoubtedly often will be in the same situation, namely, no statistically significant indications of causation changes. Here the line of inquiry would deal with how the operational decision-making process should function in the face of no evidence from the control chart methods.

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Appendix A

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The bibliography is partitioned into nine categories according to the major emphasis of the references as they pertain to the work on this project.

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Appendix B

MATHEMATICAL DERIVATIONS

Topic One: Hypotheses and Decision Rules for the Three Control Chart Systems

Let the number of accidents Y_t observed on a fixed-length roadway in the tth time period of length T be Poisson distributed with parameter λ. We shall consider three separate control chart systems, each based on hypotheses concerning the parameter λ. Systems A and B are based on a one-sided argument; System C, on a two-sided argument.

1.1 The Systems

The null hypothesis H_0 and alternative H_1 for each system are as follows:

System A: Detection of a "worsening" in the causation process

$$H_0: \lambda = \lambda_0$$

$$H_1: \lambda = \lambda_1, \ (\lambda_1 > \lambda_0)$$

where

$$\lambda_1 \triangleq \lambda_0 + K\lambda_0, \ 0 < K < \infty$$

System B: Detection of an "improvement" in the causation process

$$H_0: \lambda = \lambda_0$$

$$H_1: \lambda = \lambda_1, \ (\lambda_1 < \lambda_0)$$

where

$$\lambda_1 \triangleq \lambda_0 - K\lambda_0, \ 0 < K < 1$$

System C: Detection of either "improvement" or "worsening" in the causation process

$$H_0: \lambda = \lambda_0$$

$$H_1: \lambda = \lambda_1 \ (\lambda_1 \neq \lambda_0)$$

where

$$\lambda_1 \triangleq \lambda_0 \pm K\lambda_0$$

For each of the three control chart systems we shall insist that the following probability statements hold:

$$\Pr\{\text{accept } H_0 \mid H_0\} = 1 - \alpha \tag{1.1.1}$$

$$\Pr\{\text{accept } H_0 \mid H_1\} = \beta \tag{1.1.2}$$

1.2 The Decision Rules

The decision rules for each control chart system are as follows:

System A

If the observed value of Y_t in period t of length T is:

$$y_t < a \left\{ \begin{array}{l} \text{accept } H_0 \text{ and conclude no change} \\ \text{in the causation process in period t} \end{array} \right.$$

$$y_t \geq a \left\{ \begin{array}{l} \text{reject } H_0 \text{ and conclude a worsening} \\ \text{in the causation process in period t} \end{array} \right.$$

where a is the least integer such that

$$\sum_{y=a}^{\infty} \frac{e^{-\lambda_0} \lambda_0^y}{y!} \leq \alpha \tag{1.2.1}$$

is satisfied.

System B

If the observed value of Y_t in period t is:

$$y_t > b \left\{ \begin{array}{l} \text{accept } H_0 \text{ and conclude no change} \\ \text{in the causation process in period t} \end{array} \right.$$

$$y_t \leq b \left\{ \begin{array}{l} \text{reject } H_0 \text{ and conclude an improvement} \\ \text{in the causation process in period t} \end{array} \right.$$

where b is the largest integer such that

$$\sum_{y=0}^{b} \frac{e^{-\lambda_0} \lambda_0^y}{y!} \leq \alpha \tag{1.2.2}$$

is satisfied.

System C

If the observed value of Y_t in period t is:

$$c < y_t < d \left\{ \begin{array}{l} \text{accept } H_0 \text{ and conclude no change} \\ \text{in the causation process in period t} \end{array} \right.$$

$$y_t \geq d \begin{cases} \text{reject } H_0 \text{ and conclude a worsening} \\ \text{in the causation process in period t} \end{cases}$$

$$y_t \leq c \begin{cases} \text{reject } H_0 \text{ and conclude an improvement} \\ \text{in the causation process in period t} \end{cases}$$

where c and d are the largest and smallest integers, respectively, such that

$$\left[\sum_{y=0}^{c} \frac{e^{-\lambda_0} \lambda_0^y}{y!} \leq \frac{\alpha}{2}, \sum_{y=d}^{\infty} \frac{e^{-\lambda_0} \lambda_0^y}{y!} \leq \frac{\alpha}{2} \right] \tag{1.2.3}$$

are satisfied.

For each control chart system the probability β of accepting H_0 when H_1 is true (1.1.2) is given by:

System A

$$\beta_A = \sum_{y=0}^{a-1} \frac{e^{-\lambda_1} \lambda_1^y}{y!} \tag{1.2.4}$$

System B

$$\beta_B = \sum_{y=b+1}^{\infty} \frac{e^{-\lambda_1} \lambda_1^y}{y!} \tag{1.2.5}$$

System C

$$\beta_C = \sum_{y=c+1}^{d-1} \frac{e^{-\lambda_1} \lambda_1^y}{y!} \tag{1.2.6}$$

Topic Two: The Determination of the Control Chart Time Period for a Fixed-Length-Roadway Chart

In the following discussions we shall only consider System A, as similar reasoning applies for the other systems.

Consider the space $\{\lambda_0, \alpha, \beta, K\}$ obtained by solution of Eqs. 1.2.1 and 1.2.4, where β is a dependent variable and λ_0, K and α are allowed to vary over a respective set of values. Entering the space with a particular set of values of α, β, and K (say, α^*, β^*, K^*) we may find a λ_0^* which can be interpreted geometrically as the value of λ_0 at which the lines $\alpha = \alpha^*$, $\beta = \beta^*$, $K = K^*$ intersect the surface of λ_0. In terms of the accident causation process, λ_0^* is the expected number of accidents in time period of length T that is necessary to insure a Type I error of magnitude no greater than α^*, and a Type II error of magnitude β^* associated with a K^* increase in the parameter λ.

Thus, if m is the expected number of accidents per unit time with estimate $\hat{m}$, the control chart time period, T, that is necessary to insure a chart of strength at least (α^*, β^*) is given by:

$$T_{\alpha^*, \beta^*, K^*} = \frac{\lambda_0^*}{\hat{m}} \tag{2.0.1}$$

2.1 Graphical Representation of the {λ_0, α, β, K} Space for a Particular Control Chart System

Graphical representation of the {λ_0, α, β, K} space presents a convenient medium for determining a λ_0^* associated with a given (α^*, β^*, K^*) triplet. With λ_0^* determined it is then a simple matter to determine the control chart time period $T_{\alpha^*, \beta^*, K^*}$.

Consider a graphical representation in which α is taken as a page parameter and β vs K is plotted for set values of λ_0. Rewriting Eq. 1.2.1 as an equality relationship, we have

$$\sum_{y=a}^{\infty} \frac{e^{-\lambda_0} \lambda_0^y}{y!} = \alpha - \epsilon \tag{2.1.1}$$

where α is fixed, ϵ is a function of λ_0, and a is the least integer such that Eq. 1.2.1 holds.

As λ_0 tends to infinity, ϵ in Eq. 2.1.1 tends to zero. On the other hand, for small values of λ_0, ϵ can become appreciable in comparison to α. In practical terms, this behavior means that for a preset alpha and λ_0, a value y = a cannot be found that will make the summation in Eq. 2.1.1 exactly equal α. One effect of this behavior is that when α in Eq. 1.2.1 is taken as a page parameter, given values of K, α, β (say, K^*, α^*, β^*) do not necessarily lead to a unique value of λ_0^* on the graphical plots. Another effect is that a determined value of λ_0^* might be larger than is necessary to maintain a preset control chart strength. Practically, this means that the resulting control chart time period will tend to be overly conservative.

One way of circumventing these problems is to develop the graphs using an exact alpha test. This development is as follows.

In Eq. 1.2.1 with fixed values of α and λ_0, determine the value y = a, where a is the least integer such that Eq. 1.2.1 holds. The value of ϵ in Eq. 2.1.1 can then be determined by directly evaluating the summation in Eq. 2.1.1 between the limits (a, ∞) for the fixed values of α and λ_0. Thus, an observed value of Y_t that is equal to or greater than a will always fall within the region of rejection of H_0. To bring the size of the critical region exactly to alpha we include the term for y = a - 1 with probability p, where:

$$p\left[\frac{e^{-\lambda_0} \lambda_0^{a-1}}{(a-1)!}\right] = \epsilon \tag{2.1.2}$$

Thus, beta in Eq. 1.2.4 for the exact alpha test becomes:

$$\beta_A = \sum_{y=0}^{a-2} \frac{e^{-\lambda_1} \lambda_1^y}{y!} + \left[\frac{e^{-\lambda_1} \lambda_1^{a-1}}{(a-1)!}\right] \tag{2.1.3}$$

The decision rules for System A in Section 1.2 are then modified for the exact alpha test as follows:

1. An observed value $y_t \geq a$ always leads to rejection of H_0.
2. An observed value $y_t \leq a - 2$ always leads to acceptance of H_0.
3. An observed value $y_t = a - 1$ leads to rejection of H_0 with probability p and acceptance of H_0 with probability (1 - p), where p is determined in Eq. 2.1.2. This process can easily be carried out with a table of random numbers.

If the value system associated with the choice of α^* and β^* is quantified, the determination of λ_0^* based on an exact alpha test procedure can be accomplished solely by an iterative computer technique, thus eliminating graphical representation for all but instructional purposes. Otherwise, the use of a graphical representation appears to be a more practical approach to the determination of λ_0^*.

It is noted that in the descriptive examples in the main body of this report, a graphical representation based on Eqs. 1.2.1 and 1.2.4 was used in the determination of λ_0^*. The results of the examples, while correct, tend to be overly conservative; i.e., the time periods as calculated yield control charts of strengths exceeding the requirements of the specified (α^*, β^*, K^*) triplet. This, in addition to the non-uniqueness problem associated with the direct use of Eq. 1.2.1, lead to the exact alpha test procedure subsequently presented.

Topic Three: The Determination of the Roadway Length for a Fixed-Time-Period Control Chart

The problem of determining the roadway length for a fixed-time-period control chart is essentially similar to the problem discussed under Topic Two.

Let the number of accidents observed in fixed time period on a roadway of length L be Poisson with parameter λ. With this definition of λ in mind, the control chart systems discussed in Section 1.1 of Topic One apply directly. The decision rules of Section 1.2 apply with the modification that acceptance of H_0 leads to the conclusion that no change occurred in the causation process for the roadway of length L during fixed observation period T, and rejection of H_0 leads to the conclusion that a change in the causation process occurred for the roadway of length L during fixed time period T.

By thus specifying the (α^*, β^*, K^*) triplet together with the appropriate control chart system, it is possible to find a λ_0^* associated with the triplet (α^*, β^*, K^*). The exact alpha test procedure discussed in Section 2.1 applies directly to this case.

Thus, if m', with estimate $\hat{m}'$, is the expected number of accidents per unit length of roadway observed from actual accident experience on a time period of length T basis, the roadway length necessary to insure a fixed-time-period control chart of strength (α^*, β^*) for a K^* change in λ is

$$L_{\alpha^*,\ \beta^*,\ K^*} = \frac{\lambda_0^*}{\hat{m}'} \tag{3.0.1}$$

Topic Four: Optimum Trade-Off Between the Time Period and Roadway Length Subject to a Given Set of Constraints

Let us define the following value functions:

$U_T \triangleq f_1(T_i) \triangleq$ the value as a function of T_i of a control chart system of strength (α^*, β^*) when the control chart time period is T_i (4.0.1)

$U_L \triangleq f_2(L_i) \triangleq$ the value as a function of L_i of a control chart system of strength (α^*, β^*) when the roadway length is L_i (4.0.2)

Additionally, we define the following constraints on L_i and T_i:

$$T_i \leq T_{max} \qquad (4.0.3)$$

$$L_i \leq L_{max} \qquad (4.0.4)$$

If both constraints in Eqs. 4.0.3 and 4.0.4 can be satisfied for at least one paired value of T_i and L_i, the optimum trade-off between T and L for a control chart of strength (α^*, β^*) may be found by optimizing the function

$$f(T, L) = U_T T_i + U_L L_i \qquad (4.0.5)$$

subject to the constraints of Eqs. 4.0.3 and 4.0.4.

T_i and L_i in Eq. 4.0.5 are paired-values of time period and roadway length that insure a given control chart strength (α^*, β^*) associated with a K^* change in λ. A pair (T_i, L_i) is determined by evaluation of either Eq. 2.0.1 or 3.0.1 depending on whether T or L is considered fixed. The value $T_i = T^*$ and $L_i = L^*$ that maximize Eq. 4.0.5 thus yield the optimum trade-off of T and L for a control chart system of fixed strength (α^*, β^*). It is beyond the scope of this Appendix to discuss methods of maximizing Eq. 4.0.5.

The case might arise where T_{max} and L_{max} are so chosen that constraints in Eqs. 4.0.3 and 4.0.4 cannot be simultaneously satisfied for any paired values of T_i and L_i. In this case it is still possible to obtain "pseudo-optimum" trade-offs if we relax the appropriate constraint equation.

The regions of relaxation are depicted on an (L, T) space in Figure 5.

Topic Five: A Variable Weighting Scheme for Estimating the Accident Expectation

Consider the following weighting scheme (Brown, 1963, p. 101) for estimating the parameter λ of the accident process:

$$m = W \sum_{j=0}^{N-2} \left[(1 - W)^j y_{t-j-1}\right] + (1 - W)^{N-1} y_{t-N} \qquad (5.0.1)$$

where

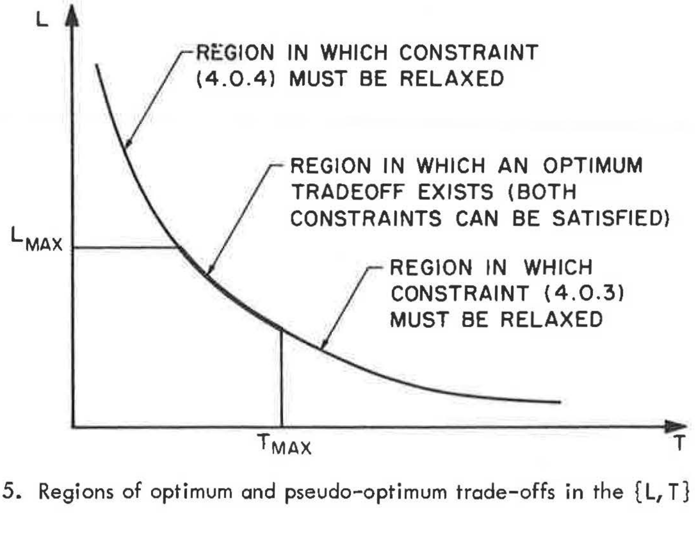

Figure 5. Regions of optimum and pseudo-optimum trade-offs in the {L, T} space.

W $\triangleq$ a weighting constant,

N $\triangleq$ the number of past time periods in estimating λ,

t $\triangleq$ the time period of interest,

j $\triangleq$ a dummy variable, and

y_i $\triangleq$ number of accidents observed in the ith time period.

The weight given to historical accident data decreases geometrically with the age of the data. With large values of W, data in the near past are strongly weighed in favor of further removed accident data, thus causing the estimate m to be highly sensitive to rapid fluctuations in the barometer of the accident process.

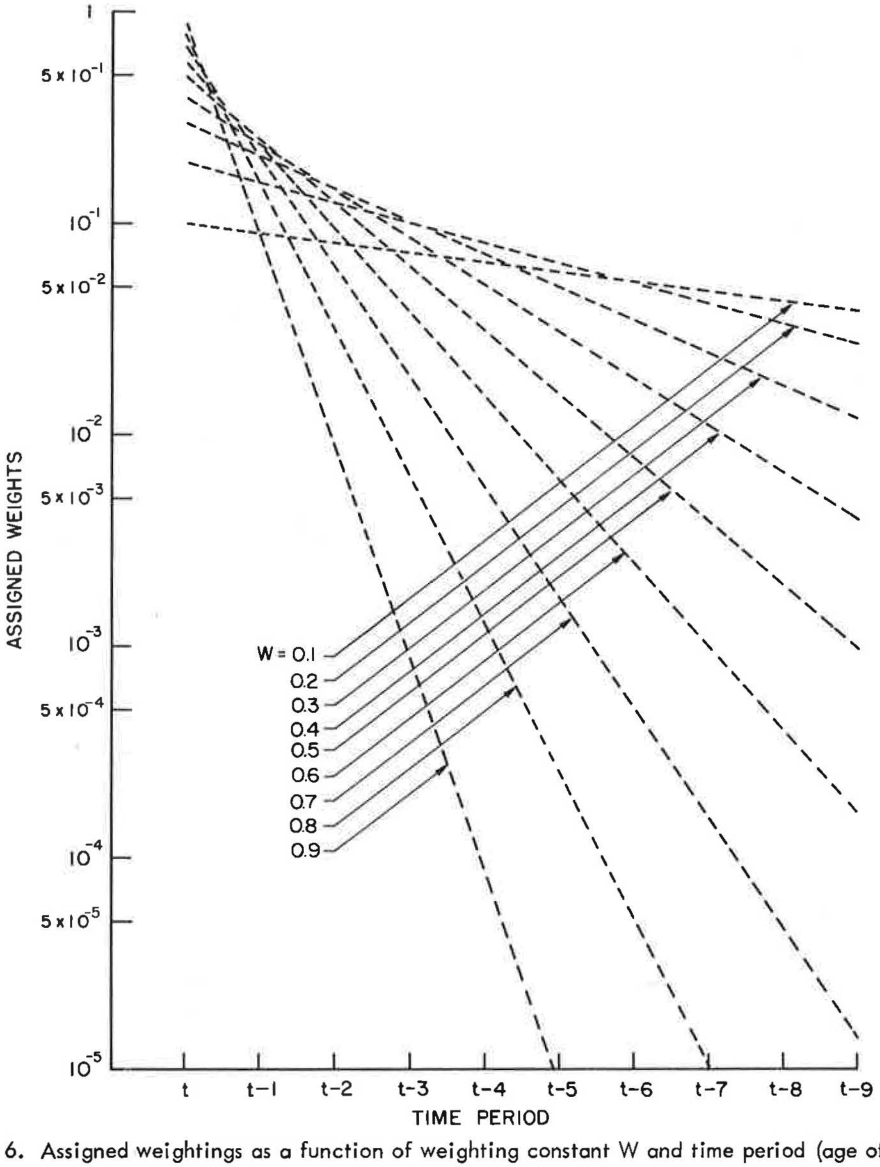

Figure 6. Assigned weightings as a function of weighting constant W and time period (age of data).

With small values of W, the estimate m behaves like the average of a large amount of historical accident data, and thus is less highly sensitive to rapidly developing changes in the barometer of the accident process than it would be if a large value of W were used. Figure 6 shows the variation of weights assigned to historical accident data as a function of age for weighting constants of 0.1(0.1)0.9.

Discussion

B. J. CAMPBELL, Director, The University of North Carolina Highway Safety Research Center—I appreciate the opportunity to comment on this attack on the problem of bringing statistical techniques to bear on the operational problems of accident control. I do not feel competent to judge the adequacy of the derivations and the statistical theory underlying this paper, but I have confidence in the authors' excellent reputations and am sure that they have buttressed their arguments with care. I hope that their work will continue to be supported.

Translating the best that science and mathematics can offer into a useful operational tool is not easy. In the present paper, it is clear that selection of values of alpha, beta, time, beat length and loss expectation (and any weighting system used) must be optimized, and I daresay that this can be accomplished only after extensive trial analysis of many data sets.

The authors mention a weighting scheme, one in which recent accident events count more heavily in the chart performance than more distant events. This weighting scheme applies to past accident experience as a means of calculating loss expectation. The procedure recognizes that some events are more relevant than others to detecting the system being "out of control." Other examples could be considered. If the chart is being used to guide police enforcement, then one might consider that accidents precipitated by flagrant violation of the law perhaps should count for more than other accidents, and thus entry of such an accident in the chart should have more effect in bringing the situation to an "out of control" state. The idea of dealing with sequential events in a way that takes account of degree of relevancy to the total situation is being studied at the Cornell Aeronautical Laboratory, and I suggest that the authors might contact Dr. Kihlberg of the Transportation Research Department there. The work of Dr. Kihlberg and the work of the present authors might harmonize usefully.

I would like to question whether there is a danger that this control chart system may give a false indication that an improvement has been effected. For example, if the accident situation on a given enforcement beat increases and the accidents go "out of control," and if an operational change in level of enforcement is made to bring the situation under control, is there not a likelihood that the subsequent time period has a high probability of showing an "improvement" because of a "regression to the mean" phenomena. If this is a theoretical problem, perhaps it is not serious in an operational context using proven countermeasures. However, in our field we have so few proven countermeasures and often we are in the process of evaluating rather than simply applying a countermeasure.

Finally, I would like to comment on the appealing possibility that we might after all be able to use accident frequency to make program decisions rather than having to deal with the troublesome problem of obtaining exposure data so as to generate accident rates. The reasoning goes something like this. Suppose that we have one road segment that causes ten deaths during a given time despite a low rate (but of course a high volume) on that road. We ask if this segment is more worthy of action than a second road segment that causes five deaths during the same period at a higher rate but a much lower volume. After all, we are trying to prevent accidents. There is, I agree, much appeal to this but I would like to express some doubts. For one thing, the frequency of accidents in a given place at a given time is just one quick look at a dynamic moving phenomena. For example, five fatal accidents per unit time on a high-rate facility with a low volume is a transient characteristic, and in a period of rapidly growing vehicle exposure the situation can change almost before there is time to impose effective countermeasures.

Another consideration has to do with the effect of the countermeasures not only on accidents, but on the whole stream of traffic. Suppose we have ten accidents on one facility, a low-rate high-volume facility, and eight accidents on another facility, a high-rate but low-volume facility. If we decided that our countermeasure was to be a very substantial reduction in allowable speed, then application of this countermeasure to the low-rate high-volume road would aim at somewhat more accidents but would also inconvenience large numbers of travelers. In this particular example, it seems that considering not only accident suppression but minimizing inconvenience to the non-accident traffic stream is necessary, and would dictate working on the high-rate but lower-volume facility.

As I have said, this paper represents an important and productive project that has already shown good results, and will no doubt produce more through the further exercise of theories being developed therein.

R. BRENNER, G. R. FISHER and W. W. MOSHER, JR., Closure—The authors would like to take this opportunity to thank B. J. Campbell for his pertinent remarks and suggestions concerning this paper. In his discussion, Campbell raised the question as to whether there would be, following an "out of control" situation, a high probability of the control chart system falsely indicating an "improvement" in the subsequent time period due to (a) operational changes in level of enforcement, and (b) "the regression to the mean" phenomena. We can briefly reply to his question in two steps.

Regarding the effects of operational changes in level of enforcement, two assumptions are implicit: that level of enforcement directionally affects accident generation and that the time lag associated with the effect of a change in enforcement is comparable to the control chart time period. Assuming these two assumptions hold, an "improvement," if detected by the system, would be an actual improvement.

If the term "regression to the mean" is interpreted as the tendency of an estimate to lag behind the true mean in a changing process, then there would be an increased likelihood of falsely detecting an "improvement," if the data point for the "out of control" time period were included in the set of sample values used to generate the estimate. However, since we do not include this "out of control" data point, "regression to the mean," as we have interpreted it, should not pose a problem in control chart applications.

Campbell also commented on the use of weighting schemes to estimate accident expectation. It should be pointed out that the choice of a particular weighting scheme generally arises from statistical considerations. This should not be confused with other measures which, for example, can be used to differentially weigh separate types of accidents as to their degree of importance or relevance in particular operational problems.

Campbell's final remarks are pertinent to the manpower allocation process in general and point out the necessity of evaluating trade-offs between sometimes conflicting goals and the necessity of considering value criteria in a rational approach to manpower deployment. It should be noted that the authors are presently engaged in the development of optimum allocation models utilizing the statistical techniques reported in this paper.

Application of Statistical Concepts To Accident Data

DONALD A. MORIN, Urban Transportation Planning Engineer, U. S. Bureau of Public Roads, Portland, Oregon

•THE concern being expressed nationwide over the highway accident toll has generated a flood of magazine articles, promoted legislation and encouraged discussion within technical circles as to what can and should be done. As might be expected, there is no pat answer or agreement on the solution. Some believe the solutions hinge on stricter enforcement, others on more and better driver education, others on improved highways, and still others on safer vehicles. There does seem to be agreement on one point, however, and that is the lack of adequate accident records to enable agencies to establish with desirable accuracy the occurrence of highway accidents.

The purpose of this report is not to propose a method for obtaining adequate records, but to suggest methods by which better analyses of the limited accident data can be made, and above all, to guarantee that erroneous conclusions are not drawn from the data at hand.

THE CASE FOR STATISTICAL CONCEPTS

Accidents are by nature rare events (a few occurrences per million vehicle-miles of travel). The universe in which they occur is extremely large (many hundreds of millions of vehicle-miles). As a statistician would say, "We are dealing with a small sample of a large population." Given these conditions, it is very easy to draw erroneous conclusions from accident data unless well-established statistical concepts are utilized which will enable the engineer to be assured of its significance.

Most highway and traffic engineers cannot lay claim to being very well trained in statistics. Our understanding of this subject, however, should be sufficient to enable us to recognize when there is a need to utilize the training of statisticians. The following cases are cited to illustrate the need to apply statistical concepts to the analyses of accident data.

In one state, priority listings of hazardous rural and urban highway sections were prepared by listing sections based on the observed accident rates from highest on down. A rural section one mile long that had only three accidents (none involving personal injuries or fatalities) ranked number four on the priority scale. Another one-mile long rural section that experienced 186 accidents with 89 personal injuries ranked number 47 on the priority scale! In the urban listing, a 0.2-mile section that had 66 accidents and 12 injuries ranked number 13 while another 0.2-mile urban section with 123 accidents, 70 injuries and 3 fatalities, ranked number 190!

In another state, the annual state highway accident report was prepared which lists by route the accident rate for every control section. Prior to the reports being submitted, someone had gone through them and underlined in red pencil all sections that had a rate of 10 or more accidents per million vehicle-miles. Examination of these red-penciled sections showed that many of the over-10 rates were obviously not significant or worthy of closer scrutiny because only one or two accidents occurred which, when coupled with low vehicle-miles of travel, produced high rates. There were other sections with rates slightly below 10 that did appear to be significant since there were high vehicle-miles of travel present, but these were not singled out by the red pencil underlining.

Paper sponsored by Committee on Highway Safety and presented at the 46th Annual Meeting.

The highway and traffic engineers for a certain city determined that the cure for the high number of accidents at a complicated intersection was the installation of overhead sign bridges, improved signals and some limited approach widening. During the 3-month period following the improvement project, a decrease of 8 accidents was observed. A press release was prepared titled "Intersection Made Safer" showing how" ______ 's most dangerous intersection at ______ apparently has been tamed." At the end of a still too short 8-month period, however, the picture changed. There were only 5 fewer accidents for a 12 percent decrease which was far short of the 38 percent needed to assure reliability. No press release or publicity was given to this.

The proper application of statistical concepts could preclude the pitfalls cited by giving the answer to such questions as, "How much variation in the accident rate should be expected as the result of normal chance variation?" or "How high must an accident rate be before it can be concluded that it definitely is above a tolerable limit that has been set?" or "How much of a reduction in the number of accidents must be experienced before it can be concluded that the improvement definitely helped?"

For the remainder of this article an attempt will be made to summarize statistical concepts that have been developed and applied to this problem area. It is interesting to note that many of these applications were developed over ten years ago, but, as yet, only limited use has been made of them.

FLUCTUATIONS IN ACCIDENT RATES

The Office of Technical Services of the U. S. Department of Commerce in 1958 distributed a report (1) which described a procedure for determining the amount of variation in the accident rate that could be expected due to chance probability for any highway control section. The input required is the overall accident rate for the highway and the number of vehicle-miles of travel on the highway control sections. By applying the following formulas, both upper and lower control limits on the overall accident rate are established for each control section:

$$\text{Upper Control Limit} = \lambda + 2.576 \sqrt{\lambda/m} + \tfrac{1}{2}m$$

$$\text{Lower Control Limit} = \lambda - 2.576 \sqrt{\lambda/m} - \tfrac{1}{2}m$$

where

λ = overall accident rate for the highway, and
m = number of vehicle miles of travel on a control section.

It is possible with the use of these equations to compare the observed accident rate for each control section with the control limits to determine whether the variation from the overall rate is greater than could be attributed to chance (Fig. 1).

In 1966, S. K. Dietz discovered an error in the original equations described in the Office of Technical Services report (1) and later articles in HRB Bulletins 117 (2) and 341 (3). The Appendix contains this comment by Dietz which shows how the validity of the equations is improved if the "correction term" 0.829/m as appears in the original equations is omitted.

The coefficient of the second term (2.576) in the equation assumes a ½ percent probability that either the upper or lower control limit could be exceeded by chance variation in the observed accident rate. Other coefficients may be used, as described in the Appendix, which would increase the probability that chance fluctuation in the observed rate could cause the control limits to be exceeded.

Notice the high observed rate for Point E in Figure 1. Due to low vehicle-miles of travel on this section, the control limits differ widely from the overall rate. It could be concluded that the apparently high rate at Point E is not worthy of investigation since it is within the range of variation that could be expected by chance. By comparison, see the observed accident rate at Point D. It does not appear to be very much higher than the overall rate and certainly is much lower than Point E, but the fact that it is outside the control limit for that section indicates that its variation from the overall

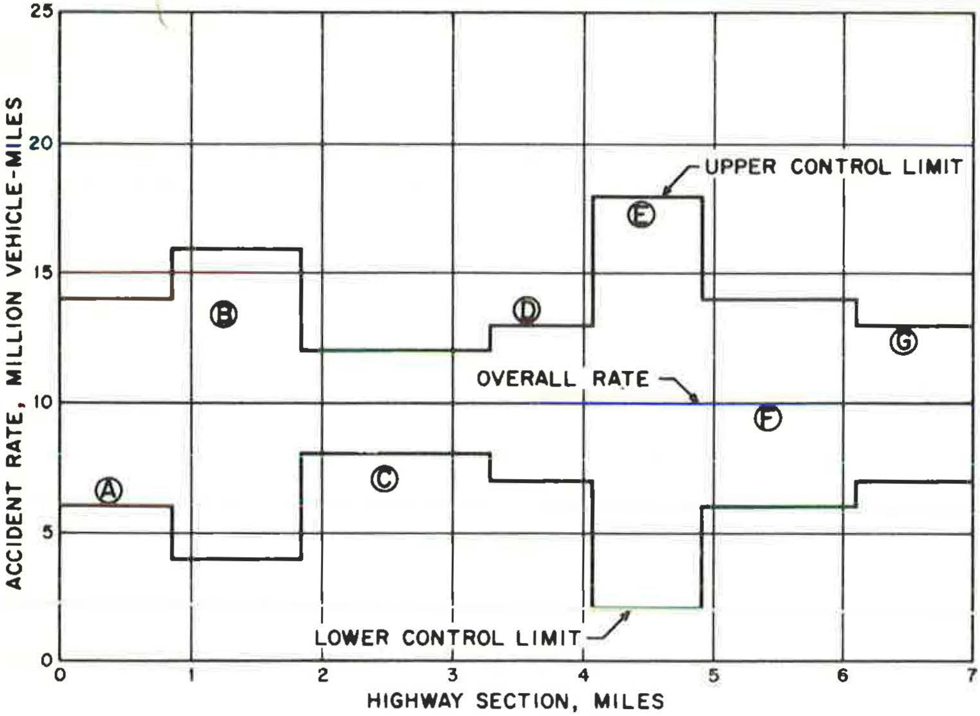

Figure 1.

rate is more than could be attributed to chance. In other words, something is definitely wrong and this section of road should be analyzed to find the reason. By the same token, the section indicated by Point C should be investigated since it can be concluded that something other than chance variation is present for this accident rate to be so much lower than average. Possibly, by finding out what is good, more insight could be gained and applied to other sections.

The article by Rudy (3) in 1962 describes the application of this technique to a route in Connecticut. The Montana Highway Department recently programmed this procedure for their IBM 1620 computer and successfully ran their 1965 accident data. The program prints out the upper and lower control limits and the observed accident rate for each highway control section. The results are incorporated in the 1965 Annual Accident Report by printing an asterisk alongside the computed accident rate for those sections that are out of control. Examination of the annual accident report shows that the procedure is not only identifying quite a few sections that are out of control with respect to the upper control limits, but also many that are "out" with respect to the lower control limit. Because it can safely be said that for those sections that are out of control the variation from the overall rate did not occur by chance, the next logical step is to conduct an investigation to find the reasons for the abnormally high and low rates.

An approach is under consideration which would assemble all possible data concerning the time and exact location of the accidents, the accident type, weather conditions, roadway alignment, cross-section details, and sight distance for those out-of-control sections into one report. A team consisting of possibly a traffic engineer, design engineer, maintenance engineer, and law enforcement officer could then study the assembled data and view the highway sections on the ground to try to determine the reason for the abnormal rates.

CRITICAL RATE ANALYSIS

A somewhat simpler application of statistical analyses to accident rate data that utilizes the same basic concepts, but approaches it from a different aspect, is being utilized in Idaho. It has been described in a 1964 report (4).

TABLE 1

MINIMUM ACCIDENT RATE TO ASSURE CRITICAL ACCIDENT RATE IS EXCEEDED
(Probability Level = 0.95)

Critical Accident Rate (acc/MVM)	Number of Accidents per Section					
	5	10	20	30	50	100
2.0	5.0	3.7	3.0	2.8	2.6	2.4
3.0	7.5	5.6	4.5	4.2	3.9	3.6
5.0	12.5	9.3	7.5	7.0	6.4	5.9
7.0	17.5	13.0	10.5	9.8	9.0	8.3
10.0	25.0	18.5	15.0	14.0	12.8	11.9

The procedure requires that a "critical accident rate" be selected. This could be thought of as the rate which has been determined to be the highest that can be tolerated. For any given critical rate, the procedure indicates the minimum accident rate that is significantly higher than the critical rate for any given number of accidents on the section. Table 1 gives values for different critical rates.

Figure 2 shows the values expressed graphically. With reference to the observed rates indicated by Points A through D and an established critical rate of 10 accidents per million vehicle-miles of travel, it can be concluded that the observed rate of 15 based on 10 accidents (Point B), and 13 based on 30 accidents (Point C), are not significantly higher than the critical rate of 10. The observed rates shown by Points A and D, however, should be attributed to something other than chance variation. The observed rate of 20 accidents per million vehicle-miles based on 10 accidents (Point A), and 14 accidents per million vehicle-miles based on 50 accidents (Point D), are significantly higher than the established rate of 10 accidents per million vehicle-miles.

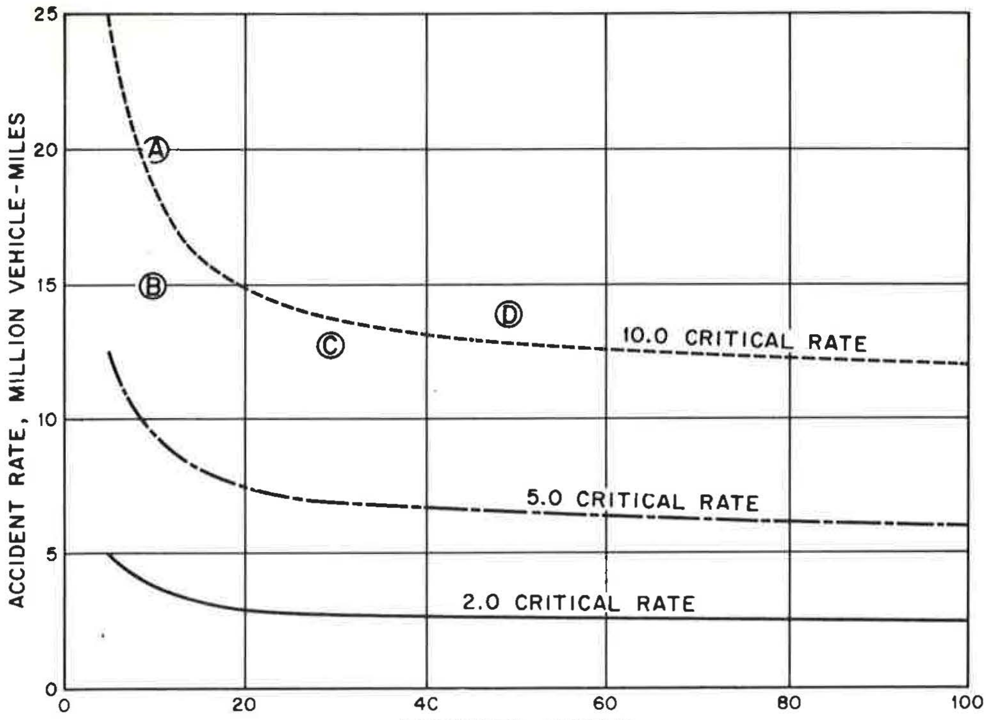

Figure 2.

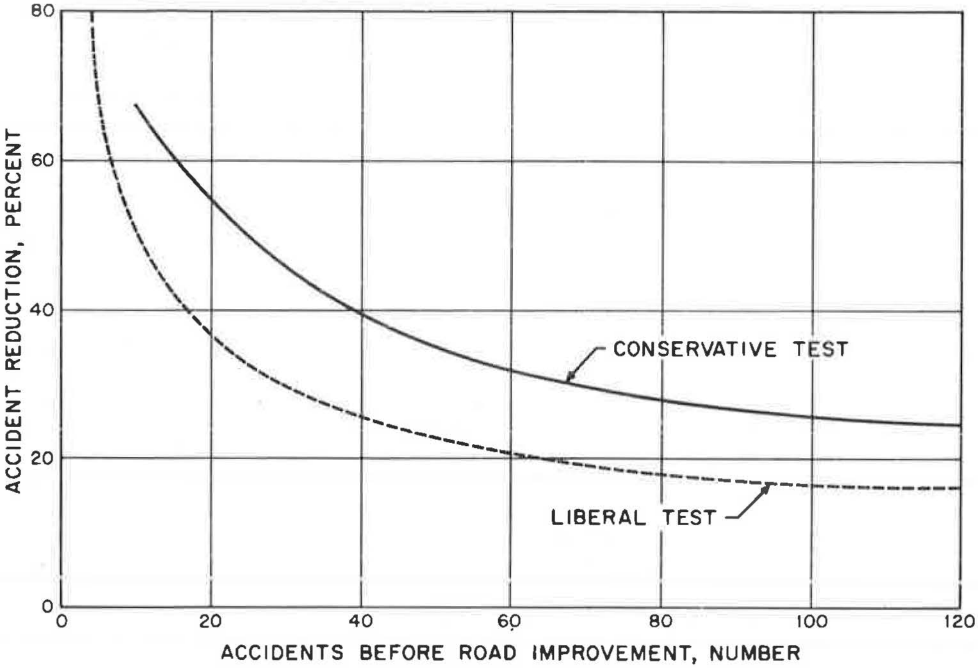

Figure 3.

While this procedure provides a quick method for identifying those sections that do have rates significantly above the predetermined "critical" or "tolerable" rate, it does not pinpoint sections with significantly low accident rates, thereby precluding the possibility of profiting from what is really good.

EVALUATING THE EFFECTIVENESS OF IMPROVEMENT PROJECTS

In 1959, R. M. Michaels published a procedure for establishing whether the percent reduction in the number of accidents "after" an improvement was made was statistically significant compared to the "before" situation (5).

The procedure considers the Poisson distribution as an appropriate approximation of the accident probability for what is called the "Liberal Test," and the chi-square test to determine whether the before and after samples differ significantly for what is called the "Conservative Test." One of the main advantages of this procedure is that the engineer can test for significance knowing only the number of accidents before the improvement was made and the percent reduction after. The test involves spotting this point on a graph (Fig. 3) to see whether the reduction is enough to be considered significant.

It is regrettable that a simple check, such as the one mentioned, has not been used more widely to permit definite conclusions to be drawn regarding the effectiveness of spot improvement projects. A recent memorandum from the U. S. Bureau of Public Roads (6) has drawn attention to the importance of this in evaluating the effectiveness of spot improvement projects. The September 1966 issue of "Traffic Engineering" contains a reprint of the procedure (7). With this recent publicizing of the procedure, it is hoped more use will be made of it by engineers.

CONCLUSION

The value of and need for application of the foregoing statistical concepts to analyses of improvements which were reported in recent issues of "Traffic Engineering" is worthy of comment. In one article (8) an author states: "While the small sample to date is not too significant statistically...." A check of the percent reduction in accidents (adjusted for differences in the vehicle-miles of travel) with the procedure recommended by Michaels shows that the reduction in the number of accidents is statistically significant by the "conservative" test.

Another article (9) states: "...the improvement in the accident experience clearly indicates that the...has eliminated, as much as possible, the hazards involved...." Checking the percent reduction shows that the reduction is not statistically significant.

By contrast, the authors of another article (10) state: "This result indicates that the program, as currently followed, does reduce the accidents significantly." This is one of the few articles on the subject where the writers have indicated that statistical tests to validate their conclusions have been made. It is evident that the authors of this article went to the necessary effort to assure that the conclusions they stated were valid.

The awareness of this need has recently been brought out by T. N. Tamburri in an excellent article (11) dealing with the problems of accident research. He states: "Another reason can be that the researchers do not establish controls that discriminate between chance variation... that is, the researchers may not understand the statistical and practical limitations of the data. The sixth pitfall, then, is the failure to establish statistical controls."

As traffic and highway engineers we have our work cut out for us. We cannot study each and every highway section in detail but, instead, will have to rely on statistical or quality control concepts, as have other disciplines, to weed out the relevant data from the mass of information. This will permit us to concentrate our limited professional manpower and financial resources in those areas that offer the greatest promise of "payoff." Certainly we cannot allow ourselves to draw unsound conclusions from accident data!

We are in a fortunate position. The techniques have been developed; all we have to do is apply them. A procedure must be found, however, to accelerate the use of these concepts over the pace of the past. The application of control limits to accident-rate data which Montana has just made operational was published originally in 1958; the critical-rate analysis procedure which Idaho started using in 1964 was developed in 1957, and the method for evaluating the effectiveness of improvement projects which has been emphasized in 1966 was published in 1959.

ACKNOWLEDGMENTS

The author especially wishes to express his gratitude to Stephen K. Dietz of Westat Research Analysts, Inc. for his efforts in discovering the error in the original equations and in reviewing the text of the Appendix for accuracy. The review of Dietz' work by Jesse Orlansky of the Institute for Defense Analyses, leading to agreement on the correction, was helpful in assuring that the equations indicated in this report are accurate.

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Appendix

CORRECTION OF EQUATIONS FOR UPPER AND LOWER CONTROL LIMITS

The use of statistical quality-control techniques for detecting accident rates which are significantly above average is presented in the report by Norden et al (2). The expression for approximating the upper control limit is given by the equation:

$$\text{Upper Control Limit} = \lambda + 2.576\sqrt{\lambda/m} + 0.829/m + \tfrac{1}{2}m \quad (1)$$

Or in general:

$$\lambda p = \lambda + k\sqrt{\lambda/m} + 0.829/m + \tfrac{1}{2}m \quad (2)$$

where k = 2.576 for P = 0.995 and

$$P = \text{Prob. } [\text{rate} \le \lambda p] \quad (3)$$

Eqs. 1 and 2 would actually be more accurate if the 0.829/m term were omitted, and become exact as $\lambda m \to \infty$ (12):

$$\lambda p = \lambda + k\sqrt{\lambda/m} + \tfrac{1}{2}m \quad (4)$$

Table 2 compares the approximations of Eq. 2 vs Eq. 4 with the true value from Eq. 5 for cases where the average number of accidents, a, varies from about 0.3 to 13 accidents for the 90 percent and 95 percent probability levels.

The true value of λp is

$$\lambda p\ (\text{TRUE}) = c/m \quad (5)$$

where c is the solution in

$$P = \sum_{x=0}^{c-1} \frac{e^{-a} a^x}{x!} = 1 - \sum_{x=c}^{\infty} \frac{e^{-a} a^x}{x!} \quad (6)$$

for specified values of P and a.

TABLE 2

COMPARISON OF EQ. 2 AND EQ. 4 WITH THE TRUE VALUE FROM EQ. 5

Probability Level	Avg. No. of Accidents ($a = \lambda$ m)	Error in Eq. 2 (%)	Error in Eq. 4 (%)
0.95	0.325	33	-8.5
0.95	1.970	12	-4.6
0.95	11.638	3	-1.4
0.90	0.530	40	-1.8
0.90	1.103	26	-1.7
0.90	12.820	4	-0.5

ALTERNATE DEFINITION OF CONTROL LIMITS

Eq. 4 provides an expression for the upper control limit, λp, which has a probability 1-P of being equaled or exceeded by chance. This is the definition used by Norden et al (2).

It is easy to forget that an accident rate is actually a discrete variable for a given value of m. For example, the accident rate for a section with m = 5 million vehicle-miles of travel during a study period can only assume the discrete values of 0, 0.2, 0.4, 0.6, . . ., etc., corresponding to 0, 1, 2, 3, . . ., etc., accidents.

If we wish to define the upper control limit, λp, as that which has a probability 1-P of being exceeded, then λp would be given by

$$\lambda p = \lambda + k\sqrt{\lambda/m} - \frac{1}{2m} \tag{7}$$

This is identical to Eq. 4, except that the sign of the $\frac{1}{2m}$ term is reversed.

By the same token, if we define the lower control limit, λp, as that which has a probability 1-P of being equaled or exceeded (by a more negative number) then λp would be given by

$$\lambda p = \lambda - k\sqrt{\lambda/m} - \frac{1}{2m} \tag{8}$$

If we wish to define the lower control limit, λp, as that which has a probability 1-P of being exceeded (by a more negative number) then λp would be given by

$$\lambda p = \lambda - k\sqrt{\lambda/m} + \frac{1}{2m} \tag{9}$$

ALTERNATE PROBABILITY LEVELS

The coefficient, k, of 2.576 in Norden et al (2) assumes a probability level for the upper and lower control limits of 0.990 or a $1-\overline{P}$ of 1 percent. Eq. 2, in discussing the upper control limit only, uses a k value of 2.576 for a probability level of 0.995 or a 1-P of ½ percent. The difference is whether we are talking about the probability of either or both of the control limits being exceeded.

If we use a k value of 2.576, it would therefore mean that 1 percent of the locations which have only a "normal" or "average" accident rate could be expected to fall beyond the control limits by chance even though there is nothing out of the ordinary about them, and that ½ percent of the locations which have only a "normal" or "average" accident rate could be expected to fall above the upper, or below the lower, control limit by chance even though there is nothing out of the ordinary about them.

Other coefficients which would change the probability of labeling a rate as out of the ordinary when it is in fact "normal" could be used as follows: (a) 2.576 for 1 percent false detection of both or ½ percent of either, (b) 1.960 for 5 percent false detection of both or 2½ percent of either, (c) 1.645 for 10 percent false detection of both or 5 percent of either, (d) 1.440 for 15 percent false detection of both or 7½ percent of either, and (e) 1.282 for 20 percent false detection of both or 10 percent of either.

Motorcycle Accidents—An Epidemic

JOHN J. O'MARA, Associate Professor, Civil Engineering, University of Iowa

•APPROXIMATELY 1580 drivers and passengers of motorcycles and motor scooters were killed during 1965 in traffic accidents in the United States. Although this toll was but 3 percent of the 49,000 killed in all motor vehicle accidents, it was more than the military fatalities in Viet Nam in 1965, and it is growing at a very alarming rate.

Motorcycle[1] fatalities have been increasing at a much faster rate than total motor vehicle deaths, although the latter have risen from an annual toll of 38,000 in 1961 to 49,000 in 1965 (Fig. 1). Even more striking is the comparison of motorcycle occupant deaths to those of the occupants of all motor vehicles (Table 1 and Fig. 2). Motorcycle deaths rose 41 percent in 1965 from 1118 in 1964.

The situation is epidemic for the nation as a whole as Dr. James C. Drye determined it to be for Louisville and Jefferson County, Kentucky, and as did Drs. Dillihunt, Maltby and Drake for Portland, Maine (2, 7). There were 23 deaths in Iowa and 276

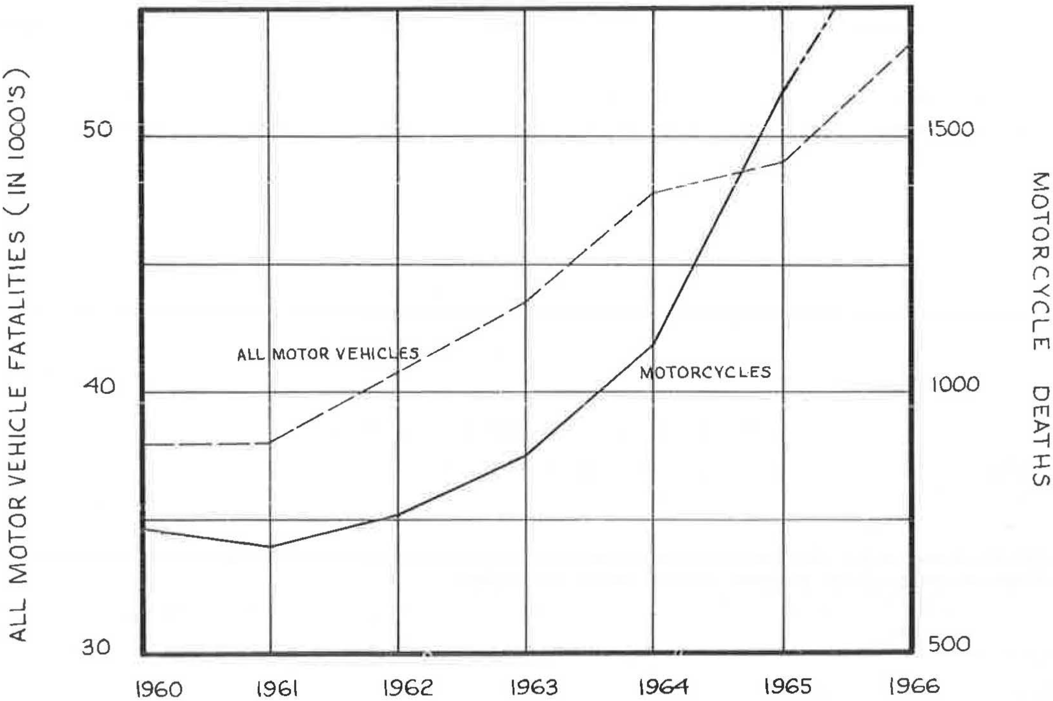

Figure 1. All motor vehicle fatalities vs motorcycle deaths.

[1]In this paper the term motorcycle is used to include the motorcycle proper, the motor scooter, the moped, and the mini-bike.

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TABLE 1

MOTORCYCLE AND TOTAL MOTOR VEHICLE DATA[a]
(1960-1965)

Year	Vehicles				Deaths			
	Motorcycles		Total Mot. Veh.		Motorcycle Riders		All Mot. Veh. Occupants	
	No.	Yearly Change (%)	No.	Yearly Change (%)	No.	Yearly Change (%)	No.	Yearly Change (%)
1965[b]	1,380,726	+30.8	91,300,000	+4.6	1,580	+41.3	39,400	+4.0
1964	984,763	+25.2	87,300,000	+4.6	1,118	+26.8	37,885	+9.2
1963	786,318	+19.1	83,500,000	+4.8	882	+16.2	34,694	+7.4
1962	660,400	+10.9	79,700,000	+4.3	759	+ 8.9	32,311	+8.2
1961	595,669	+ 3.5	76,400,000	+2.6	697	- 4.7	29,886	+0.4
1960	574,080		74,500,000		730		29,742	

[a]Source: Vehicles—U.S. Bureau of Public Roads; motorcycle riders—National Center for Health Statistics; motor vehicle occupants—National Safety Council. "Motorcycles" includes motor scooter, motorized bicycle, and motorized tricycle.
[b]Estimated.

fatal accidents in California (9). There are brief periods of remission during extremely cold weather followed by onsets of greater intensity.

The growth in motorcycle accidents is a direct result of growth in numbers and in use of these vehicles. The number of vehicles and the number of deaths have doubled in three years (Fig. 3). There is undoubtedly a correlative increase in vehicle-miles, but no records are kept of these data in the United States. (Even casualties often are not tabulated separately but recorded simply as motor vehicle deaths and injuries.)

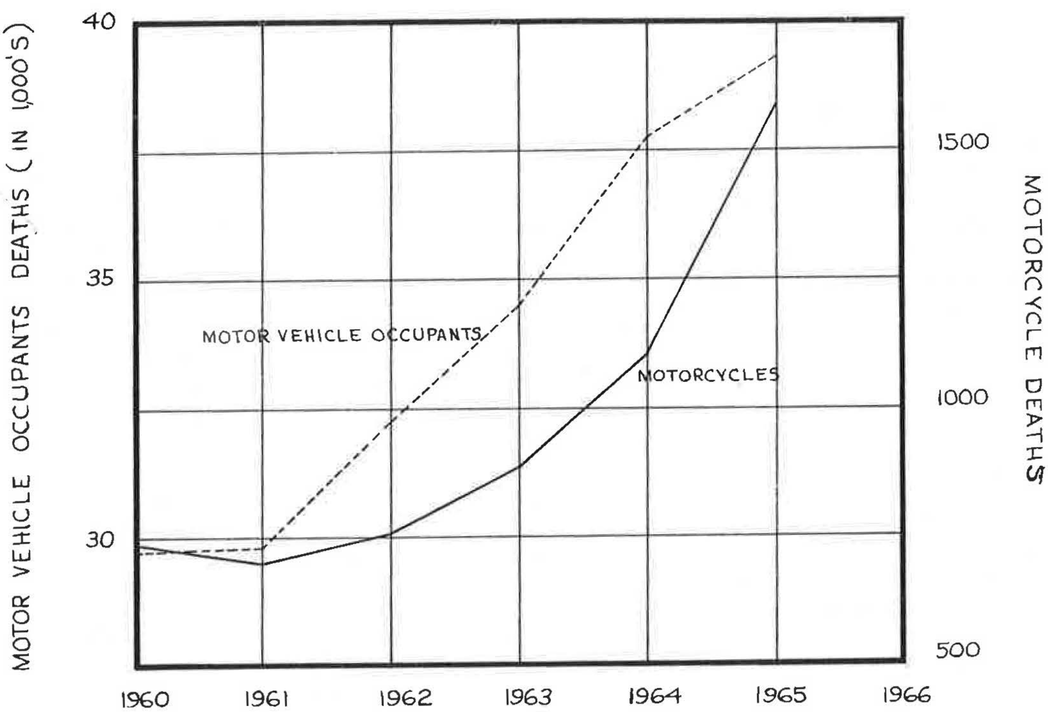

Figure 2. Motor vehicle occupant deaths vs motorcycle deaths.

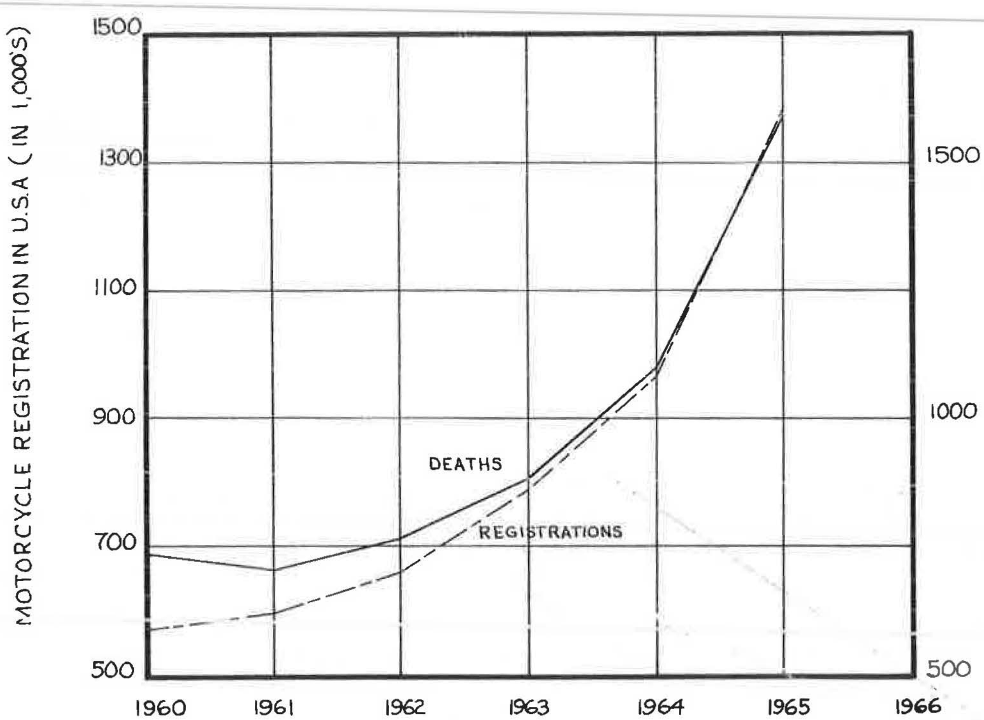

Figure 3. Motorcycle registration in USA vs motorcycle deaths.

INCREASED AVAILABILITY

Other developments compound the danger of the increased number of motorcycles. Until recent years, the machine used in the United States was the American-made motorcycle—a large heavy machine with a big frame and wide wheels. These were relatively expensive, some models as costly as small cars, and available only by outright purchase. The situation began to change several years ago with the importation of the glamorous motor scooter of postwar Europe. This started an increase in the number of vehicles and a concomitant deterioration of quality, first characterized by the importation of the lighter European motorcycle, and then by the swamping of the American market with the very light, fragile, and cheap Japanese machines. Now, American and European manufacturers are producing similar machines and all are coming to resemble the "moped" (motor-assisted pedal bicycle), but with a much greater power plant. A recent import vehicle weighs 180 lb and can achieve a velocity of 65 mph carrying a 200-lb passenger (3).

The corresponding reductions in cost have brought the motorcycle within the reach of millions of Americans who previously could not afford much more than a simple bicycle, to say nothing of the more expensive American motorcycles. Some contemporary imports are priced under $300, and American chain stores are selling models for less than $200. Furthermore, cycles can now be purchased or rented on terms that are very tempting. Rental machines are available at $1.00 an hour, and purchasing can be arranged for as low as $5.00 down and $10.00 a month. The rental business has boomed during the past few years, catering almost exclusively to teenagers seeking thrills. The low-cost purchase terms seem to induce many young adults to buy cycles for both recreation and daily commuting. Thus, recent years have seen not only an increase in the number of motorcycles, but also an equally large increase in the number of inexperienced drivers, and a great decrease in the quality of the vehicle, especially in its capacity to absorb some of the forces of collision.

The growth in the popularity and use of the motorcycle in recent years has been engendered, in part, by its establishment as a glamorous social symbol (12). This was further fostered and compounded by the consequent adoption of the motorcycle as an advertising symbol to induce buying interest in a variety of merchandise from soft drinks to women's clothes. Even one insurance company used the motorcycle symbol in advertisments for life insurance.

OTHER FACTORS

The driver, the vehicle, and the distance driven are the primary factors affecting the number and severity of cycle accidents. Road conditions and weather have about the same relationship to these accidents as they do to all motor vehicle accidents. The majority of traffic accidents occur on straight, level sections of highway, in daylight, clear weather, and on dry pavement. In these respects, motorcycle accidents seem to be no exception in general, although cycle operation is more affected by adverse weather and roadway conditions.

There may be a disproportionate number of cycle accidents in urban areas. In 1962, motorcycle accidents in New York City alone accounted for nearly 41 percent of all cycle accidents in the state, despite the fact that the city accounted for only 25 percent of all motorcycles registered in New York (Table 2).

The most meaningful index or rate of accident experience available is that which measures the accidents or their severity against the distance traveled—the latter usually expressed in units of million vehicle-miles, 100 million vehicle-miles, or simply miles driven. There is little motorcycle information of this sort available in the United States. Great Britian, however, devotes much attention to motorcycle statistics, because nearly one-fifth of those killed on British roads and streets are motorcyclists and their passengers. The British Road Research Laboratory made an exhaustive study of all vehicle accidents in Great Britain for the years 1954 to 1959. The study included accidents involving more than 300,000 deaths or serious injuries to motorcyclists, comparable numbers of accidents involving other motor vehicles, and billions of miles traveled by motorcycles and other vehicles (4, 5).

The British study revealed the following about motorcycle accidents:

1. The chance of a motorcyclist being killed per mile ridden is about 20 times the chance of a car driver being killed.
2. The risk of death or injury to a (pillion) passenger is about 5 percent higher than the risk to the driver.
3. The personal-injury accident rate of solo motorcycles is about four times and that of motorcycles with sidecars about twice as great as that of cars.
4. Ninety-seven percent of the total casualties in collisions between motorcycles and cars or trucks are motorcyclists.
5. Most of the motorcyclists who are killed and many of those who are injured receive head injuries.
6. Motorcyclists with less than 6 months' experience have about twice as many accidents per head and per mile ridden as those with more experience.

TABLE 2

MOTORCYCLE ACCIDENTS, NEW YORK STATE, 1962

Type	Registrations	Deaths	Death Rate[a]	Injuries	Injury Rate[a]
All vehicles	5,583,656	2,407	4.3	287,048	514
Motorcycles	16,839	32	19.0	1,226	728

[a]per 10,000 registrations.

Note: New York City had 515 motorcycles involved in accidents out of a statewide total of 1,265, or 41 percent of the total, although having only 4,430 registered motorcycles, or 26 percent of the state total.

Source: New York State Department of Motor Vehicles.

THE VICTIMS

As frightening as the last conclusion is, it hardly touches the typical inexperienced driver situation in the United States. In Iowa, as in many states, the only legal control on the operator is that he is required to have a driver's license (for driving a passenger auto). William F. Sueppel, former State Safety Commissioner of Iowa, said, "In too many cases, youngsters 16 or 17 years old are renting motorbikes or motorcycles without any knowledge of the difference in their operation and the operation of cars which they learned to drive (previously). The problem is further compounded when passengers are put on these vehicles."

Dr. Drye says, "The individuals who are being injured are largely high school and college people. They are not 'leather jacket boys'." Drs. Dillihunt, Maltby and Drake, of the Maine Medical Center, say, "A most distressing fact is that the group involved are young, otherwise healthy persons. This is not an epidemic involving the aged or the infirm—rather it involves a group of young, healthy people who must be regarded as a most important group in our society."

MOTIVATION

The victims are primarily the users, and, as was noted earlier, much use of the motorcycle in America is for recreation, some use even being in the category of seeking thrills from the danger involved in driving and riding these vehicles. There is a small amount of productive usage through commuting and work trips.

However, most use is casual, well intentioned and not vicious in any sense. "They are mostly children whose parents are able to buy them cycles and, unsuspecting of the danger, think it would be nice for them to have cycles during the summer to ride to tennis courts, swimming pools and other recreational areas. These bikes are inexpensive and fun to drive" (2).

Parental approval often comes only after initial strong objection. Drs. Dillihunt et al say, "In many of our cases, parents were opposed to their offspring having such vehicles. After considerable pressure, the parents reluctantly agreed. When an accident occurred following such a situation, the psychological problems were tremendous."

THE SEVERITY OF INJURIES

The motorcycle accident victim (4) is more likely to be killed or severely injured than any other vehicle user (Table 3). Every reported motorcycle accident in Iowa City in the first 11 months of 1966 involved personal injury. Dr. Drye says, "I have treated a number of these injuries; they are bad. The only ones comparable to them are the battlefield injuries due to artillery fire that I saw in the infantry and the field hospitals of World War II."

TABLE 3

SEVERITY OF INJURY TO DIFFERENT CLASSES OF ROAD USER CASUALTIES

Class	Severity of Injury: $\frac{100 \times \text{Fatal Casualties}}{\text{Total Casualties}}$	Severity of Injury: $\frac{100 \times \text{Fatal and Serious Casualties}}{\text{Total Casualties}}$
Pedestrians	3.7	30
Pedal cyclists	1.3	21
Moped riders	1.5	27
Motorcyclists	2.1	31
Motorcycle passengers	1.6	24
Drivers	1.6	22
Passengers	1.2	20
All road users	2.0	25

Source: Research on Road Safety, British Road Research Laboratory.

TABLE 4

MECHANISM OF INJURY

Type	No. of Patients
Lost control of vehicle and overturned	14
Hit another vehicle (automobile)	16
Hit or swerved to miss a dog	2
Fell off vehicle (passenger)	3
Pedestrian struck by vehicle	1
Miscellaneous	2

TABLE 5

AGE GROUPS

Age	No. of Patients
15 to 20 years	23
21 to 25 years	11
26 to 30 years	2
Over 30 years	2

TABLE 6

TYPE OF INJURY

Type	No. of Patients
Major head and neck injury	9
Extremity fractures	13
Upper extremity (2 simple, 1 compound)	3
Lower extremity (4 simple, 6 compound)	10
Spine fractures	2
Pelvic fractures	2
Intra-abdominal injury, severe	2
Miscellaneous soft-tissue injuries without other injury	19

The experience at the Maine Medical Center in Portland, with motorcycle accident victims during the four months, May through August 1965 inclusively, reveals a total of 38 such victims. Of this total, there were 27 drivers, 10 passengers, and a single pedestrian. The mechanism of injury is given in Table 4, the age groups in Table 5 and the type of injury in Table 6. There were three deaths in this group; they are briefly described next. Also presented is a nonfatal case with a particularly serious outcome.

REPORT OF CASES

Case 1

This 23-year-old woman was driving a small-type motorcycle which was hit from behind by an automobile on May 23, 1965. The patient was brought to the emergency room unconscious. She died a few hours later despite vigorous emergency therapy. Postmortem examination revealed cerebral contusion, massive subarachnoid hemorrhage, and retroperitoneal hematoma (severe concussion, hemorrhage into the brain and internal bleeding).

Case 2

This 24-year-old man was a passenger on the vehicle driven by the woman described in Case 1. He was thrown from the vehicle and killed almost instantly. Postmortem examination disclosed transection of the abdominal aorta, fractures of the spine, fractures of the right tibia and fibula, separation of the symphysis, and subarachnoid hemorrhage (ruptured aorta, multiple broken bones, hemorrhage into the brain).

Case 3

This 19-year-old girl was riding a motorcycle on July 22, 1965, and struck a dog. She lost control of the vehicle and was thrown to the road. Shortly thereafter she was seen by a physician who noted a dilated, fixed right pupil and hemiparesis on the left. The patient was transferred to the Maine Medical Center where immediate exploration revealed an acute subdural hematoma accompanied by severe cortical contusion and laceration. She died of these injuries shortly thereafter (brain lacerations and hemorrhage beneath the lining of the brain).

Case 4

This 17-year-old girl was given a small motorcycle as a present on her 17th birthday. One day later, on July 30, 1965, she was involved in an accident which resulted in almost three months' hospitalization. When discharged, she was blind, disfigured and paraparetic (partially paralyzed).

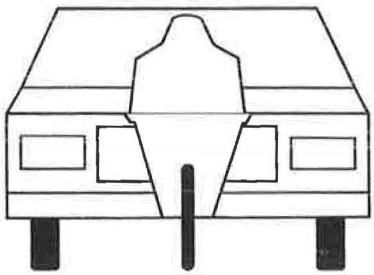

Figure 4. Silhouette comparison, motorcycle and passenger car, end view.

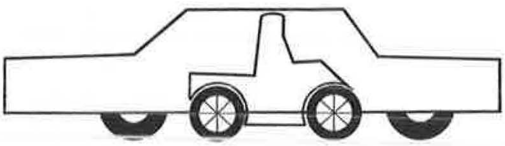

Figure 5. Silhouette comparison, motorcycle and passenger car, side view.

THE MACHINE

The motorcycle in general use in the United States today is a small vehicle with a wheelbase of about 4 to 5 ft. It varies in weight from less than 100 lb to approximately 600 lb, has engines which develop from 2 to more than 60 hp, and is capable of speeds from 35 to well over 100 mph. (A small number of vehicles, mostly those in professional use, are of the older type and may weigh more than 1000 lb.) Generally, the weight-to-horsepower ratio and the weight per occupant ratio are very unfavorable for safety. In front, side or rear elevation it presents a very small, narrow silhouette even with driver and passenger (Figs. 4 and 5).

The vehicle fatality rate, 11.5 per 10,000 vehicles, is approximately 2.7 times as great as the corresponding rate, 4.3, for all motor vehicle occupants. On a vehicle-mile basis the motorcycle is 20 times as deadly.

Although it develops some inertial stability when in motion, it is unstable to a high degree. It cannot stand alone on its own two wheels—the driver has to hold it up. It skids easily, often "walks" on its rear wheel alone, and frequently goes out of control. The vehicle is not heavy enough or strong enough to absorb in a collision even a fraction of the energy created by itself and its motor.

The lateral balance of the vehicle is very precarious. A very small lateral force is enough to destroy equilibrium either by an overturning moment or by exceeding the friction between the tires and the pavement. The tire print is very small. The overturning moment or sidewise skid often is produced by the moment or horizontal component of the weight when the vehicle is slightly inclined from the equilibrium position.

The driver and passenger are completely exposed with neither envelope nor effective shield for protection. The only security afforded the driver is his grip on the handlebars, with the consequence that he is often thrown violently into or over the colliding vehicle. The passenger, of course, has practically no security at all—only a fragile hold on the driver.

THE ENVIRONMENT

There is little doubt that the environment is hostile to this machine. In the planning, design, construction and operation of roads and streets in the United States no attention whatsoever is given to this vehicle. It is an incongruity in our traffic streams. The smallest design vehicle considered in AASHO policy is the "P Vehicle" (passenger car), 19.0 ft long and 6.5 ft wide (Figs. 4 and 5).

There are a number of elements of roadway design and traffic control which are affected by this vehicle. All aspects of sight distance would be modified if the difficulty of seeing, and seeing from, this vehicle (the height of the driver's eye and the lighting of the vehicle both front and rear) were considered. Design policy governing safe passing maneuvers and passing sight distances is based on a car driver seeing an object 4.5 ft high at varying distances up to approximately 2000 ft. If the vehicle sighted is a motorcycle, only a small portion of the driver's head, at most, would be visible over the crest of a vertical curve, virtually impossible to detect at such distances. Its lack of stability would have an important bearing on such policies as safe following distance—this vehicle can and often does stop almost instantaneously when its tires slip sidewise and the vehicle and occupants fall to the pavement. Similarly, highway capacities, superelevation of curves, design of longitudinal profiles and many other factors would be affected.

If other motor vehicles and their drivers are included in the environment, it becomes more hostile. In a large number of collisions between cycles and other vehicles the driver of the car or truck is charged with a traffic violation. There are various aspects of this situation, but one is that the ordinary driver's vision and mind are not trained or disciplined to watch for and recognize a cycle, its speed or distance. The colliding car or truck, being several times heavier and stronger than the cycle, imposes most of the damage on the cycle and its occupants. A very common comment of the motor vehicle driver is, "I didn't even see it."

OUTLOOK FOR THE FUTURE

The number of motorcycles on United States roads doubled in three years to a total of 1,380, 726 in 1965 and the deaths of motorcycle riders also doubled in the same three years (Table 1). Sales of vehicles continue to soar, and it is likely that the total population will be approximately 2,000,000 vehicles at the end of 1966. The corresponding fatality toll may be 2000 or more.

The motorcycle population is nearing 2 percent of the total vehicle population, and the cycle death toll is approaching 4 percent of the total. However, the outlook is even more disturbing. Annual sales of cycles and scooters may soon exceed 1,000,000. Two foreign producers, to say nothing of all the others, expect to export a million vehicles a year to the United States within a short time. One exporter predicts United States motorcycles will total 5,000,000 by 1970, a conservative estimate (13).

Sales of 1,000,000 cycles per year would approximate 10 percent of all vehicle sales in the United States, and this would raise the motorcycle population toward 10 percent of the total population, or approximately 10,000,000 cycles, in a few years. The prospect of the corresponding increase in deaths and serious injuries is very frightening. Motorcycle fatalities probably would rise to more than 10,000 per year if the present rate of 11.5 deaths per 10,000 vehicles is not materially reduced.

REMEDIAL MEASURES

Epidemiology applied to accidents considers three principal parts to the problem: man, machine and environment. Using this approach to the motorcycle accident problem reveals the outstanding causal factor to be the machine, or, to put it properly as Dr. Drye does, the etiological agent is the motorcycle itself.

The motorcycle is the most deadly vehicle on the highway today, and this ghastly characteristic is inherent in the machine. The most logical remedial measures, then, would be those directed at modifications of the machine to make it safe, or the elimination of it from the public highway, or narrowly restricting its public use to specific functions such as police work, and then only with some safety modifications.

There is some small measure of relief possible through driver training and increased experience and through the use of protective equipment, particularly proper helmets. However, the resulting improvements will fall short of objectives, because British and European experience indicates that although such measures have a benefical effect, motorcycle accidents continue to be a very serious problem and a very sizable part of the traffic accident situation. In Europe and elsewhere economic necessity often forces a man to accept the risk of riding a motorcycle in order to go out and make a living, but few Americans can justify the gamble.

A fundamental approach to the problem can be made through engineering and through recently opened avenues of action. There are agencies of the government now charged with assessing the safety characteristics of motor vehicles and establishing safety requirements for all vehicles sold. These agencies could contribute materially to highway safety if they would establish standards and criteria for the vehicle as a whole as well as for some of its parts. These should include, certainly, the number of wheels and their arrangement, which would be required of all vehicles for stability. They should specify the general nature of a body or envelope to protect the occupants of the machine. Along with a protective envelope they should require restraining devices for the drivers and passengers of all vehicles including cycles and scooters. Provisions now specified to preclude occupants being thrown to the pavement during an accident should be extended to all vehicles. A minimum silhouette area must be specified because vehicle operation depends on visual images.

A small measure of temporary relief might be achieved in a shorter time through enforcement measures. A motorcycle driver should be required to have a license specifically for driving a motorcycle. In order to secure this license he should be required to demonstrate his proficiency by virtue of a driving test using a motorcycle. He should be required to have completed a driver education course, accredited by the proper public agency, in motorcycle driving. Laws and ordinances could prohibit the carrying of passengers—this would have a direct effect and probably an indirect effect in reducing usage. An insurance requirement for the passenger would have the same effect, for such insurance is virtually unattainable because of the high risk. Protective gear should be required including helmets, goggles and shielding for the legs. In sum, any measures which would reduce usage and increase responsibility would probably produce some temporary relief.

The absolute danger remains, however, and actually is illustrated by these attempts to make an accommodation with these deadly devices. The danger is so great that no safety authority is willing to propose that a driver-examining patrolman ride the vehicle which the driver is using in his test, as is done in auto driver licensing.

The rental of motorcycles and motor scooters serves no useful purpose and should simply be eliminated. The business not only does nothing useful, but it presents a danger to the health and welfare of the public, especially to the youngsters who are more susceptible to the temptation of a cheap ride with plenty of thrills. Specific legislation would help eliminate these sources, but communities in most states probably could close them down under existing ordinances as public nuisances, or as hazards to the health of the community. Communities could accomplish the same end by licensing the dealer and requiring him to be responsible for injuries and to carry injury insurance on the drivers and passengers.

SUMMARY AND CONCLUSIONS

The motorcycle accident situation is serious, growing and epidemic in the United States. The etiological agent, or causal factor, is the machine itself.

The motorcycle is the most deadly vehicle operating on the public highway. It is unstable and completely exposes driver and passenger to the injurious forces of collisions. The fatality rate is 11.5 fatalities per 10,000 vehicles, which is 2.7 times as great as the rate for all motor vehicle occupants. Extensive research in Great Britain has shown that, per mile driven:

1. The chance of a cyclist being killed is 20 times that of a car driver.
2. A passenger on a motorcycle has an even greater chance of being killed than the cyclist.
3. The personal injury rate is about four times that of cars.
4. Cyclists with less than six months' experience have an accident rate double that of the more experienced.

The growth in casualties in recent years is directly attributable and proportional to the growth in numbers of motorcycles. The fatality toll and the vehicle population each doubled in the three years 1962 to 1965 and the growth rates continue to accelerate. The fatality total for 1965 is estimated at 1580, having increased 41 percent in one year.

There is no end in sight. The number of registered motorcycles in the United States grew to 1,380,726 in 1965, and sales of new vehicles are soaring. Sales probably exceeded 500,000 units in 1966 and soon may reach 1,000,000 units per year. These trends indicate that the cycle population may become something of the order of 10 percent of the total vehicle population. The resulting toll of deaths and injuries would constitute a calamity. Deaths alone might exceed 10,000 per year.

A small measure of temporary relief could come through strong enforcement actions such as driver licensing specifically for motorcycle driving, elimination of passengers, strong insurance requirements, and other measures to reduce usage and increase responsibility. A general program of informing the public of the extreme danger involved in driving or riding a cycle or scooter could be beneficial. Rental availability serves no useful purpose, constitutes a serious health hazard, and should simply be eliminated.

Permanent relief will come only through recognition of the absolute danger inherent in the present machines. A fundamental approach to a solution is possible through engineering and through control now available through governmental agencies charged with establishing policies and standards for the safeness of vehicles. These agencies should specify requirements for the motor vehicle as a whole as well as for some of its parts. They should determine the number of wheels necessary to insure stability and the arrangement and configuration of the wheels. A protective envelope or body should be required and the progressive collapse of its outer portion during an accident should protect the occupants from dangerous decelerations. Restraining devices and anti-ejection devices should be provided.

Such a policy to establish the safeness of the vehicle as a whole would culminate in the modification of the motorcycle to make it safe, or it would eliminate the motorcycle from the traffic stream. Either alternative would reduce the intolerable suffering and death now imposed, primarily on young men and young women.

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Surveillance of Accident Locations by Electronic-Processing Methods

RICHARD N. SMITH, Associate Highway Engineer, California Division of Highways

THE continual surveillance of the highway system for accident concentration locations, although a long-established procedure, has received increased emphasis in recent years. California had 115,453 reported accidents on the 14,200-mile state highway system in 1964. The large amount of data that must be processed has indicated the need for new and improved methods.

The ultimate objective of any surveillance system is to accomplish the greatest possible reduction in accidents using available funds. This objective is essentially reached by a three-step process:

1. Determine locations where concentrations of accidents are accumulating;
2. Of the locations identified, determine which are experiencing an excessive number of accidents; and
3. Of the locations experiencing an excessive number of accidents, determine which are susceptible to accident reduction and by how much.

This study was largely directed toward the first step. The present methods of hand-posting and visually inspecting accident-profile charts or index cards are tedious and require considerable manpower and time. The surveillance listings will free personnel from this largely bookkeeping task.

The second step is partially covered in this study. Listings of three types of concentration locations (ramps, intersections, and open highway) are arrayed by accident rates and by number of accidents. Neither listing (accident rates or number of accidents) provides the full answer. A location with little traffic may have a very high rate, yet have had few accidents. A location with a large number of accidents may also carry a large volume of traffic and the number of accidents may not be excessive. What is required, of course, is a standard of comparison, i.e., an estimate of the number of accidents that can be expected. Any location, such as a signalized intersection with left-turn lanes and separate left-turn signal phases, should be compared with all other similar locations to determine if the location under study has had more accidents than the average of all such similar locations. Other variables, such as traffic volumes and approach speeds, also have to be considered.

The third step is to determine how bad the location is in comparison with the proposed improvement. This requires that a reasonable prediction of future accidents be made. The estimate of accidents preventable, along with the cost of the improvement, is an important step in establishing priorities of improvements.

It was determined early in the review of this subject that more research was required to estimate expected accident experience at existing locations or to predict accident experience at proposed locations. Several studies are now under way that will help answer these questions.

BACKGROUND

A review of how accident information is now processed and used, both at the Headquarters and district levels, was made. Close coordination with the districts was maintained throughout the developmental stage.

Paper sponsored by Committee on Highway Safety and presented at the 46th Annual Meeting.

January 1965 — **ACCIDENT CODE** — Sheet 1

DISTRICT
1

A	Dist. 1	G	Dist. 7
B	" 2	H	" 8
C	" 3	J	" 9
D	" 4	K	" 10
E	" 5	L	" 11
F	" 6		

COUNTY
2, 3

01	ALA.	21	MRN.	41	S.M.
02	ALP.	22	MPA.	42	S.B.
03	AMA.	23	MEN.	43	SCL.
04	BUT.	24	MER.	44	SCR.
05	CAL.	25	MOD.	45	SHA.
06	COL.	26	MNO.	46	SIE.
07	C.C.	27	MON.	47	SIS.
08	D.N.	28	NAP.	48	SOL.
09	E.D.	29	NEV.	49	SON.
10	FRE.	30	ORA.	50	STA.
11	GLE.	31	PLA.	51	SUT.
12	HUM.	32	PLU.	52	TEH.
13	IMP.	33	RIV.	53	TRI.
14	INY.	34	SAC.	54	TUL.
15	KER.	35	SBT.	55	TUO.
16	KIN.	36	SBD.	56	VEN.
17	LAK.	37	S.D.	57	YOL.
18	LAS.	38	S.F.	58	YUB.
19	L.A.	39	S.J.		
20	MAD.	40	SLO.		

STATE ROUTE
4, 5, 6

MISCELLANEOUS ROUTE ALIGNMENT
7

- R Relignment
- D Duplicate postmile due to meandering county line
- H Realignment of duplicate postmile
- L Overlaping duplicate postmile
- S Spur
- T Temporary connection
- O Does not apply

POSTMILE (To Hundredth)
8,9,10,11,12

YEAR (Last figure only)
13

MONTH
14

A	Jan	E	May	J	Sept
B	Feb	F	June	K	Oct
C	Mar	G	July	L	Nov
D	Apr	H	Aug	M	Dec

DATE
15,16
(00=Not stated)

DAY
17

- 1 Sun.
- 2 Mon.
- 3 Tue.
- 4 Wed.
- 5 Thu.
- 6 Fri.
- 7 Sat.
- 0 Not Stated

HOUR OF DAY
18, 19

Show hour, disregard minute

24	12 Mid.	12	12 Noon
01	1 A.M.	13	1 P.M.
02	2 "	14	2 "
03	3 "	15	3 "
04	4 "	16	4 "
05	5 "	17	5 "
06	6 "	18	6 "
07	7 "	19	7 "
08	8 "	20	8 "
09	9 "	21	9 "
10	10 "	22	10 "
11	11 "	23	11 "

00 Not Stated

NUMBER OF TRAFFIC LANES
(See Separate List)

20, 21, 22

SEVERITY
23

1 Fatal 2 Injury 3 P.D.O.

NUMBER OF PERSONS KILLED
Veh. Occup. 24 — Ped. 25

NUMBER OF PERSONS INJURED
Veh. Occup. 26, 27 — Ped. 28

TYPE OF VEHICLE
Veh. 1: 29 — Veh. 2: 30 — Veh. 3: 31

- 1 Passenger car (with or w/o trailer)
- 2 Motorcycle
- 3 scooter or motor driven cycle
- 4 Pickup or panel (with or w/o trailer)
- 5 Truck or truck-trailer
- 6 Gasoline (or fuel) truck (or truck-trailer)
- 7 School bus
- 8 Common carrier bus
- 9 Emergency vehicle
- 0 Other (train, electric street car, etc.)
- Y Does not apply

DAMAGE TO VEHICLE
Veh. 1: 32 — Veh. 2: 33 — Veh. 3: 34

- 1 No damage (under $10)
- 2 Minor ($11 - 150)
- 3 Moderate ($151 - 450)
- 4 Major ($451 - 750)
- 5 Total loss (over 750)
- 9 Not stated
- Y Does not apply

NUMBER OF VEHICLES
35, 36

From state highway	From intersecting highway, county road or city street
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9 (9 or more)

DIRECTION OF TRAVEL
Veh 1: 37 — Veh 2: 38 — Veh 3: 39

- N North, N.E. or N.W. bound
- S South, S.E. or S.W. bound
- E Eastbound
- W Westbound
- H Inbound
- J Outbound
- R From right } Use only with
- L From left } codes H & J
- O Not stated or undetermined
- Y Does not apply

WEATHER
40

CHP 42				
1	1	Clear	6	Wind
2	2	Cloudy	7	Dust
3	3	Raining	8	Smoke
4	4	Snowing	9	Other
5	5	Fog	0	Not stated

LIGHT CONDITION
41

CHP 43		
1	1	Daylight
2	2	Dust or dawn
3	3	Dark - highway not lighted
4	4	Dark - highway lighted
	5	Dark - lighting not stated
	6	Tunnel - lighted
	7	Tunnel - not lighted
	0	Not stated

PAVEMENT CONDITION
42

CHP 46			CHP 47		
	0	Not stated	2	6	Loose material on surface
1	1	Dry		7	Oil
2	2	Wet		8	Miscellaneous
3	3	Muddy			
4	{4	Snow			
	{5	Frost or ice			

DRIVERS' VIOLATIONS
Dr 1: 43,44 — Dr 2: 45,46 — Dr 3: 47,48

CHP 63-64

- 00 Not stated
- 01 Under influence of alcohol
- 02 Exceeding stated speed limit
- 03 Exceeding safe speed (but not stated limit
- 04 Did not grant R/W to ped
- 05 Did not grant R/W to vehicle
- 06 Following too close
- 07 Drove through safety zone
- 08 Passing standing street car
- 09 Passing on hill
- 10 Passing on curve
- 11 Cutting in
- 12 Other improper passing
- 13 On wrong side of road--not in passing

DRIVERS' VIOLATION (Cont'd)

- 14 Failed to signal or improper sig.
- 15 Improper turn--wide right turn
- 16 Improper turn--cut corner on left turn
- 17 Improper turn--from wrong lane
- 18 Other improper turning
- 19 Disregarded police officer
- 20 Disregarded stop & go traffic sig.
- 21 Disregarded stop sign or flashing red signal
- 22 Disregarded warning sign, yield sign, or flashing yellow signal.
- 23 Disregarded other traffic control
- 24 Improper starting from parked position
- 25 Improper parking location
- 26 Failed to turn on lights
- 27 Other violations (hazardous)
- 28 No violation
- YY Does not apply

CONDITION OF DRIVER
Dr 1: 49 — Dr 2: 50 — Dr 3: 51

CHP 67	CHP 68		
	1	1	Obviously drunk
	2	2	Had been drinking, ability impaired
6		3	Apparently asleep
4		4	Medical condition (heart attack, seizure, ill, drug, etc.
5		5	Fatigued
	4	6	Had been drinking, not known if ability impaired
1,2 & 3		7	Defective eyesight, hearing or other bodily defect
	3	8	Had been drinking, ability not impaired
7	5	9	No apparent defect
		0	Not stated (or other)
		Y	Does not apply

VEHICLE CONDITION
Veh 1: 52 — Veh 2: 53 — Veh 3: 54

CHP 69

- 1 Defective brakes
- 2 Headlights insufficient or out
- 3 Headlights glaring
- 4 Rear light insufficient or out
- 5 Other lights or reflectors defective
- 6 Steering mechanism defective
- 7 Puncture or blowout
- 8 Worn or smooth tires
- 9 Other defects
- 0 No defects or not stated
- Y Does not apply

Figure 1. Accident coding sheets.

January 1965

ACCIDENT CODE

Sheet 2

SPEED PRECEDING ACCIDENT

Dr 1 55 — Dr 2 56 — Dr 3 57

CHP 70

0	0	Not stated	5	5	41 - 50
1	1	1 - 10	6	6	51 - 60
2	2	11 - 20	7	7	61 - 70
3	3	21 - 30	8	8	71 and over
4	4	31 - 40	9	9	Standing still
				Y	Does not apply

MOVEMENT PRIOR TO ACCIDENT

Veh 1 58, 59 — Veh 2 60, 61 — Veh 3 62, 63

Wrong Way Movement (Veh under control, not in passing)

01 Traveling wrong way

Crossed-Median or Crossed Center Line Strip Into Opposing Lane (Not in passing, veh. out of control)

20 Swerved to avoid other vehicle
21 Swerved to avoid pedestrian
22 Swerved to avoid animal
23 Swerved to avoid other object
24 Changing lanes on multi-lane road, not in passing
25 Due to collision
26 Due to driver condition
27 Due to driver violation
28 Due to vehicle condition
29 Due to pavement condition
30 Other or undetermined

Ran Off Road (Not in passing, not while making turns at intersections, veh. out of control)

31 Swerved to avoid other vehicle
32 Swerved to avoid pedestrian
33 Swerved to avoid animal
34 Swerved to avoid other object
35 Changing lanes on multi-lane road, not in passing
36 Due to driver condition
37 Due to driver violation
38 Due to vehicle condition
39 Due to pavement condition
40 Due to collision
45 Other or undetermined

MOVEMENT (Cont'd)

Passing Movement

41 In opposing lane while passing
42 Change lane to pass on multi-lane road
43 Ran off road while passing

Turn or Preparing to Turn

50 Making left turn
51 Making right turn
52 Making U-turn
53 Making turn - direction unk.
54 Stopped, preparing to turn lt.
55 Stopped, preparing to turn rt.
56 Stopped, preparing to U-turn
57 Stopped, preparing to turn - direction unknown

Other Movement

60 Proceeding straight ahead
61 Backing up (not parking)
62 Changing lanes in multi-lane road, not in passing
63 Entering flow of traffic from shldr, median, parking strip or private drive
64 Swerved to avoid other vehicle
65 Swerved to avoid pedestrian
66 Swerved to avoid animal
67 Swerved to avoid other object
68 Entering freeway from on ramp
69 Leaving freeway via off ramp
70 Stopped by traffic control
71 Stopped by congestion
72 Stopped by prior accident
73 Stopped by mechanical failure
74 Stopped to avoid veh, ped, animal, other object or misc.
75 Stopped - reason unknown
80 Parked
81 Parking maneuver
90 Miscellaneous
00 Not stated
YY Does not apply

TYPE OF ACCIDENTS

1st Event 64 — 2nd Event 65 — 3rd Event 66

1 Overturned
2 Head-on
3 Head-on sideswipe
4 Hit object (including ped.)
5 Rear end
6 Overtaking sideswipe
7 Approach turn
8 Overtaking turn
9 Broadside, angle collision or merging movement
0 Other or undetermined
Y Does not apply

LOCATION OF ACCIDENT

1st Event 67 — 2nd Event 68 — 3rd Event 69

A Main traveled lane-State hwy only
Z Main traveled lane - Co rd or city street
B Improved shoulders to the left (incl. parking strip)
C Improved shoulders to the right (incl. parking strip)
D Off roadway to the left (beyond shoulder, incl. sidewalk)
E Off roadway to the right (beyond shoulder, incl. sidewalk
X Off roadway - direction unknown
F Marked pedestrian cross-walk
G Left-turn lane (non-fwys only)
H Right-turn lane (non-fwys only)
J Within median
K Median opening at public road intersection
L Median opening not at public road intersection
M Ramp nose, curb return or traffic island
N Off-ramp taper (or decel. lane)
P Off-ramp roadway
R On-ramp taper (or accel. lane)
S On ramp roadway
T Auxiliary lane or collector rd.
V Freeway to freeway connector
W Miscellaneous freeway facility

0 Undetermined
Y Does not apply

MISCELLANEOUS CIRCUMSTANCES

70

Freeway Accident

1 Ramp maneuver involved
2 Ramp maneuver is not involved
3 Undetermined whether or not ramp maneuver is involved

Non-State Highway Accident

6 Cross-road of interchange facility
7 The cross-road approaches to the at-grade-intersection with a State highway

0 Undetermined
Y Does not apply

COLLISION WITH OBJECT OTHER THAN VEHICLE

1st Object 71, 72 — 2nd Object 73, 74 — 3rd Object 75, 76

Bridge

01 Side of bridge railing
02 End of bridge without guardrail
03 End of bridge with guardrail (both were struck)
04 Pier or abutment w/o guardrail
05 Pier or abutment with guardrail both were struck)

Light or Signal Pole

10 Pole without guardrail
11 Pole with guardrail (both were struck)
12 Pole without guardrail at gore on freeway
13 Pole with guardrail at gore on freeway

Traffic Sign

20 Sign or signpost w/o guardrail
21 Sign or signpost with guardrail (both were struck)
22 Sign or signpost w/o guardrail at gore on freeway
23 Sign or signpost with guardrail at gore on freeway

Other Pole

30 Utility Pole

Guard Rail (Use when only the guard rail is struck)

40 Guardrail at end of bridge
41 Guardrail at pier or abutment
42 Guardrail at light or signal pole
43 Guardrail at sign
44 Guardrail at edge of roadway

Barrier (In median only)

50 Metal beam guardrail barrier
51 Cable chain link fence barrier
52 Concrete barrier
53 Other median barrier

COLLISION WITH OBJECT (Cont'd)

Miscellaneous - Fixed Objects

60 Concrete wall (not in median)
61 Other signs (not traffic)
62 Other poles (not light, signal or utility)
63 Curb
64 Dike
65 Traffic island
66 Raised bars or traffic buttons
67 Culvert (or pipe) headwall
68 Guidepost, culvert or milepost marker
69 Cut slope or embankment, struck from below
70 Over embankment (not in water)
71 In water (river, lake, canal, etc
72 Drainage ditch
73 R/W fence
74 Trees
75 Plants

Miscellaneous - Mobile Objects

80 Pedestrian (hitch-hiker, vender,
81 Pedestrian (dismounted from veh.)
82 Bicycle
83 Bicyclist or equestrian (mounted or dismounted)
84 Animal (wild or domesticated)
85 RR train or streetcar - across hwy
86 Highway work equipment
87 Other mobile object

Miscellaneous

90 Rocks, fallen trees or other natural material on road
91 Object fell from other road above
92 Temporary barricades
93 Hwy construction or work material
94 Other object on road
95 Other object off road

99 No fixed object involved
00 Not stated
YY Does not apply

ACCIDENT NUMBER

Book 77 — Page 78,79 — Line 80

Figure 1. Continued

Headquarters Operations

Headquarters Traffic Department receives one copy of each accident report on the state highway system. Copies are initially sent by the law enforcement reporting agencies to the districts where they are located by county name, route number, and postmile location. One copy of each report is retained in the district and a duplicate copy is forwarded to the Headquarters Traffic Department.

Coding of Accidents—Each accident is coded in Headquarters for keypunching onto data-processing cards. Figure 1 shows the 1965 coding. All columns of information are coded for each accident. The information coded is as follows:

1. Location—district, county, route, route alignment and postmile.
2. Date of accident—year, month, date, day and hour.
3. Severity—accident severity (fatal, injury, or property damage only), number of persons killed and injured.
4. Conditions at accident site—number of traffic lanes (which includes degree of access control and width and type of median), weather, light condition and pavement condition.
5. Information on each vehicle (to a maximum of three per accident)—type of vehicle, damage to vehicle, direction of travel, vehicle condition and movement prior to accident.
6. Information on each driver (to a maximum of three per accident)—driver violation, condition of driver and speed preceding accident.
7. Information on each event (to a maximum of three per accident)—type of accident collision, location of accident and objects struck.
8. Other information—number of vehicles from state highway and intersecting highway, and miscellaneous circumstances.

A senior clerk and 14 intermediate clerks, under the direction of a traffic engineer are required to code and file the approximately 115,000 accident reports per year. One clerk can code about 50 to 60 reports per 8-hour working day. The total coding cost, salaries and overhead is about $90,000 per year.

The cost to keypunch these reports and the cost in computer time to make the consistency check (a program that compares various coded items for inconsistencies that may indicate errors in coding) and to store the information on computer tapes ready for use in various tabulations is about $30,000 per year.

Tabulations—Electronic data-processing methods have been utilized for a number of years to obtain various accident tabulations. Nearly all tabulations have been on a statewide basis. Summaries of numbers of accidents and accident rates by road type classification and by individual roadway sections are made annually. Several other annual statewide tabulations by accident type are made in considerable detail. These include fixed-object accidents, daytime and nighttime accidents, pedestrian accidents, etc.

Other machine tabulations have been made for research studies conducted at Headquarters. Some examples are listings of accidents in fog, accidents involving wrong-way movements, and accidents involving state-owned vehicles.

A few special tabulations have also been made for the districts. Examples are accidents on wet pavement and ran-off-the-road type accidents. However, machine data-processing methods have been used relatively little, so far, to keep up-to-date records of accident locations, and as an aid in the study and analysis of individual "spot" accident locations.

District Operations

The District Traffic Engineers are responsible for the maintenance of accident records and up-to-date charts showing accident locations on all sections of state highways within their districts, and are continually studying and observing accident locations and congested areas with a view toward improving the safe and expeditious movement of traffic. They also assemble the traffic data required for project reports and for design, budget, and other special studies.

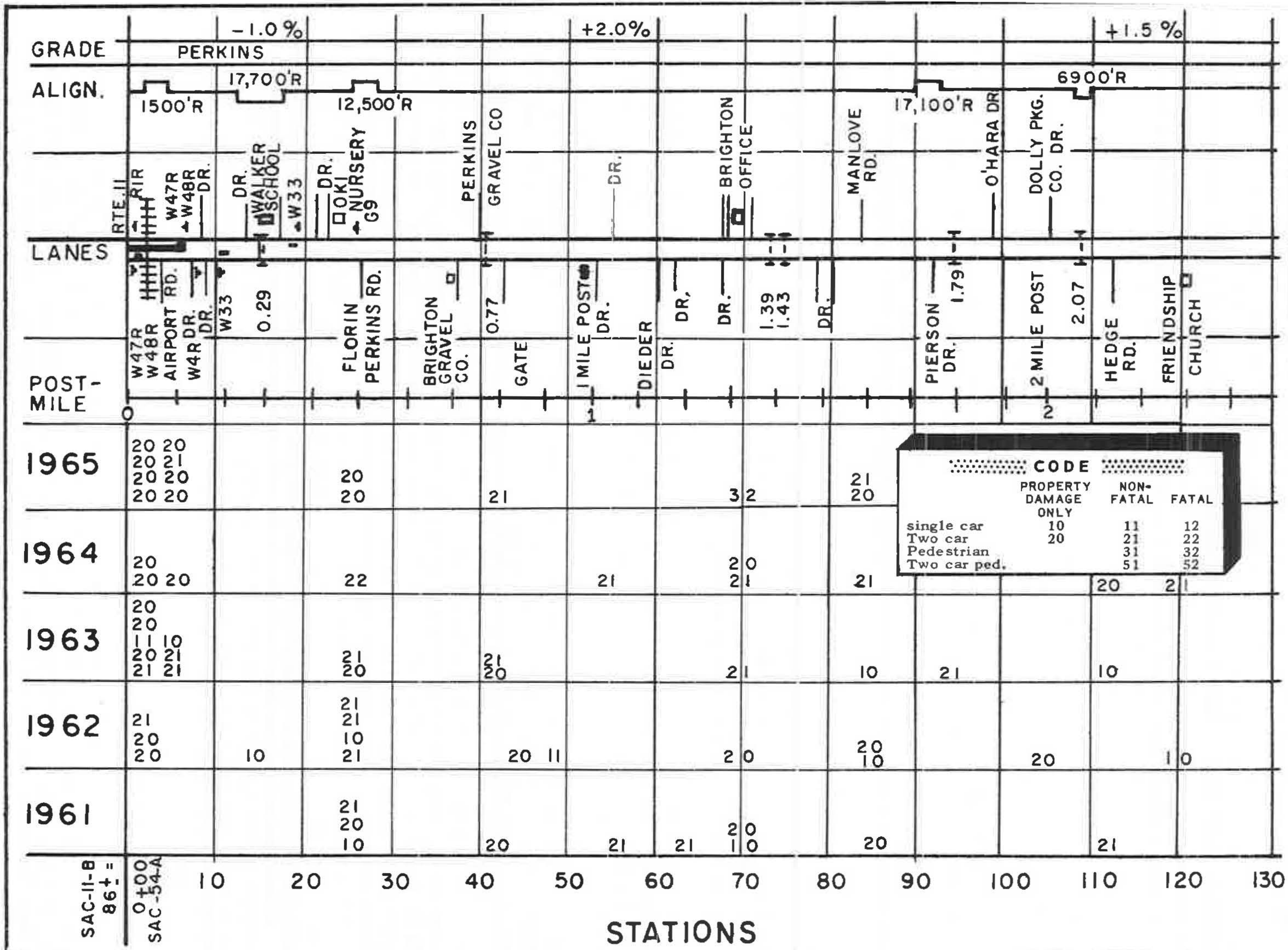

Figure 2. Accident profile.

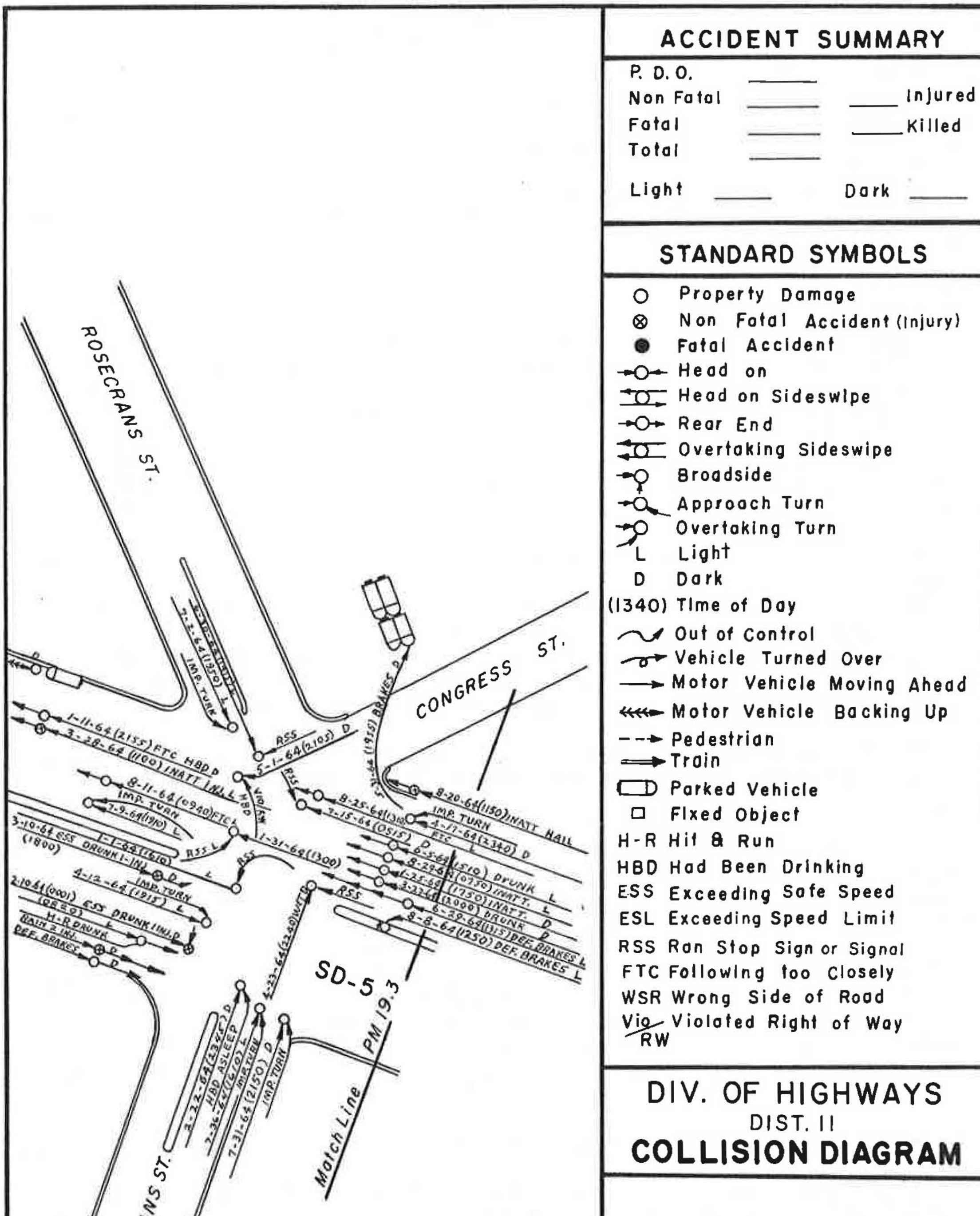

Figure 3. Strip collision diagram.

Accident Records—Different display methods are used in the 11 districts for the visual presentation of accident data. Accident profile maps (Fig. 2) are used in many districts. Accidents are plotted on line diagrams of the highway system in one district. Section index cards are used by Headquarters and by some districts. One district plots continuous collision diagrams for all highways and one other district plots them for freeways only. Figure 3 shows a portion of one collision diagram. Whatever the method used, each accident is plotted by symbol or code on a map or chart. One copy of each accident report is also retained in the district files.

Review of Maps or Charts—Accident strip maps and charts are reviewed periodically for developing accident concentration points. The districts make this complete review at least once each year. Some districts have instructed the accident plotters to note each location that has developed some minimum number of accidents (usually 3 or 5) in the current year.

Listing Concentration Points—The procedure varies from district to district. Most lists array the concentration points by decreasing number of accidents. Some listings are arrayed by decreasing accident rates. A common definition of a concentration point is a location about one-half mile long or less that has had three or more accidents in a year.

Six annual machine tabulations were prepared in Headquarters for 1963 and 1964 accidents to aid the districts in the listing of concentration points. The tabulations were as follows:

1. Number of intersection accidents listed in order by district, county, route and milepost.
2. Intersection accidents listed by decreasing number of accidents in each district.
3. Intersection accidents listed by decreasing number of accidents statewide.
4. All accidents listed in order by district, county, route and milepost (Fig. 4).
5. All accidents listed by decreasing number of accidents in each district.
6. All accidents listed by decreasing number of accidents statewide.

These tabulations were the predecessors of those discussed in the next section. Several shortcomings that limited the usefulness of the tabulations became apparent. They were

1. Accidents were summarized in 0.10-mile increments, beginning at each 0.10-mile starting point (postmile 9.00 or 9.10, etc.). This did not necessarily select the 0.10-mile length with the maximum number of accidents, as the maximum concentration point could have begun at, say, postmile 9.03.
2. Intersection accidents were limited by coding definition to those where the original point of impact was within the area common to both intersecting roadways. This excluded rear-end and other accidents attributable to the intersection on the approach legs.
3. Accidents in arbitrary 0.10-mile increments are not associated, except by coincidence, with physical features on the ground. For instance, accidents from 9.10 to 9.20 do not necessarily represent the accident experience on a curve that extends from 9.14 to 9.23.

The tabulations and listings discussed in the next section were designed to eliminate these shortcomings.

Collision Diagrams—Collision diagrams are drawn for many locations where the possibility of corrective measures is being investigated. These diagrams depict accident patterns and may suggest treatments that will be effective in reducing accidents. Figure 5 shows one such diagram. The diagrams are also made for "before and after" studies in evaluating the effectiveness of corrective improvement projects.

Construction of collision diagrams requires a detailed reading of each accident report. Information required for the diagrams is already coded in Headquarters. Another objective of the surveillance program, therefore, is to provide computer printouts that will eliminate much of this duplication of reading of reports in both Headquarters and the districts.

TABLE TS 12 SUMMARY OF ALL 1964 ACCIDENTS
(0.10 MILE INCREMENTS IN DISTRICT, COUNTY, ROUTE AND MILEPOST ORDER)

DIST	CO.	RTE	CITY RURAL	MLEPST	PDO	NFATL	FATAL	TOTAL ACC	OCC INJRD	OCC KILLD	SNGLE	2 OR MORE	OFF ROAD	OVER TURN	HEAD ON	HIT OBJECT	REAR END	OVRTK SDESP	APPRO TURN	OVRTK TURN	BROAD SIDE	MISCL
01	HUM	101	R	83.20	2	1		3	2		3		3									
01	HUM	101	R	83.30	3			3			1	2	1					1	1			
01	HUM	101	R	83.50	2	1		3	1		2	1	2				1					
01	HUM	101	R	83.60		1		1	1		1		1									
01	HUM	101	R	83.70	3			3			1	2	1		1			1				
01	HUM	101	R	83.80	2	1		3	1			3					2	1				
01	HUM	101	R	83.90	1	1	1	3	1	1		3							1		2	
01	HUM	101	R	84.10	1			1			1		1									
01	HUM	101	R	84.30	1			1				1					1					
01	HUM	101	R	84.40	1			1				1						1				
01	HUM	101	R	84.50	1	1		2	3		1	1	1				1					
01	HUM	101	R	84.70	1			1			1		1									
01	HUM	101	R	84.90	1	1		2	1			2						1		1		
01	HUM	101	R	85.00	1	2	1	4	8	2	1	3				1			1		2	
01	HUM	101	R	85.30		1		1	3			1							1			
01	HUM	101	02	86.00	8	5		13	13			13					7			2	4	
01	HUM	101	02	86.10	3	3		6	4		1	5	1				4	1				
01	HUM	101	02	86.30		1		1	1		1		1									
01	HUM	101	02	86.40		1		1	1			1					1					
01	HUM	101	02	86.50	1			1			1		1									
01	HUM	101	02	86.70	4	6		10	11		3	7	2				3			2	2	
01	HUM	101	R	86.80	1			1				1					1					
01	HUM	101	02	86.90	2	1		3	2			3							1		2	
01	HUM	101	R	87.00		1		1	1		1		1									
01	HUM	101	R	87.10		1		1	1			1								1		
01	HUM	101	R	87.30	2			2				2						1			1	
01	HUM	101	R	87.50	1	2	1	4	4	2	3	1	2			1		1				
01	HUM	101	R	87.60	1	1		2	1		1	1	1								1	
01	HUM	101	R	87.70	7	1	1	9	5	1	3	6	1			2	3		1	1	1	
01	HUM	101	R	87.90	1	1		2	2			2					2					
01	HUM	101	R	88.20	2			2			1	1				1	1					
01	HUM	101	R	88.70	6	4		10	11		2	8	2				2	2	1	1	2	
01	HUM	101	R	88.80	1			1				1					1					
01	HUM	101	R	89.20	1			1			1					1						

Figure 4. 0.10-mile accident listing.

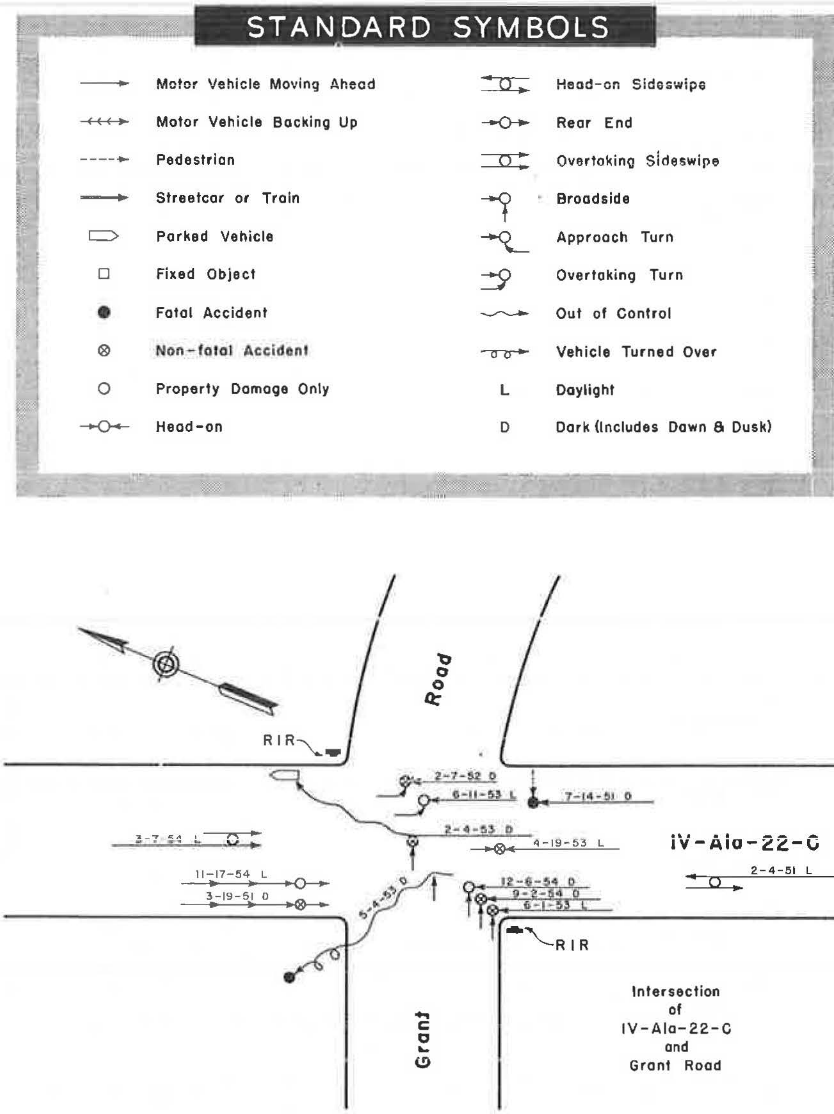

Figure 5. Collision diagram.

Other Uses—Accident and traffic data are also used for a number of other purposes. These data appear in project reports and traffic reports on proposed new construction and in the planning program, which is prepared annually for budgeting considerations and for the scheduling of construction projects.

A minimum of information is generally required. Usually a summary of accidents by severity between project limits with the corresponding accident rates (accidents per million vehicle-miles) is used. Although these calculations are relatively simple, they are numerous and put a considerable work load on the districts.

The tabulations proposed in this study were designed primarily to maintain a surveillance of "spot" locations. However, the requirements for project reports and planning programs were kept in mind, and the machine tabulations with minor modifications can be used for these purposes.

Cost of District Operations—The equivalent of 54 full-time employees in the 11 districts is engaged in the location-coding of accident reports by postmile, the hand-posting of accident maps, the review of the maps, the listing of concentration points, the preparation of collision diagrams and the calculation of information for the planning programs and project reports. This represents an expenditure of about $400,000 per year.

Coordination With Districts

In the development of the surveillance program, 8 of the 11 district traffic departments were visited during August and September 1964. Information was gathered on existing practices and procedures. Discussions were held with responsible personnel to determine what information should be included in the surveillance program, and in what form. District personnel with day-to-day knowledge, at the operational level, of the problems involved were contacted whenever possible.

Contact with the Los Angeles County Road Department was made early in the study. Many of the ideas for the Detailed Accident Listing of the next section were derived from them.[1]

Mock-ups of the proposed tabulations were sent to each district in December 1964. The district personnel were again given the opportunity to comment and propose changes in the form or content of the listings. Changes were made as a result of this review.

The surveillance program described in the next section is, then, a composite of the ideas and experience of many persons in the traffic engineering departments.

The surveillance programs are intended as an aid in the identification, rating and analysis of high-accident locations. They should supplement or even supplant much of the present laborious manual postings and calculations required to develop accident information.

TABULATIONS

The tabulations provide, essentially, a three-step process in the identification and analysis of accident concentration locations. First is a listing of all accidents along each route with a notation of where the concentration locations lie. Second, based on this information plus other data and knowledge of the highway geometrics and traffic, listings of concentration locations are compiled. The locations are arrayed in these listings by decreasing numbers of accidents and by decreasing accident rates, which give indications of which locations should receive the earliest attention. Third, detailed information of each accident at selected locations is obtained to aid in the analyses of the problems.

Monthly Accident Summary

The purposes of the monthly accident summary (Table 1) are (a) to provide a current record of all accidents during a year; (b) to give a quick summary of all accidents between any two points; and (c) to give an indication of accident concentration locations. This tabulation was designed as a replacement for the existing accident profile maps, index cards or strip maps.

Table 1 is forwarded routinely to the districts about 30 days after the end of each month. It contains all accidents in the current year received in Headquarters by the twentieth day following the end of that month.

The listings are in district-route-postmile order. That is, each route is carried in geographic order through all counties in each district, and the accidents are arranged in increasing postmile order within each county. (In California's system, postmile 0.00 is generally at each southern or western county line and increases in a northerly or easterly direction.)

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[1]Tabulation of Accident Concentrations, Computer Program 8370, George B. Gurrett, Los Angeles County Road Department, May 1963.

TABLE 1

M O N T H L Y   A C C I D E N T   S U M M A R Y
T A B L E   I

DATE OF REPORT 11/01/65

06 TUL 137

FROM 01/01/65 TO 08/31/65

Part I (Location Information)				Part II: ACCIDENTS IN EACH 0.01 MILE								Part III: CUMULATIVE TOTAL NUMBER OF ACCIDENTS								Part IV: ACCIDENT CONCENT IN 0.10 MILE								PREVALENT TYPE OF ACCIDENTS
CITY	R / U	LANES	POST MILE	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	
	R	2 C 201	.55	1			1		1	1		1			1		1	1										
	R	2 C 201	2.94	2		1	1	1	1	1	1	3		1	2	1	2	2	1									
	R	2 C 201	3.58	1		1		1			1	4		2	2	2	2	2	2									
	R	2 C 201	7.20	1		1		1		1		5		3	2	3	2	3	2	3		2	1	1	2	3		ANGLE
	R	2 C 201	7.28	2		1	1		2	2		7		4	3	3	4	5	2									
	R	2 C 201	10.96	1		1		1			1	8		5	3	4	4	5	3									
TUL	U	2 C 202	14.55	1			1		1	1		9		5	4	4	5	6	3									
TUL	U	2 C 202	14.93	1		1			1		1	10		6	4	4	6	6	4									
TUL	U	2 C 202	15.03	1			1		1	1		11		6	5	4	7	7	4									
TUL	U	3 C 301	15.19	1			1		1		1	12		6	6	4	8	7	5									
TUL	U	3 C 301	15.39	2			2		2		2	14		6	8	4	10	7	7	3			3		3	1	2	NONE
TUL	U	3 C 301	15.45	1			1		1	1		15		6	9	4	11	8	7									
TUL	U	4 C 403	15.55	3		1	2		3	3		18		7	11	4	14	11	7	5		2	3		5	5		APP TURN
TUL	U	4 C 403	15.61	1			1		1	1		19		7	12	4	15	12	7									
TUL	U	4 C 403	15.64	1		1			1	1		20		8	12	4	16	13	7									
TUL	U	4 C 403	15.73	8			8		8	4	4	28		8	20	4	24	17	11	14		2	12		14	8	6	APP TURN
TUL	U	4 C 403	15.76	1			1		1		1	29		8	21	4	25	17	12									
TUL	U	4 C 403	15.80	5		2	3		5	4	1	34		10	24	4	30	21	13									
TUL	U	4 C 403	15.87	3			3		3	3		37		10	27	4	33	24	13									
TUL	U	4 C 403	15.95	3			3		3	2	1	40		10	30	4	36	26	14	12		3	9		12	6	6	REAR END
TUL	U	4 C 403	15.96	2		1	1		2	1	1	42		11	31	4	38	27	15									
TUL	U	4 C 403	15.98	1			1		1		1	43		11	32	4	39	27	16									
TUL	U	4 C 403	15.99	1			1		1	1		44		11	33	4	40	28	16									
TUL	U	4 C 403	16.00	1			1		1		1	45		11	34	4	41	28	17									
TUL	U	4 C 403	16.01	1		1			1		1	46		12	34	4	42	28	18									
TUL	U	4 C 403	16.03	3		1	2		3	2	1	49		13	36	4	45	30	19									
TUL	U	4 C 403	16.06	2			2		2	2		51		13	38	4	47	32	19	6		1	5		6	6		SIDESWIPE
TUL	U	4 C 403	16.08	1			1		1	1		52		13	39	4	48	33	19									

* = INDICATES PRESENCE OF RAMP ACCIDENTS

Table 1 consists of four parts. Part I gives the location of the accident and related information. The district number, abbreviated county name, and route number is given in the heading. The abbreviated city name is given in the first column on the left. The column is left blank if the location is outside of a city. The next column is the area classification, rural or urban. The terms rural and urban are not necessarily the same as inside and outside of incorporated city boundaries. Urban areas are defined and approved by the U.S. Bureau of Public Roads on the general basis of urban characteristics and do not necessarily coincide with city boundaries. All areas not defined or approved as urban are rural. It is believed that this definition is more indicative of the characteristics associated with accidents (roadside development, number of cross streets or interchanges per mile, etc.) than the city boundary definition. Next is the number of lanes and type of road. Codes used are: F—divided roads with full control of access (freeways); E—divided roads with partial control of access (expressways); D—divided roads with no access control; S—divided one-way street couplets; and C—all other roads, i.e., conventional highways and streets. Next is a code for the number of lanes which gives in more detail the transverse geometrics (Fig. 6). The last part of the location information gives the postmile location of each accident. Postmile prefix codes (see "Miscellaneous Route Alignment" in Fig. 1) are shown where applicable.

Part II of Table 1 lists all accidents at each postmile. Total accidents, accidents by severity (fatal, injury and property damage only), single and multi-vehicle accidents, and accidents by light condition (light or dark) are summarized.

Part III gives the cumulative numbers of accidents along each route. The cumulative totals are started over at each county line and at the end of each route. A quick summary of accidents between any given postmile limits can be obtained by simple subtraction. These totals are used for a number of purposes. The most useful is in the preparation of project reports and planning programs. In planning, it can be used to see quickly the effect of shifting projects limits to maximize the safety benefits of the earliest scheduled projects.

Part IV indicates those 0.10-mile increments where there have been a concentration of three or more accidents in the current year. This is done entirely by machine programming. The computer program logic is discussed in the next section. The choice of using a 0.10-mile increment is somewhat arbitrary. It is a compromise between getting an increment long enough to include all accidents at a given location (considering that there is some uncertainty in the exact postmile locations determined from the original accident reports) and an increment short enough to isolate individual locations. It is obvious that where intersections are located closer than 0.10 mile (528 ft) apart, it is possible to have more than one intersection in a single concentration point. Another factor is that a concentration "point" can be anything from a single light pole to a 1,000-foot long curve. The intent here is to point out, or flag, general areas of accident concentrations. A 0.10-mile increment includes, in some instances, more accidents than there are at a single location. A variable increment length to take into account all possible situations would be impractical. Experience in the use of Table 1 will indicate whether a modification in this length, or even the use of two concentration lengths—one for freeways and rural conventional roads and one for urban streets—will be desirable to isolate and identify single concentration locations. The last column lists the most prevalent type of accident, whenever there are two or more of one kind. The type of accident is that coded as the first event of column 64 on the coding sheet (Fig. 1). This notation is intended to give a first indication of what might be wrong in the given 0.10 mile.

Figure 7 is a manual plot of one year's accidents along a heavily traveled conventional city street. It illustrates the concentration selection problem. The street has irregular and close block spacings. The 0.10-mile intervals and the total number of accidents that would be selected by the computer program are shown. Note that due to the block spacings some concentration points include more than one intersection; however, attention is drawn to concentrations of accidents. The ability to start the 0.10-mile concentration point at any 0.01-mile point rather than at only the 0.10-mile points maximizes the numbers of accidents. As an attention getter, it is better to include more accidents at a given concentration point than fewer.

NUMBER OF TRAFFIC LANES

Jan. 1965

20, 21, 22,

100	1 lane-Under 16' low type surface Under 15' high type surface, no center stripe
101	1 lane, under traffic control
102	1 lane, with occasional turnouts for meeting and passing
103	1 lane, one way only
104	1 to 2 lane transition
105	
106	
107	
109	1 lane, misc. or undetermined
200	2 lane, not separated or striped
201	2 lane, single center stripe
202	2 lane double center stripe
203	2 lane, center curb, parking strip or physical barrier
204	2 lane, incidentally 4 at crest
205	2 lane, incidentally 4 divided
206	2 lane to 3 lane transition
207	2 lane to 4 lane transition
208	2 lane to 4 divided transition
209	2 lane, miscellaneous or undertermined
300	3 lane, not separated or striped
301	3 lane, separated by single stripes
302	3 lane, incidentally 2 lane by double striping
303	3 lane, 1 up 2 down by double striping
304	3 lane, incidentally 4 lane double striped at crest
305	3 lane, incidentally 4 divided at crest
306	3 lane, to 4 lane transition
307	3 lane, to 4 divided transition
308	3 lane to 6 lane transition
309	3 lane, misc. or undetermined
400	4 lane not separated or striped
401	4 lane center stripe only
402	4 lane separated by single stripes
403	4 lane double center stripe and single side stripes
404	
405	4 lane to 5 lane divided transition
406	4 lane to 4 divided transition
407	4 lane to 6 lane transition
408	4 lane to 6 divided transition
409	4 lane, misc. or undetermined

500	4 lane divided, neutral stripe bounded by two double painted stripes
501	4 lane divided, traversable dirt or paved strip up to 6' wide
502	4 lane divided, traversable dirt or paved strip 6' to 16' wide
503	4 lane divided, traversable dirt or paved strip 16' to 46' wide
504	4 lane divided, traversable dirt or paved strip over 46' wide
505	4 lane divided, with raised bars
506	4 lane divided, with curbed center division
507	4 lane divided a) non-traversable but enterable b) semi-traversable c) non-traversable with emergency strip or strips
508	4 lane divided, non-traversable due to single curb or vertical barrier
509	4 lane divided, with non-traversable strip
50V	4 lane divided transition to undivided
50T	4 lane divided transition to other divided
50W	4 lane divided to 6 div. frwy. transition
50Y	4 lane divided, misc. or undeter.
50R	4 to 9 divided freeway transition
600	5 lane *undivided*
601	*5 lane divided*
602	
603	6 lane double center stripe and single side stripe
604	
605	6 lane to 6 lane divided
606	6 lane to 8 lane transition
607	6 lane to 8 lane divided transition
608	
609	6 lane - Misc. or undetermined
700	Other divided, neutral strip bounded by double painted stripes
701	Other divided, traversable dirt or paved strip up to 6' wide
702	Other divided, traversable dirt or paved strip 6' to 16' wide
703	Other divided, traversable dirt or paved strip 16' to 46' wide
704	Other divided, traversable dirt or paved strip over 46' wide
705	Other divided, with raised bars
706	Other divided, with curbed center division
707	Other divided a) non-traversable but enterable b) semi-traversable c) non-traversable with emergency strip or strips
708	Other divided, non-traversable due to single curb or vertical barrier
709	Other divided, non-traversable strip
70R	Other divided - transition to undivided
70T	Other divided - transition to divided
70W	
70Y	Other divided - Misc. or undetermined

800	8 lane, not separated or striped
801	8 lane, center stripe only
802	8 lane, separated by single stripes
803	8 lane, double center stripe and single side stripes
804	
805	
806	
807	
808	
809	8 lane, misc. or undetermined
900	6 lane divided, neutral strip bounded by two double painted stripes
901	6 lane divided, traversable dirt or paved strip up to 6' wide
902	6 lane divided, traversable dirt or paved strip 6' to 16' wide
903	6 lane divided, traversable dirt or paved strip 16' to 46' wide
904	6 lane divided, traversable dirt or paved strip over 46' wide
905	6 lane divided, with raised bars
906	6 lane divided, with curbed center division
907	6 lane divided a) non-traversable but enterable b) semi-traversable c) non-traversable with emergency strip or strips
908	6 lane divided, non-traversable due to single curb or vertical barrier
909	6 lane divided, with non-traversable strip
90R	6 lane divided, transition to undivided
90T	6 lane divided, transition to divided
90W	6 lane divided, incidentally 8 lanes
90Y	6 lane divided, misc. or undetermined
TOY	*Toll plaza & approaches at bridge*

Freeway and Expressway Codes (Column 20 to be used with median Code in Columns 21,22)

B--	2 lanes lim. access hwy. (exp.)
C	3 lanes lim. access hwy. (exp.)
D	4 lanes lim. access hwy. (exp.)
E	4 lanes div. lim. access hwy. (exp.)
F	6 lanes div. lim. access hwy. (exp.)
G	5 lanes div. lim. access hwy. (exp.)
H	8 lanes div. lim. access hwy. (exp.)
K	2 lanes full freeway
L	3 lanes full freeway
M	4 lanes full freeway
N	4 lanes div. full freeway
P	5 lanes div. full freeway
W	6 lanes div. full freeway
S	7 lanes div. full freeway
Q	8 lanes div. full freeway
R	9 lanes div. full freeway
X	10 lanes div. full freeway
Z	*12 lanes div. full fwy*
Y	*More than 12 lanes div. full fwy*

Median Code (Columns 21, 22) for Expressways and freeways (Divided Hwy.) Letter of Exp. or Fwy. is shown in Column 21

-00	Neutral strip bounded by two double painted stripes
01	Traversable dirt or paved strip up to 6' wide
02	Traversable dirt or paved strip 6' to 16' wide
03	Traversable dirt or paved strip 16' to 46' wide
04	Traversable dirt or paved strip 46' and over
05	Raised bars. (deterrent strip)
06	Curbed center division (deterrent strip)
07	(A) Non-traversable but enterable (B) Non-traversable with emergency strip or strips
08	Non-traversable due to single curb, vertical barrier, chain link fence or parabolic guard rail
09	Non-traversable strip div. by barrier, posts, separate roads, trees, ditch, elevated roadway or 4:1 or steeper
11	Cable barrier (With or without mesh or headlight screens)
12	Blocket-out metal beam barrier
13	Concrete wall barrier
14	Miscellaneous or undetermined barriers

Code for Transitions:

a. Conventional highways - as listed.

b. Expressways & Freeways - combine the lane code of the 2 lane types.

Example:

1. 4-lane ~~expressway~~ to 6-lane expressway : code EOF.

2. 4-lane fwy to 6-lane fwy : code NOW.

3. 4-lane expressway to 4-lane full fwy : code EON.

Figure 6. Number of traffic lanes codes.

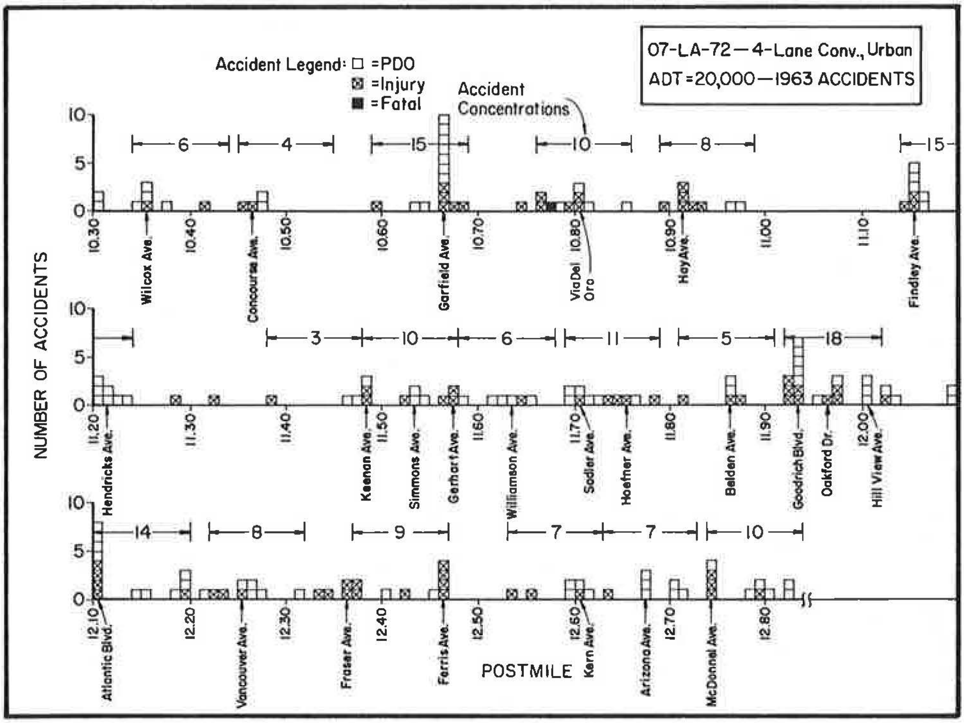


Figure 7. Accident profile.

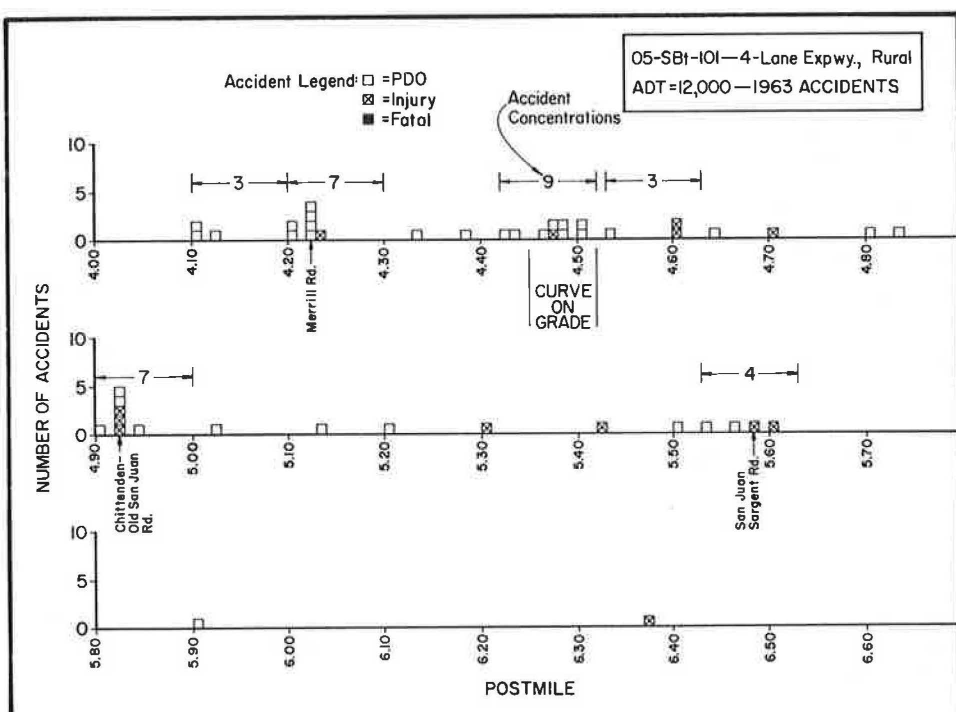


Figure 8. Accident profile.

Figure 8 is a manual plot of a more typical road. The highway is a four-lane, rural expressway with moderate traffic volumes. The figure shows the concentrations that would be selected by the computer program. Note that the groups of accidents are associated quite well with a condition on the ground—an intersection, a curve, etc.

Quarterly Accident Concentration Listing

The purpose of the quarterly accident concentration listing (Table 2) is to aid in the development of "hot spot" or "hit parade" lists of accident concentration locations, which are used, along with other considerations, to develop priority scheduling of site investigations and corrective projects.

The districts specify which locations, along with their postmile geographic limits, to include in this tabulation. From reference to construction plans, or other document records, the location of single intersections or single curves, for instance, can be determined and accident data accumulated for distinct individual locations. Only those locations requested by the districts are included in the tabulations.

The listings are separated into (a) ramp locations, (b) intersection locations, and (c) all other locations (which would normally be open highway locations). Each of the three listings are arrayed in order of decreasing number of accidents, and in order of decreasing accident rates. The listings are separated because it is desired to rate the locations in order of relative importance, and it is believed that each of these three types of locations present a different situation. A seventh listing is compiled which consists of all the requested locations arrayed in postmile order.

Part I in Table 2 lists the location information—district, county, route, city if within city limits, and postmile limits. Part II is the accident summary—total number of accidents, accidents by severity (fatal, injury, and property damage only), single and multi-vehicle accidents, light and dark accidents and persons killed and persons injured. Part III is the traffic data—the average daily traffic (ADT) on the main route, or on the ramp if it is a ramp location, and the ADT on cross streets at intersections. Part IV is the calculated data—million vehicles (MV) passing the location and the accident rates per MV for the sum of fatal and injury accidents and for total accidents. Part V is a word description of the location. This is often a convenient method for persons familiar with the highway system to identify and visualize the locations.

The methods of calculating accident rates are tentative at this time. It is believed that in short sections million vehicle-mile are meaningless. One accepted method is to base the accident rates on million vehicles. Accident rates per million vehicle-miles on short sections are extremely sensitive to the arbitrary choice of the location length. For instance, if the limits are varied 50 ft at a location basically 250-ft long, the accident rate can vary as much as 25 percent.

The listings are based on input data furnished by the districts for those locations they wish to examine. Figure 9 shows a data-input form. A comprehensive list of concentration locations contains, as a minimum, the following: (a) locations "flagged" in Table 1, (b) major intersections, (c) major ramps, and (d) other locations that the district wishes to investigate.

The selection of the postmile limits to enter on the input forms are based on a number of considerations which are discussed in the following paragraphs.

The selection of individual postmile limits should consider not only the physical limits of the locations but also variations in accident locating as determined from police accident report descriptions. It is better to make the limits somewhat longer and include more accidents rather than omit some.

In California, ramp accidents from the ramp nose to the beginning or ending of the ramp are now coded to the mainline postmile of the ramp nose. The computer programs require that the limits span at least 0.01 mile, even though all accidents on a ramp may have been coded to one point. The direction of travel is shown on the last part of the input form for each ramp to eliminate in the computer selection process accidents on ramps that may be on the opposite side of the roadway from the ramp desired. The directions refer to the general, overall direction of the route, not the cardinal directions at the individual locations. (A ramp numbering and mileposting system is now being

STATE OF CALIFORNIA - HIGHWAY TRANSPORTATION AGENCY - DIVISION OF HIGHWAYS
COMPUTER SYSTEMS

ACCIDENT CONCENTRATION LISTING SHEET

Table II

TYPE OF LOCATION
CODE 1 - RAMPS
2 - INTERSECTIONS
3 - OTHER LOCATIONS

CHARGE-ABLE DIST. 61 62

DIST. (1-2)	COUNTY (3-5)	ROUTE (6-8)	POSTMILE LIMITS FROM P (9)	FROM To 1/100 Mile (10-14)	TO P (15)	TO To 1/100 Mile (16-20)	AVERAGE DAILY TRAFFIC ON ROUTE OR RAMP (21-26)	ON X-STREET OR X-ROAD (27-32)	LOCATION DESCRIPTION (33-58)	TYPE (59)	DIR. (60)
03	YOL	5		6.30		6.40	6100	1200	JCT RTE 16	2	
〃	〃	〃		7.31		7.46		800	KENTUCKY AVE, CO RD 120	2	
〃	COL	〃		5.79		6.04			CURVE 1.1 MI N BRUSH CR	3	
〃	NEV	80	R	62.01	R	62.18	1000		EB ON-RAMP INDIAN SPRINGS	1	E

Remarks *For 1965 "Hit Parade" List.*

By *R. Smith* Phone *485-8978* Date *10/20/65*

Chd. *J. Silva* Date *10/20/65*

VERIFY

Sheet *1* of *1*

P = Postmile prefix *DIR = Direction of travel for ramps*

Figure 9. Input form for Table 2.

TABLE 2

QUARTERLY ACCIDENT CONCENTRATION LISTING
TABLE II A
ALL LOCATIONS - ROUTE ORDER

DATE OF REPORT 11/05/65
FROM 01/01/65 TO 09/30/65

Part I (Location Information)					Part II (Accident Summary)										Part III (Traffic Data)		Part IV (Calculated Data)			Part V
DST	CO	RTE	CITY	POST MILE LIMITS	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	PERSONS KLD	INJ	ADT ON RTE/RMP	ADT ON X ST	MILL VEH	ACC PER F + I	MV TOTAL	DESCRIPTION
07	LA	010	LA	2.25- 2.35	21		12	9	1	20	14	7		19	32,900	8,700	11.36	1.06	1.85	OLYMPIC BLVD AT BUNDY DR
07	LA	010	LA	2.62- 2.72	7		3	4	1	6	3	4		4	33,352	1,200	9.43	.32	.74	OLYMPIC BLVD AT ARTEMUS AV
07	LA	010	LA	3.00- 3.09	3		2	1		3	2	1		4	32,994	300	9.23	.22	.33	OLYMPIC BLVD AT PURDUE AVE
07	LA	010	LA	3.10- 3.22	7		6	1		7	5	2		9	36,300	6,000	11.55	.52	.61	OLYMPIC BLVD AT SAWTELLE B
07	LA	010	LA	R 5.90-R 6.04	10		6	4	4	6	7	3		10	42,093		11.49	.52	.87	CURVE S ROBERTSON BLVD
07	LA	010	LA	R 6.54-R 6.89	14		8	6	9	5	4	10		11	49,220		13.44	.59	1.04	CURVE AT LA CIENEGA BLVD
07	LA	010	LA	R 7.66-R 7.68	3		1	2	3		2	1		2	2,800		.76	1.32	3.95	WBOFF-TO WASHINGTON BLVD
07	LA	010	LA	R 9.51-R 9.60	13	1	6	6	2	11	8	3	2	13	47,321		12.92	.54	1.01	CONST ZONE NR CRENSHAW BVD
07	LA	010	LA	R 9.55-R 9.56	4		3	1	4		2	2		5	6,700		1.83	1.64	2.19	EBOFF TO CRENSHAW BLVD
07	LA	010	LA	R 10.20-R 10.21	3		2	1	2	1	1	2		3	9,800		2.68	.75	1.12	WBOFF TO WESTERN AVE
07	LA	010	LA	R 10.70-R 10.79	11		5	6	4	7	7	4		6	46,718		12.75	.39	.86	S OF NORMANDIE AVE
07	LA	010	LA	R 10.70-R 10.71	2		1	1	2		2			1	8,650		2.36	.42	.85	EBOFF TO NORMANDIE AVE

QUARTERLY ACCIDENT CONCENTRATION LISTING
TABLE II B
RAMPS - DECREASING NUMBER OF ACCIDENTS

DATE OF REPORT 11/05/65
FROM 01/01/65 TO 09/30/65

DST	CO	RTE	CITY	POST MILE LIMITS	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	PERSONS KLD	INJ	ADT ON RTE/RMP	ADT ON X ST	MILL VEH	ACC PER F + I	MV TOTAL	DESCRIPTION
07	LA	010	LA	R 9.55-R 9.56	4		3	1	4		2	2		5	6,700		1.83	1.64	2.19	EBOFF TO CRENSHAW BLVD
07	LA	010	LA	R 7.66-R 7.68	3		1	2	3		2	1		2	2,800		.76	1.32	3.95	WBOFF-TO WASHINGTON BLVD
07	LA	010	LA	R 10.20-R 10.21	3		2	1	2	1	1	2		3	9,800		2.68	.75	1.12	WBOFF TO WESTERN AVE
07	LA	010	LA	R 10.70-R 10.71	2		1	1	2		2			1	8,650		2.36	.42	.85	EBOFF TO NORMANDIE AVE

QUARTERLY ACCIDENT CONCENTRATION LISTING
TABLE II C
INTERSECTIONS - DECREASING ACCIDENT RATES

DATE OF REPORT 11/05/65
FROM 01/01/65 TO 09/30/65

DST	CO	RTE	CITY	POST MILE LIMITS	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	PERSONS KLD	INJ	ADT ON RTE/RMP	ADT ON X ST	MILL VEH	ACC PER F + I	MV TOTAL	DESCRIPTION
07	LA	010	LA	2.25- 2.35	21		12	9	1	20	14	7		19	32,900	8,700	11.36	1.06	1.85	OLYMPIC BLVD AT BUNDY DR
07	LA	010	LA	2.62- 2.72	7		3	4	1	6	3	4		4	33,352	1,200	9.43	.32	.74	OLYMPIC BLVD AT ARTEMUS AV
07	LA	010	LA	3.10- 3.22	7		6	1		7	5	2		9	36,300	6,000	11.55	.52	.61	OLYMPIC BLVD AT SAWTELLE B
07	LA	010	LA	3.00- 3.09	3		2	1		3	2	1		4	32,994	300	9.23	.22	.33	OLYMPIC BLVD AT PURDUE AVE

QUARTERLY ACCIDENT CONCENTRATION LISTING
TABLE II C
OTHER LOCATIONS - DECREASING ACCIDENT RATES

DATE OF REPORT 11/05/65
FROM 01/01/65 TO 09/30/65

DST	CO	RTE	CITY	POST MILE LIMITS	TOT	FAT	INJ	PDO	SNG VEH	MUL VEH	LT	DK	PERSONS KLD	INJ	ADT ON RTE/RMP	ADT ON X ST	MILL VEH	ACC PER F + I	MV TOTAL	DESCRIPTION
07	LA	010	LA	R 6.54-R 6.89	14		8	6	9	5	4	10		11	49,220		13.44	.59	1.04	CURVE AT LA CIENEGA BLVD
07	LA	010	LA	R 9.51-R 9.60	13	1	6	6	2	11	8	3	2	13	47,321		12.92	.54	1.01	CONST ZONE NR CRENSHAW BVD
07	LA	010	LA	R 5.90-R 6.04	10		6	4	4	6	7	3		10	42,093		11.49	.52	.87	CURVE S ROBERTSON BLVD
07	LA	010	LA	R 10.70-R 10.79	11		5	6	4	7	7	4		6	46,718		12.75	.39	.86	S OF NORMANDIE AVE

studied for use in the future. This would give a positive identification of which accidents are on which ramps without having to resort to the directional analysis, and it would also give the locations of the accidents longitudinally along each ramp.)

At intersections, the length of postmile limits selected varies from location to location, depending on length of back-ups, approach speeds, nearness of adjacent intersections and other conditions. It appears now that, in most cases, 0.05 mile (264 ft) each side of the center of the intersection includes most accidents associated with that intersection. Accidents on the cross-street approaches to many intersections are now being received by the division of highways and coded. These accidents are coded to the postmile of the center of the intersection, and are included in the tabulations. The accidents on cross streets are separately identified as such on the coding sheet (see column 70 of Fig. 1).

The ADT on state highways is available within the electronic data-processing records. The ADT on ramps and cross streets is not, however, included in the machine records and must be entered on the input forms where required. To provide flexibility, an ADT value for state highway traffic may be entered on the input forms, in which case the entered value is used in the accident rate calculations. (In connection with the new ramp numbering and mileposting system mentioned previously, it is planned to enter ramp ADT's into the machine data records.)

The accident rates for ramps and "other" locations calculated for Table 2 are per million vehicles regardless of ramp lengths or the lengths of the other locations.

At intersections, an ADT value may be entered or it may be omitted for cross streets. This flexibility is necessary at the present time because traffic volume counts for cross streets are not available at most intersections. Accident rates per million vehicles are calculated, in effect, from the sum of traffic entering all legs whenever the cross-street ADT is given. Studies have indicated that accident rates are a function of the sum of entering traffic. If cross-street traffic is not given, the rates are calculated using the state highway ADT only. The location description is entered in the latter portion of the input form.

The initial listing of accident locations was obtained from input data on this form. These same locations are tabulated each subsequent quarter unless changes have been requested. A special listing of the same locations shown in Table 2 is forwarded to the districts with each run of Table 2. Any desired changes in any items of the listed locations, or any deletions, are shown in red on the special listing. New locations are entered on the input forms.

Detailed Accident Listing

The purpose of the detailed accident listing (Table 3) is to give information in decoded form on each accident between specified limits. The listing is used to plot collision diagrams, or the review of these listings may eliminate the necessity of plotting collision diagrams in some cases. The listing contains all information that is required to plot the diagrams. Reference to portions of the original reports is required in some cases, however, to obtain a more complete concept of why the accidents happened. This listing can save considerable time in the districts and avoid the necessity of a complete reading of accident reports that have previously been read and coded in Headquarters.

Requests for detailed accident listings are being processed, initially, twice a month. Depending on demand, more frequent listings will be considered in the future. The intent is to give as rapid service as possible within economical limits.

These listings are requested by the districts on the input form shown in Figure 10. The postmile limits and descriptions are specified in the same manner as for the quarterly accident concentration listing. Accidents which occurred during the time limits specified on the input form are listed.

Table 4 gives the abbreviations used in Table 3 along with the codes of the 1965 coding sheet. An attempt was made to make Table 3 readable within itself without having to refer to a coding sheet.

TABLE 3

D E T A I L E D   A C C I D E N T   L I S T I N G
T A B L E III

DATE OF REPORT 08/30/65

01 MEN 101 UKI 24.70- 24.89
E SMITH ST IN UKIAH

FROM 01/01/65 TO 07/31/65

POST MILE	DATE	24HR TIME	SEV	KILLD OC	KILLD PD	INJRD OC	INJRD PD	WTHR COND	LGHT COND	PAVE COND	NO. VEH I	NO. VEH S	VEH TYPE	D I R	VEHICLE MOVEMENT	MOVEMENT REASON	VEH DEFECT	DRIVER VIOLATION	DRIVER DEFECT	COLLISION TYPE	LOCATION	FIXED OBJECT
24.80	05-06-65	24	INJ			1		CLR	DARK	DRY		2	CAR	N	TURNING	LT TURN	NONE	VIO OF ROW	HBD-2	APP TURN	TRVLD WAY	NONE
													CAR	S	STRAIGHT		NONE	NONE	HBD-2			NONE
																						NONE
24.82	07-04-65	14	PDO					CLR	LGHT	DRY		2	CAR	S	TURNING	LT TURN	NONE	VIO OF ROW	NONE	OVER TURN	TRVLD WAY	NONE
													CAR	S	TURNING	LT TURN	NONE	NONE	NONE			NONE
																						NONE
24.83	04-16-65	15	INJ				1	RAIN	LGHT	WET		1	CAR	S	STRAIGHT		NONE	VIO OF ROW		HIT OBJ	PED X WLK	PED
																						NONE
																						NONE
24.83	05-26-65	21	INJ			3		CLR	DARK	DRY		2	CAR	S	STRAIGHT		NONE	FOL TOO CL	NONE	REAR END	TRVLD WAY	NONE
													CAR	S	STOPPED	OTHER	NONE	NONE	NONE			NONE
																						NONE
24.84	04-28-65	12	INJ			1		CLR	LGHT	DRY		2	TRK	S	STRAIGHT		NONE	FOL TOO CL	NONE	REAR END	TRVLD WAY	NONE
													CAR	S	STOPPED	OTHER	NONE	NONE	NONE			NONE
																						NONE
24.85	01-08-65	08	PDO					CLR	LGHT	DRY		2	CAR	N	STRAIGHT		NONE	NONE	NONE	HEAD ON	TRVLD WAY	NONE
													CAR	S	WRNG WAY		NONE	WRONG WAY	NONE			NONE
																						NONE
24.86	04-25-65	18	PDO					CLR	LGHT	DRY		2	CAR	N	STOPPED	CONGEST	NONE	NONE	NONE	REAR END	TRVLD WAY	NONE
													CAR	N	STRAIGHT		NONE	FOL TOO CL	NONE			NONE
																						NONE
24.88	06-01-65	19	PDO						LGHT		1	1	CAR	E	ENTERING		NONE			ANGLE	TRVLD WAY	NONE
													CAR	S	STRAIGHT		NONE					NONE
																						NONE

TABLE 4

Detailed Accident Listing
(For Table III)

Entry on Listing	Accident Code Sheet Column	Code
Title in upper left corner as: 07-Ora-171-Stt-PM 10.12-10.24	Location & postmile limits of summary requested by user.	
Beach Blvd. at Orangewood Ave.	Description furnished by user.	
Date in upper right corner	Date computer listing run.	
From To	Time interval of accident data.	
Following information for each accident.		
Postmile	8,9,10,11,12	
Date	14,15,16,13	
24-hour Time	18,19	
Severity	23	
Fat		1
Inj		2
PDO		3
Killed (Number of Persons)		
Oc (vehicle occupants)	24	
Pd (pedestrians)	25	
Injured (number of persons)		
Oc (vehicle occupants)	26,27	
Pd (pedestrians)	28	
Weather Condition	40	
Clr		1
Cldy		2
Rain		3
Snow		4
Fog		5
Wind		6
Dust		7
Smke		8
(Blank)		0,9
Light Condition	41	
Lght		1
Dark		2,3,4,5,6,7
(Blank)		0
Pavement Condition	42	
Dry		1
Wet		2
Mud		3
Snow		4
Ice		5
Lmtl		6
Oil		7
(Blank)		0,8

TABLE 4 (Continued)

Entry on Listing	Accident Code Sheet Column	Code
No. of vehicles involved in accident		
I (From intersecting highway)	36	
S (From State highway)	35	
Following information for each vehicle involved in accident (3 vehicles maximum).		
Vehicle Type	29,30,31	
Car		1
MtrC		2
Sctr		3
Pu		4
Trk		5,6
Bus		7,8
Emer		9
Othr		0
Veh Direction (Direction going prior to accident)	37,38,39	
Cardinal Directions		N,S,E,W
I		H
O		J
R		R
L		L
(Blank)		0
Vehicle Movement (Prior to Accident)	58,59;60,61;62,63	
Wrng Way		01
X Med/CL		20,21,22,23,24,25,26,27,28,29,30
Off road		31,32,33,34,35,36,37,38,39,40,45
Passing		41,42,43
Turning		50,51,52,53
Stopped		54,55,56,57,70,71,72,73,74,75
Straight		60
Backing		61
Lane Chg		62
Entering		63,68
Leaving		69
Swerved		64,65,66,67
Parked		80
Parking		81
Misc		90
(Blank)		00
Movement Reason	58,59;60,61;62,63	
Swrv Veh		20,31
Swrv Ped		21,32
Swrv Anl		22,33
Swrv Obj		23,34

STATE OF CALIFORNIA - HIGHWAY TRANSPORTATION AGENCY - DIVISION OF HIGHWAYS

COMPUTER SYSTEMS

DETAILED ACCIDENT LISTING SHEET

Table III

CHARGE-ABLE DIST.	
61	62
1	3

DIST. (1–2)	COUNTY (3–5)	ROUTE (6–8)	POSTMILE LIMITS FROM P (9)	FROM To 1/100 Mile (10–14)	TO P (15)	TO To 1/100 Mile (16–20)	BEGINNING Mo. (21–22)	BEGINNING Day (23–24)	BEGINNING Yr. (25–26)	ENDING Mo. (27–28)	ENDING Day (29–30)	ENDING Yr. (31–32)	LOCATION DESCRIPTION (33–58)
03	YOL	5		6.28		6.42	01	01	65	03	31	65	JCT RTE 16
〃	〃	〃		7.32		7.48	03	31	65	06	30	65	KENTUCKY AVE., CO RD 120
〃	COL	〃		5.75		6.50	01	01	65	06	30	65	CURVES 1 MI N BRUSH CR
	NEV	80	R	62.00	R	62.20	01	01	65	06	30	65	EB ON-RAMP INDIAN SPRINGS

Remarks *For Special Studies, Before and After Reports, and Collision Diagrams.*

By *R. Smith* Phone *485-8978* Date *10/20/65*

Chd. *J. Silva* Date *10/20/65*

VERIFY

Sheet *1* of *1*

P = Postmile prefix

Figure 10. Input form for Table 3.

TABLE 4 (Continued)

Entry on listing	Accident Code Sheet Column	Code
Lane Chg		24,35,42
Collsn		25,40
Dr Cond		26,36
Dr Viol		27,37
Veh Cond		28,38
Pav Cond		29,39
Other		30,45,74,75
Opp Lane		41
Off Road		43
Lt Turn		50,54
Rt Turn		51,55
U Turn		52,56
Dir Unk		53,57
Vehicle		64
Ped		65
Animal		66
Object		67
Trf Cont		70
Congest		71
Accident		72
Mech		73
(Blank)		01,60,61,62,63,68,69,80,81,90,00
Vehicle Defect	52,53,54	
Brakes		1
Lights		2,3,4,5
Steer		6
Tires		7,8
Other		9
None		0
Driver Violation	43,44;45,46;47,48	
Drinking		01
Ex Spd Lmt		02
Ex Sfe Spd		03
Vio of ROW		04,05,07
Fol Too Cl		06
Impr Pass		08,09,10,11,12
Wrong Way		13
No Signal		14
Impr Turn		15,16,17,18
Ran Signal		20
Ran Sign		21,22,23
Impr Park		24,25
No Lights		26
None		28
Other		19,27
(Blank)		00

TABLE 4 (Continued)

Entry on Listing	Accident Code Sheet Column	Code
Driver Defect	49,50,51	
Drunk		1
HBD-1		2
HBD-2		6
HBD-3		8
Medical		4,7
Asleep		3
Fatigue		5
None		9
(Blank)		0
Following information for each event in an accident (3 events Maximum).		
Collision Type	64,65,66	
Ped	(Must also be an 80 or 81 in Column 71,72;73,74;75,76)	4
Hit Obj		4
Overturn		1
Head On		2
Hd On Swp		3
Rear End		5
Sideswipe		6
App Turn		7
Over Turn		8
Angle		9
(Blank)		0
Location (of accident)	67,68,69	
Trvld Way		A
Lt Shldr		B
Rt Shldr		C
Off Rd Lt		D
Off Rd Rt		E
Off Rd Uk		X
Ped X Wlk		F
Lt Trn Ln		G
Rt Trn Ln		H
Median		J
Med Open		K,L
Ramp Nose		M
Off Taper		N
Off Ramp		P
On Taper		R
On Ramp		S
Aux Lane		T
Fwy Conn		V
Misc Fwy		W
Cross St		Z
(Blank)		O

TABLE 4 (Continued)

Entry on Listing	Accident Code Sheet Column	Code
Fixed Object	71,72;73,74;75,76	
Bridge		01,02,03,04,05
Pole		10,11,12,13,30,62
Sign		20,21,22,23,61
G Rail		40,41,42,43,44
Med Br		50,51,52,53
Wall		60
Curb		63
Dike		64
Trf Is		65
Bars		66
Hdwall		67
Gdpost		68
Cut Bk		69
Embank		70
Ditch		72
Fence		73
Tree		74
Ped		80,81
Cycle		82,83
Animal		84
Train		85
Wrk Eq		86
Misc		71,75,87,90,91,92,93,94,95
None		99
(Blank)		00

MACHINE DATA PROCESSING METHODS

Figure 11 (sheets 1 through 4) shows the system flow diagram for the surveillance program. The programs contain three basic sets of data: (a) Traffic Log, (b) accident records, and (c) postmile limit records.

Traffic Log

The Traffic Log (point ① in Fig. 11, sheet 2) contains a full description of the state highway system. The Traffic Log has three main functions: (a) to provide information used in the surveillance tables that is not coded into each accident record; (b) as a coding device to locate accidents to the correct point along each route; and (c) to correlate and select out accidents and vehicle-miles of travel that occurred on replaced or superseded sections of roadway.

Figure 12 shows one page from the Traffic Log. Two lines of data are shown for each entry. The first line, from the far left through field C, contains location information—route number, a sorting sequence number, district, county, city, federal-aid route numbers, rural-urban codes, federal-aid route codes, special highway system codes (forest highways, toll roads, etc.) and a location description.

Fields D up to F contain postmile data—postmile prefix code, base postmile value, postmile suffix code, county odometer, length to following entry and route odometer.

Transverse geometrics are shown in field F to the end of the first line—type of pavement codes on the left and right roadways, width of left and right roadway, total traveled way width, number of lanes, existing road type (expressways, etc.), ultimate road type, direction of route, and state expressway or freeway system (heading not shown).

The second line, in fields J up to K, contains traffic volume data—average ADT at the point, ADT at the following traffic profile point if the entry is itself a traffic profile point, intervening mileage to next traffic profile point, and the daily vehicle-miles of travel between each point.

Lane code information (Fig. 6) is shown in field K—current lane code, effective date of current lane code, and previous lane code. Field L will contain engineers' stationing.

Because the postmile system contains numerical gaps and overlaps at equations which are occasioned by highway realignments and by other conditions, it is not practical to

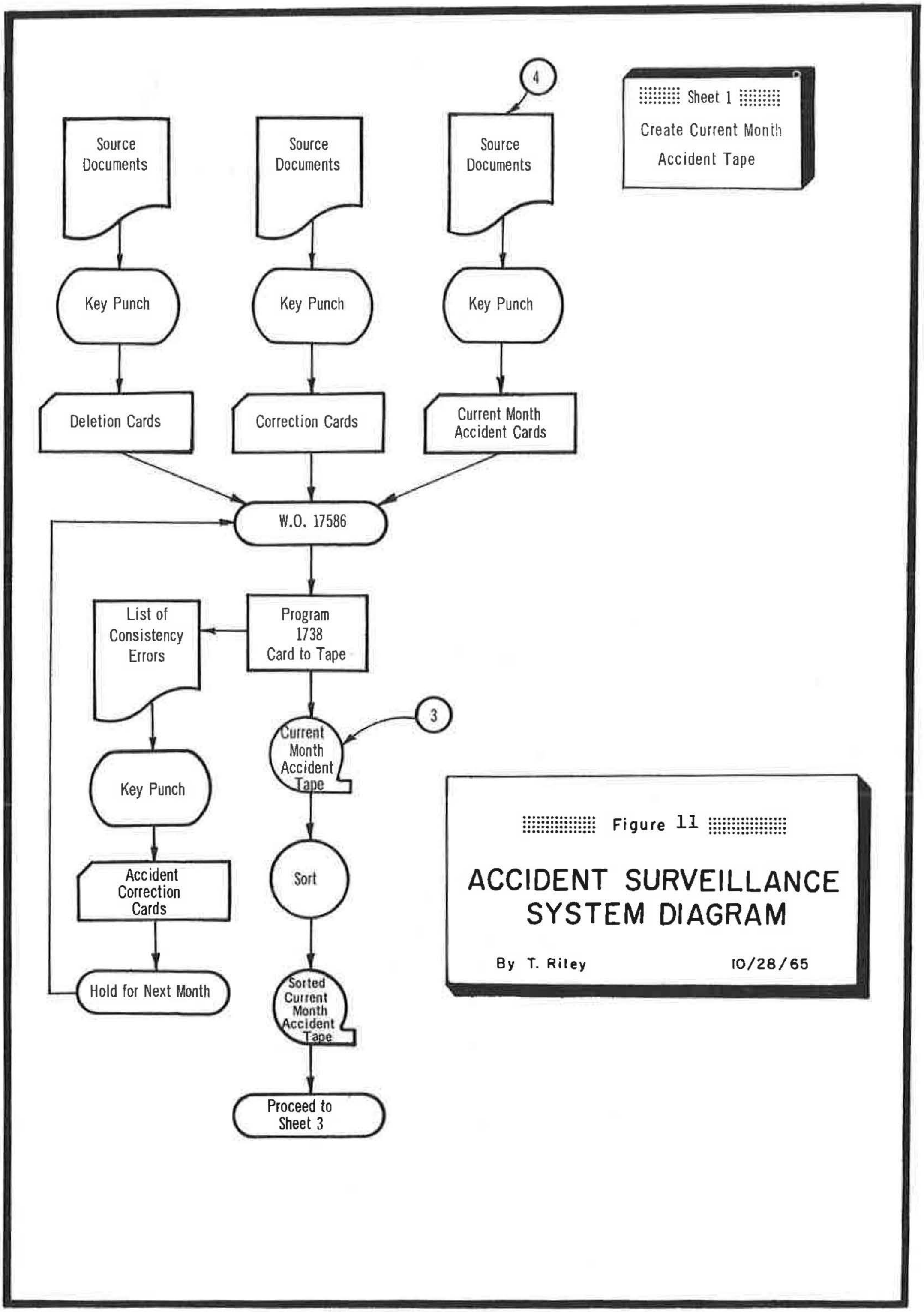


Figure 11, sheet 1. Computer system diagram.

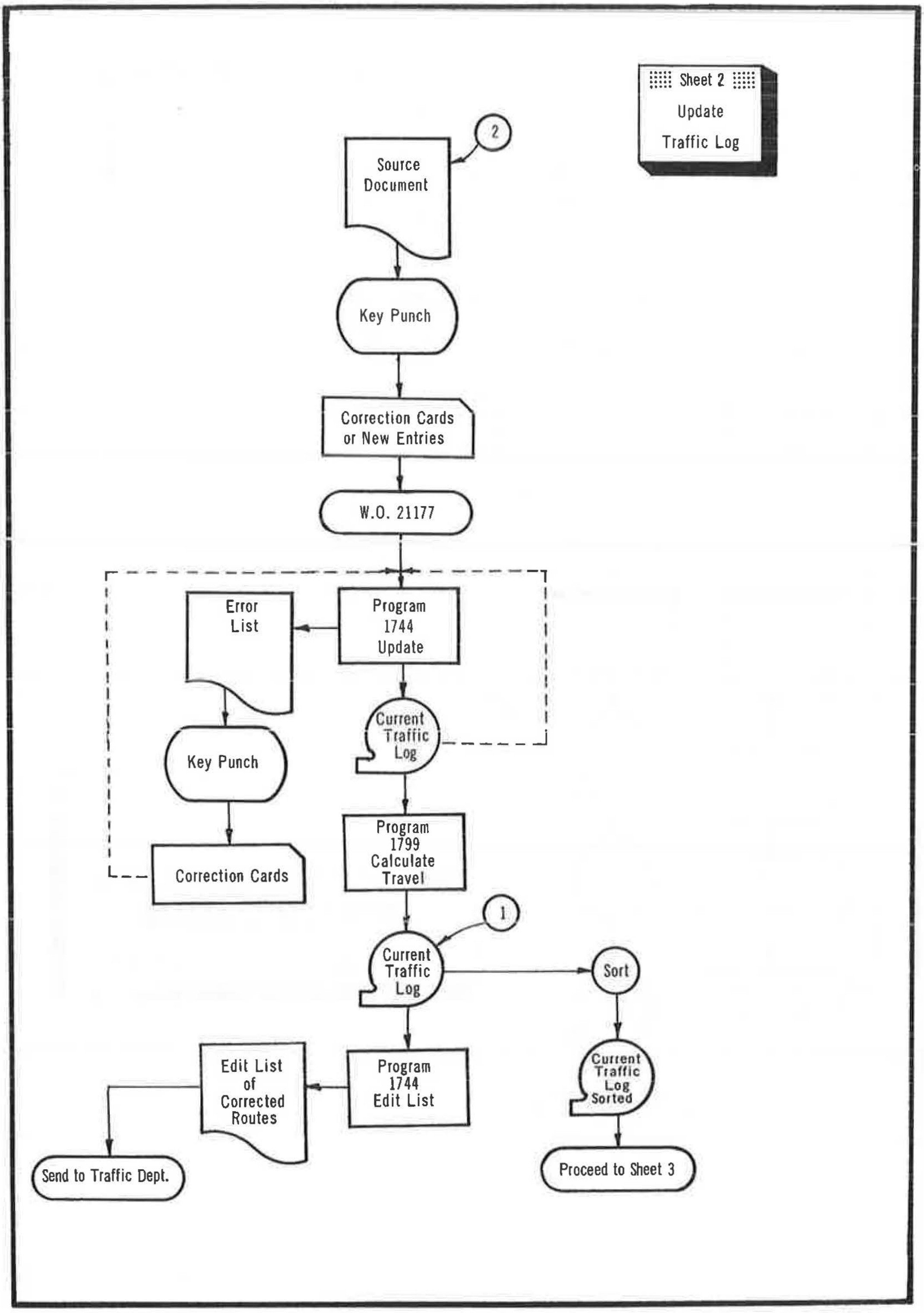


Figure 11, sheet 2.

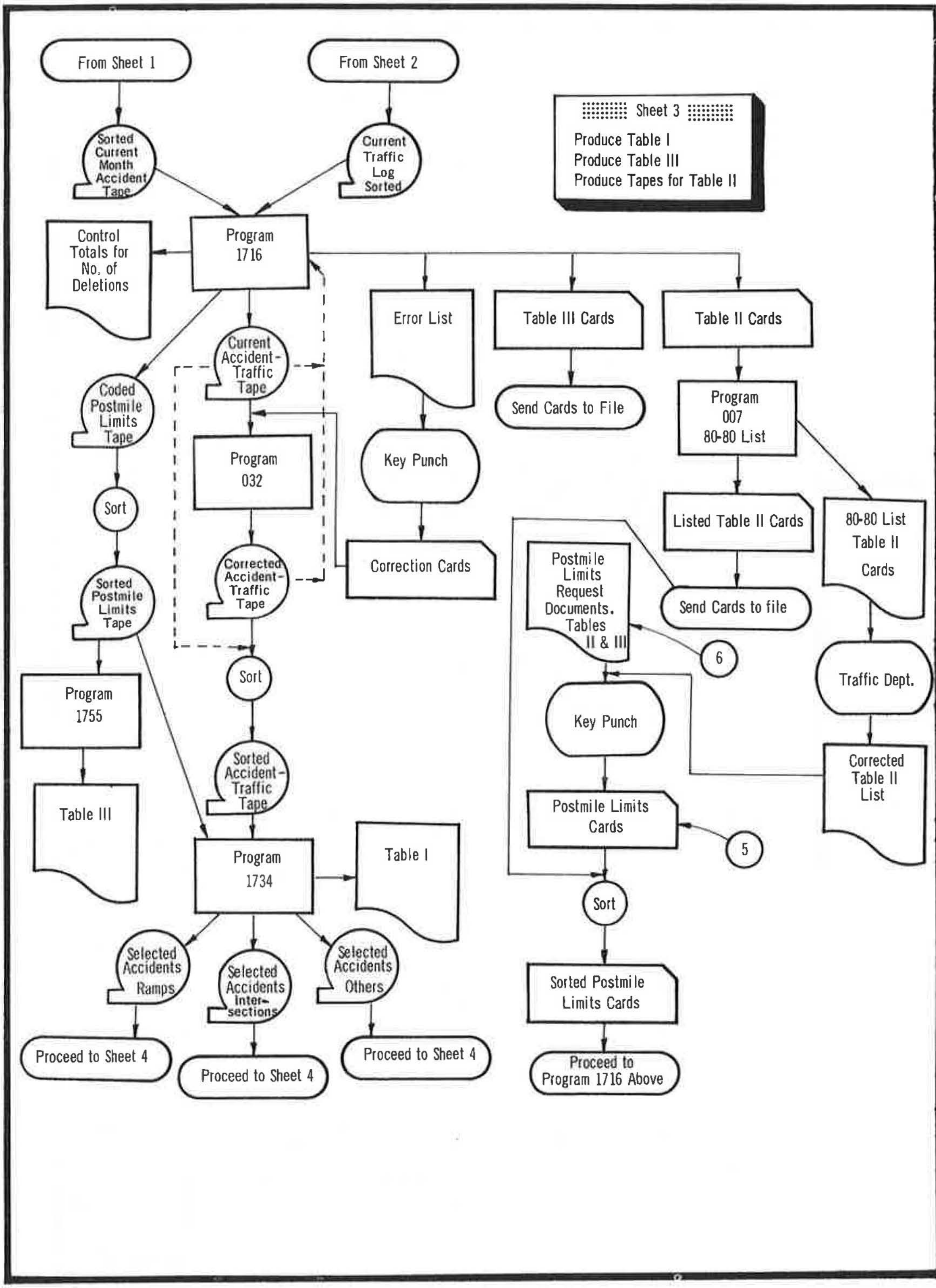


Figure 11, sheet 3.

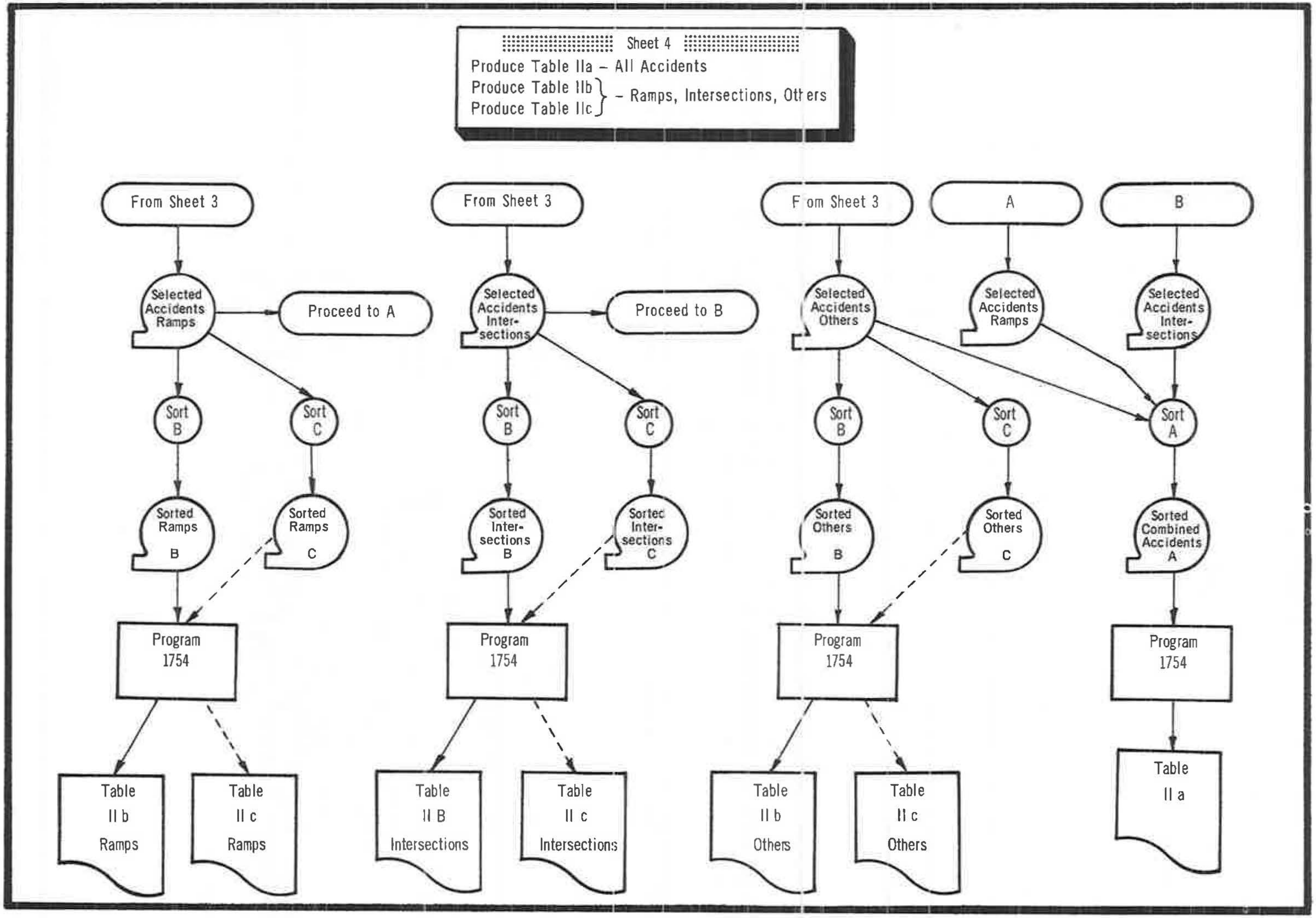


Figure 11, sheet 4.

```
                                     "Fields"
                                                                                              03/28/66   PAGE  277
                   --A- ------B---- -----------C-----------  ----D----  ------E------        -------F-------  ----G---
RTE  SEQ  DIST CO  CITY FED.  R F E       DESCRIPTION        P  BASE E COUNTY LENGTH   ROUTE   TRAVELED  WAY      NO  RD P  N  E
     NO.                AID   / A T                          M  POST / ODOM            ODOM   LEFT    RIGHT  TOT  LN  TP O  /  R
                        RTE   U   C                          C  MILE C                        TP WID TP WID  WID         P  S  R

                    ---J---                                ---------K--------                                                -Z-
                    A.D.T.  A.D.T.  INT. MI. VEH. MILES    CLN.  DATE   PLN.  STATION

101  20950  04  SON SRO  P001  J 6 0  CONTROL COUNT POINT      019.646  019.646 00.000 483.507 C  024  C  024  48  04  F  F  1 F
                 *   21400                                 N03* 07-20-64 E06      + .                                          P

101  20960  04  SON SRO  P001  J 6 0  JCT ST 12 FAP 24         019.646  019.646    .   483.507                              F  F  1 F
                                                                 -  -             + .

                SUB-TOTAL                      *         *


101  20970  04  SON SRO  P001  J 6 0  ST 12 101 SEP 20 208     019.646  019.646 00.046 483.507 C  024  C  024  48  04  F  F  1 F
                 *   26000   28000     .504        1,200   N03* 07-20-64 E06      + .                                         TP

101  20980  04  SON SRO  P001  J 6 0  NE CONNECTOR OC 20 207   019.692  019.692 00.143 483.553 C  024  C  024  48  04  F  F  1 F
                     26182                         3,785   N03* 07-20-64 E06      + .

101  20990  04  SON SRO  P001  J 6 0                           019.835  019.835 00.019 483.696 C  024  C  024  48  04  E  F  1 F
                     26750                           509   N03* 07-20-64 E06      + .

101  21000  04  SON SRO  P001  J 6 0                           019.854  019.854 00.109 483.715 C  024  C  024  48  04  E  F  1 F
                     26826                         2,948   E06  01-01-64          + .                                          L

101  21010  04  SON SRO  P001  J 6 0  SANTA ROSA CR 20 34      019.963  019.963 00.026 483.824 BR 032  BR 032  64  04  E  F  1 F
                     27258                           710   E06  01-01-64          + .

101  21020  04  SON SRO  P001  J 6 0                           019.989  019.989 00.161 483.850 C  024  C  024  48  04  E  F  1 F
                     27362                         4,456   E06  01-01-64          + .

                SUB-TOTAL                   .504*      13,608*
```

Figure 12. Traffic Log.

use postmile values directly in the computer calculations. Route odometer values are used instead. Route odometers are mileage values which are generated for the Traffic Log using the lengths shown in field E of Figure 12. The odometer system is continuous throughout each route within the state and is free from all gaps and duplicate values. Thus, direct subtractions yield true lengths which are required for the accident rate calculation. Odometer values are also used to sort the accident records (and postmile limit records) into order along each route. Difficulties arising from the use of different, non-sequential postmile prefix codes (see Fig. 1, column 7) are thus avoided. Accident and postmile limit records are correlated with the Traffic Log and coded with the odometer values corresponding to their respective postmile values. Route odometer values are recalculated and recoded onto all appropriate documents whenever there has been any change in route lengths.

The postmile prefix codes and the lane codes, along with the effective dates, are used to select out accidents and vehicle-miles of travel that have occurred on realigned or significantly altered sections of highway. The surveillance tables, therefore, contain only information on the current road system.

The Traffic Log is kept current, with updating records added monthly when required. Updating records are added at point (2) in Figure 11, sheet 2.

Accident Records

Accident records consist of 80 columns of coded information (Fig. 1) for each accident. The current accident tape is shown at point (3) in Figure 11, sheet 1, and the monthly addition of new accident records is at point (4). Accident records which fail to pass the consistency check (contain possible errors) are corrected and included in the next month's run. Experience shows that about one percent of the accident records fail to pass the consistency check and it would not be reasonable to delay the production of the surveillance tables to include these few additional accidents.

Postmile Limit Records

The card records of postmile limit locations are shown at point (5) in Figure 11, sheet 3. New or corrected postmile limit records are entered at point (6). These give the postmile limits of the locations requested by the districts for inclusion in the quarterly accident concentration listings (Table 2) and in the detailed accident listings (Table 3). Figures 9 and 10 show the input request forms.

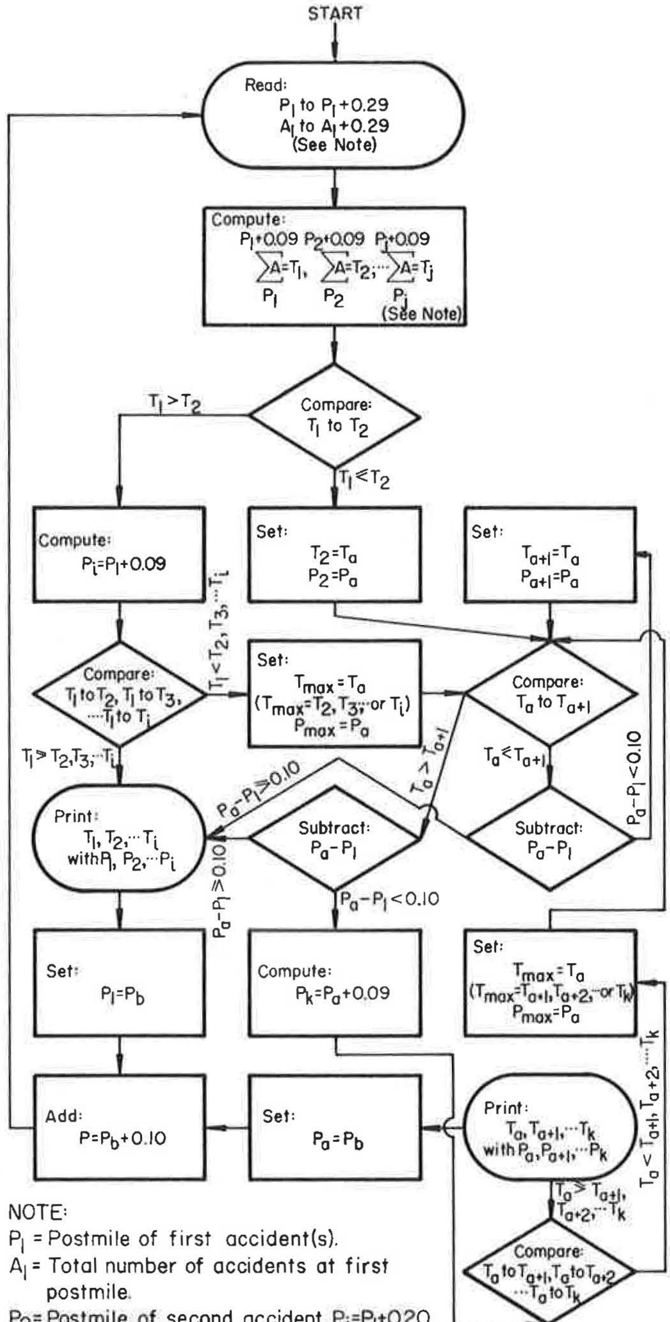
Accident Concentration Selection Procedure

The last portion of the monthly accident summary (Table 1) lists accident concentration locations.

The computer logic is shown in some detail in Figure 13. Accident concentrations in 0.10-mile increments are identified on a floating or sliding scale whereby locations with three or more accidents are selected in such a way that the 0.10-mile increments with the maximum number of accidents are noted. In a few cases, the maximum concentrations and some intervals of 0.09 mile or less containing three or more accidents are not selected. However, in all cases there are concentration points within 0.10 mile to draw attention to the areas.

The selection process consists essentially of comparing successive groupings of "total" accidents to determine which groupings contain the maximum number of accidents. The groupings, of 0.10-mile length, begin at the postmile value of each accident. Note that a particular accident may be included in more than one grouping during the selection process, but that the final concentrations selected are mutually exclusive. The accident information for the concentrations are printed at the postmile of the beginning of the 0.10-mile increment in Table 1.

Table 5 illustrates the concentration selection procedure. The total number of accidents in the concentration intervals that would be selected by the computer program are indicated by asterisks. A portion of the same data is depicted in Figure 7.



NOTE:
P_1 = Postmile of first accident(s).
A_1 = Total number of accidents at first postmile.
P_2 = Postmile of second accident. $P_j = P_1 + 0.20$
Example: $P_1 + 0.29 = 10.34 + 0.29 = 10.63$; $A_1 = 1$; $T_1 = 6$ (See Table 5).
Only "Total" accidents are shown in this diagram since the concentration selection routine applies only to the "Total" accidents. Fatal, Injury, Property Damage Only, Single Vehicle, Multi-Vehicle, Light, Dark, and Types of Accidents are summarized and printed along with the sum of "Total" accidents, in the 0.10 mile increments, at the postmile of the beginning of the concentration point.

Figure 13. Flow diagram for selection of 0.10-mile concentration points.

TABLE 5

SELECTION OF 0.10 MILE CONCENTRATION POINTS

Post-mile	(1)	(2)	Post-mile	(1)	(2)
10.34	1	* 6	11.48	3	*10
10.35	3	5	11.52	1	9
10.37	1	4	11.53	2	9
10.41	1	5	11.54	1	8
10.45	1	* 4	11.56	1	9
10.46	1	3	11.57	2	8
10.47	2	2	11.58	1	* 6
10.59	1	*15	11.61	1	9
10.63	1	14	11.62	1	9
10.64	1	13	11.63	1	9
10.66	10	13	11.64	1	9
10.67	1	5	11.65	1	9
10.68	1	5	11.69	2	*11
10.74	1	10	11.70	2	9
10.76	2	*10	11.71	1	7
10.77	1	8	11.72	1	7
10.78	1	7	11.73	1	6
10.79	1	6	11.74	1	5
10.80	3	6	11.75	1	4
10.81	1	3	11.76	1	3
10.85	1	7	11.78	1	6
10.89	1	* 8	11.81	1	* 5
10.91	3	7	11.86	3	15
10.92	1	4	11.87	1	13
10.93	1	3	11.92	3	*18
10.96	1	2	11.93	7	17
10.97	1	1	11.95	1	11
11.14	1	*15	11.96	1	10
11.15	5	14	11.97	3	9
11.16	2	9	12.00	3	8
11.20	3	8	12.02	2	13
11.21	2	5	12.03	1	11
11.22	1	3	12.09	2	13
11.23	1	3	12.10	8	*14
11.28	1	2	12.14	1	9
11.32	1	2	12.15	1	8
11.38	1	* 3	12.18	1	12
11.46	1	9	12.19	3	11
11.47	1	9	12.21	1	8

(1) Total number of accidents at each postmile.
(2) Total number of accidents in 0.10 mile, beginning at each postmile. Computer logic applied to these values.
* Beginning of concentration points as selected by computer program.

TABLE 5 (Continued)

SELECTION OF 0.10 MILE
CONCENTRATION POINTS

Post-mile	(1)	(2)	Post-mile	(1)	(2)
12.22	1	* 8	12.84	2	16
12.23	1	7	12.85	1	16
12.25	2	8	12.86	6	16
12.26	2	6	12.89	1	*17
12.27	1	6	12.91	3	16
12.31	1	8	12.92	2	13
12.33	1	8	12.93	1	11
12.34	1	7	12.94	2	11
12.36	2	7	12.95	1	9
12.37	2	* 9	12.96	1	9
12.40	1	7	12.97	1	8
12.42	1	6	12.98	5	8
12.45	1	6	13.03	1	*12
12.46	4	6	13.05	1	11
12.53	1	* 7	13.07	1	10
12.55	1	7	13.08	1	9
12.59	2	9	13.09	6	8
12.60	2	7	13.10	2	2
12.61	1	7			
12.63	1	* 7	(End of Route)		
12.67	3	10			
12.70	2	10			
12.71	1	9			
12.74	4	*10			
12.78	1	15			
12.79	2	14			
12.80	1	13			
12.82	2	15			

(1) Total number of accidents at each postmile.

(2) Total number of accidents in 0.10 mile, beginning at each postmile. Computer logic applied to these values.

* Beginning of concentration points as selected by computer program.

Data Processing Costs

Table 6 gives in detail the estimated costs, in computer time and dollars, to produce the three surveillance tables. These are, in summary

Surveillance Table No.	Annual Machine Time, Hours	Cost per Year
I	115	$11,500
II	32	3,200
III	23	2,300
Total	170	$17,000

TABLE 6

Estimated Cost in Dollars for Processing Accident Data Showing Accidents to 0.01 Post Mile And its Concentration Points - Table I

Machine Operation

Month	1/ A1	1/ A2	2/ A3	2/ A4	2/ A5	2/ A6	2/ A7	2/ A8	2/ A9	Total Cost	Hrs. & Minutes
1	35	75	35		42	15	35	35		247	2:30
2	35	75	35	25	62	30	70	70		377	3:45
3	35	75	35	38	82	45	105	105	82	577	5:45
4	35	75	35	50	102	60	140	140		612	6:07
5	35	75	35	62	122	75	175	175		729	7:18
6	35	75	35	75	142	90	210	210	142	989	9:54
7	35	75	35	88	162	105	245	245		965	9:40
8	35	75	35	100	182	120	280	280		1,082	10:50
9	35	75	35	112	202	135	315	315	202	1,401	14:01
10	35	75	35	125	222	150	350	350		1,317	13:10
11	35	75	35	138	242	165	385	385		1,435	14:20
12	35	75	35	150	262	180	420	420	262	1,814	18 09
	420	900	420	963	1,824	1,170	2,730	2,730	688	11,546	115:29

Estimated Cost in Dollars for Processing Accident Data Showing Accident Concentration Points for Ramps, Intersections, and Other Locations

Machine Operation

Table II (a), (b), (c)

Quarter	3/ B1	4/ B2	4/ B3	4/ B4	4/ B5	Total Cost	Hours & Minutes
1st	105	53	53	53	53	317	3:10
2nd	210	105	105	105	105	630	6:19
3rd	315	158	158	158	158	947	9:30
4th	420	210	210	210	210	1,260	12:36
	1,050	526	526	526	526	3,154	31:35

TABLE 6 (Continued)

Estimated Cost for Processing Accident Data
Showing Decoded Information between Postmile Limits
Table III

Machine Operation

Number of Request	5/ Total Cost	Hours and Minutes
30	$ 2,250	22:30

Composite Estimated Cost in Dollars
for Processing Accident Data
Tables I, II, and III

Machine Operation

	Months												Total for Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Cost in Dollars	434	564	1,082	800	916	1,807	1,153	1,269	2,535	1,505	1,622	3,262	16,949
Hours and Minutes	4:21	5:38	10:49	8:00	9:10	18:05	11:32	12:40	25:25	15:03	16:12	32:35	169:30

Notes: All machine costs are based on $100 per hour utilizing the EDP machine #1460.
1/ - 29,000 records processed.
2/ - 10,000 records the 1st month, 20,000 the 2nd month, etc.
3/ - 30,000 records the 1st quarter, 60,000 the 2nd quarter, etc.
4/ - 15,000 records the 1st quarter (3 tabs X 5,000 records), 30,000 the 2nd quarter, etc.
5/ - 40,000 records per request ($75.00 per request).

TABLE 6 (Continued)

ESTIMATED COST PER YEAR FOR PROCESSING TRAFFIC DEPARTMENT"S ACCIDENT DATA

Machine Operation

	Total Yearly Hours	Machine Cost per Hour	Machine Cost for Year	Personnel Cost per Hour	Personnel Cost for Year	Total Machine Rm. Cost for Year
Key Punching - 024	20.0	0.283	$ 6.	2.90	$ 58.	$ 64.
Verifying - 056	20.0	0.355	7.	2.90	58.	65.
Sorting - 082	3.0	0.390	1.	3.27	10.	11.
Computer -1460	169.5	100.000	16,949.			16,949.
Clerical	50.0			4.00	200.	200.
	262.5		$16,963.		$326.	$ 17,289.
Reserve for Contingencies - 40%						$ 6,916.
Reserve for Administrative Overhead						3,285.
Total Machine Operation Charge						$ 27,490.

Key Punch, verifying, and sorting costs are based on 5,000 cards per year.

One-time Costs

Program and Procedures:	Man Days	Man Hours	Man Cost Per Hour	Total Cost
Table I	30	240	$ 4.70	$ 1,128.
Table II (2)	25	200	4.70	940.
Table III	12	96	4.70	451.
EDP Machine (Testing)	**Machine Hours**	**Mach. Cost Per Hour**		
Table I	4	$100		400.
Table II	3½	100		350.
Table III	2	100		200.
				$ 3,469.
Reserve for Contingencies - 40%				$ 1,388.
Reserve for Administrative Overhead				659.
Total One-Time Costs				$ 5,516.

Costs are based on $100 per hour utilizing the IBM 1460 computer. The costs are not independent in that many of the steps required to produce Table 1 are also required for Tables 2 and 3.

The total yearly cost, including keypunching, verifying, sorting, clerical help, contingencies and administrative overhead, is estimated at $27, 500. The total one-time cost to program and test the entire surveillance package is estimated at $5, 500.

An estimate was received from each of the 11 districts of the yearly savings accruable to them with the use of the surveillance program. The total statewide estimate was $57, 500. This compares to the $27, 500 yearly cost to produce the tables by data-processing methods. This results in an estimated net savings to the state of approximately $30, 000 per year.

SUMMARY

The objective of this study was to determine the feasibility of computer editing of accident data by producing tabulations which could be used as aids in identifying, rating and analyzing problem locations.

A complete review of the existing methods of processing, analyzing and using accident data was made. Operations at both the Headquarters and district levels were studied. All reports of accidents on the state highway system are coded for electronic data processing in Headquarters. Various machine tabulations have been made in the past, mostly on a statewide basis. The districts have maintained a separate record of these same accidents and have plotted the accident information on strip maps and accident cards. The plots are reviewed visually for accident concentrations, and various manual summaries made for listings of concentration locations. Detailed reading of accident reports has been necessary to construct accident collision diagrams.

The surveillance system was designed to accomplish by electronic data-processing methods much that is now done manually in the districts. The surveillance tables, developed in close coordination with the districts, consist of the following:

1. A monthly accident summary of all accidents listed in route order. This tabulation also lists cumulative numbers of accidents and 0.10-mile accident concentrations where three or more accidents have occurred.
2. A quarterly accident concentration listing which is arrayed three ways: in route order, in order of decreasing number of accidents, and in order of decreasing accident rates. Locations to be included in this listing, along with their postmile limits, are furnished by the districts.
3. A detailed accident listing which lists the details of each accident between limits specified by the districts. This tabulation is produced as often as twice monthly if required.

The surveillance program is feasible from a machine processing standpoint. The surveillance tabulations should eliminate or reduce much of the present laborious manual postings, listings, and calculations required to develop accident information. The system provides up-to-date information that should result in a better surveillance of the state highway system for developing accident concentrations.

It is estimated that this expanded use of electronic data processing will provide the state with a net savings of approximately $30,000 per year.

The production of the surveillance tables was initiated in October 1965; thus, little experience in the use of the tables is yet available.

It is not expected that the program as outlined in this report is final. Undoubtedly changes and modifications will occur as dictated by experience. It will take at least a year to fully evaluate the usefulness and economics of this surveillance system.

ACKNOWLEDGMENTS

Many individuals made valuable contributions to the development of this accident surveillance program. Appreciation is expressed to all of the district traffic personnel who contributed their thoughts and experience.

Special acknowledgment is made to Blair Geddes, District 03 Traffic Engineer; R. L. Richardson, District 04 Traffic Engineer—Administration; Albert M. Smilie and Albert Kaufman, District 07 Traffic Operations Section; and George B. Gurnett, Accident Statistics and Analysis Unit, County of Los Angeles Road Department, who offered particulary valuable assistance.

The systems analysis and the writing of the actual computer programs are being accomplished by Troy Riley, William Dair, and others of the Headquarters Computer Systems Department. Their continuing suggestions for improvements are gratefully appreciated.

Motor Vehicle Accident Costs in the Washington Metropolitan Area

GERARD L. DRAKE, Principal Associate, and
MERWYN A. KRAFT, Project Director, Wilbur Smith and Associates

•THE need exists for comprehensive and accurate data on costs of motor vehicle accidents in a form that will allow analysis and precise evaluation of the national highway transportation system from the standpoint of losses through traffic accidents.

Most previous estimates of motor vehicle accident costs have been based on insufficient data and have lacked precise detail. As a result, these estimates have been questionable and have been of relatively little use in practical problems of highway planning and traffic control where detail and precise measurement are required. This is not to imply that these past estimates were valueless. They represented an honest and sincere attempt to evaluate accident losses, and if better data had been available they would have been refined further. They also indicated recognition of the need for motor vehicle accident cost data and served as a forerunner for the comprehensive motor vehicle accident cost study.

The Washington Area Motor Vehicle Accident Cost Study is the first comprehensive study of traffic accident costs to concentrate on a predominantly urban area (1). The study benefited from results of several previous projects of this type undertaken on a statewide basis in Massachusetts, Utah, New Mexico, Illinois and Ohio. Procedures were utilized which were developed by a special committee of the Highway Research Board, of which the Project Director was a member, and outlined in a manual of procedures published by the U.S. Bureau of Public Roads (2). The fundamental theory applied was that the cost of motor vehicle accidents may be represented by the money value of damages and losses to persons and property plus expenditures in connection with the accident potential. According to this theory, it is immaterial whether damages are repaired or losses recovered.

PURPOSE AND SCOPE OF STUDY

The primary objective of this study was to determine the cost of motor vehicle accidents and incidents occurring in the Washington Metropolitan Area during a 12-month period and involving Washington area residents. The study also was designed to permit detailed analyses of accident frequencies and costs related to pertinent variables of the highway, vehicle, driver, environment, and traffic operations. Also to be determined were the various elements of cost attributable to these accidents.

The accurate measurement of accident cost elements, and the determination of accident frequencies and costs associated with the many variables to be considered, required in-depth interviews with persons (owners, drivers, pedestrians, passengers) involved in motor vehicle accidents which had occurred within the study area. Only direct costs were considered and these costs only as they applied to vehicles registered within the study area. Costs related to vehicles registered outside the study area were excluded, even though these vehicles may have been involved in accidents within the area. This followed the pattern used in previous studies of this type; thus, only the direct costs specifically applicable to the Washington Metropolitan Area were measured.

Paper sponsored by Committee on Highway Safety and presented at the 46th Annual Meeting.

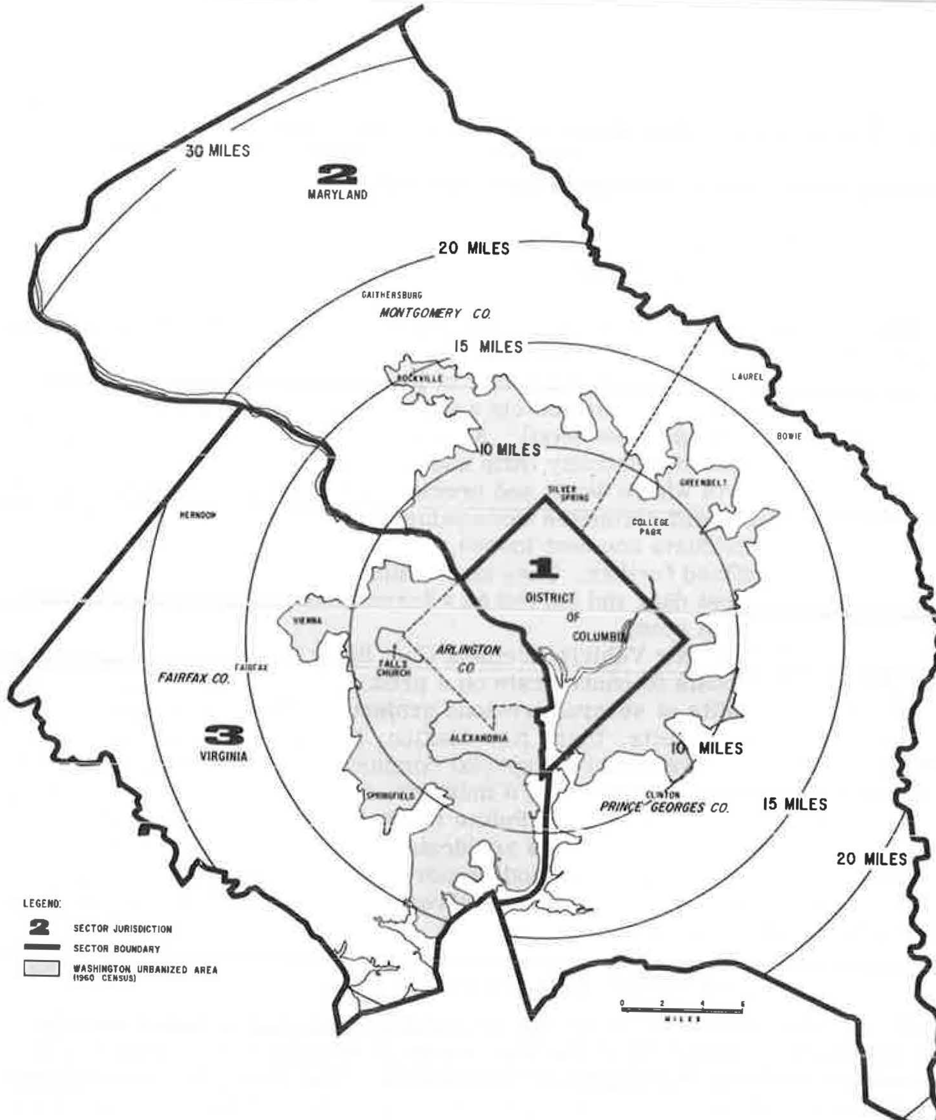


Figure 1. The study area.

Also, certain types of motor vehicles were excluded from the study, namely buses, motorcycles, motor scooters, fire equipment or other emergency vehicles, vehicles with diplomatic license plates, and miscellaneous vehicles used primarily on farms or for construction purposes. When such vehicles were involved in accidents with one or more "in-scope" vehicles, the cost of the "out-of-scope" vehicle involvement was not determined.

Only those vehicles which were involved in accidents from April 1, 1964, through March 31, 1965, or which were registered in the area on June 30, 1964 were considered in this study. This 12-month period represented most nearly the vehicle registration year for the three jurisdictions (District of Columbia, Maryland, and Virginia) and provided a good common base from which to select interview samples.

The study area was the Washington, D. C., Standard Metropolitan Statistical Area used for 1960 census purposes. This area (Fig. 1) covers almost 1,500 square miles and had a 1960 population of 2,002,000. The urbanized parts of the study area, which include the District of Columbia and contiguous suburban areas of Maryland and Virginia, are represented by the shaded area in Figure 1.

SAMPLING PROCEDURES

Since this study was organized to compile data on monetary losses incurred by residents from both reported and unreported accidents and incidents, systematic samples were selected from official police records for the study of reported involvements and from motor vehicle registration lists for the study of unreported involvements. Home interviews were conducted in connection with the sample of reported involvements, and mail questionnaires were issued to the vehicle owners included in the sample of unreported involvements; home interviews also were conducted with the latter vehicle owners identified as having been involved in the unreported accidents.

The police accident records of each jurisdiction were systematically sampled after they had been stratified (to reduce sample variability) on the basis of accident severity and vehicle class. There were three primary accident severity categories—fatal injury, nonfatal injury, and property-damage-only—although the latter two categories were subdivided for certain purposes. For example, because of special interest in freeway accident experience, freeway accidents involving a nonfatal injury or property-damage-only were distinguished in the sampling process from accidents occurring on other types of roadway. Taxicabs were included in this study and treated as a separate vehicle class, as were passenger cars, single unit trucks, and truck combinations.

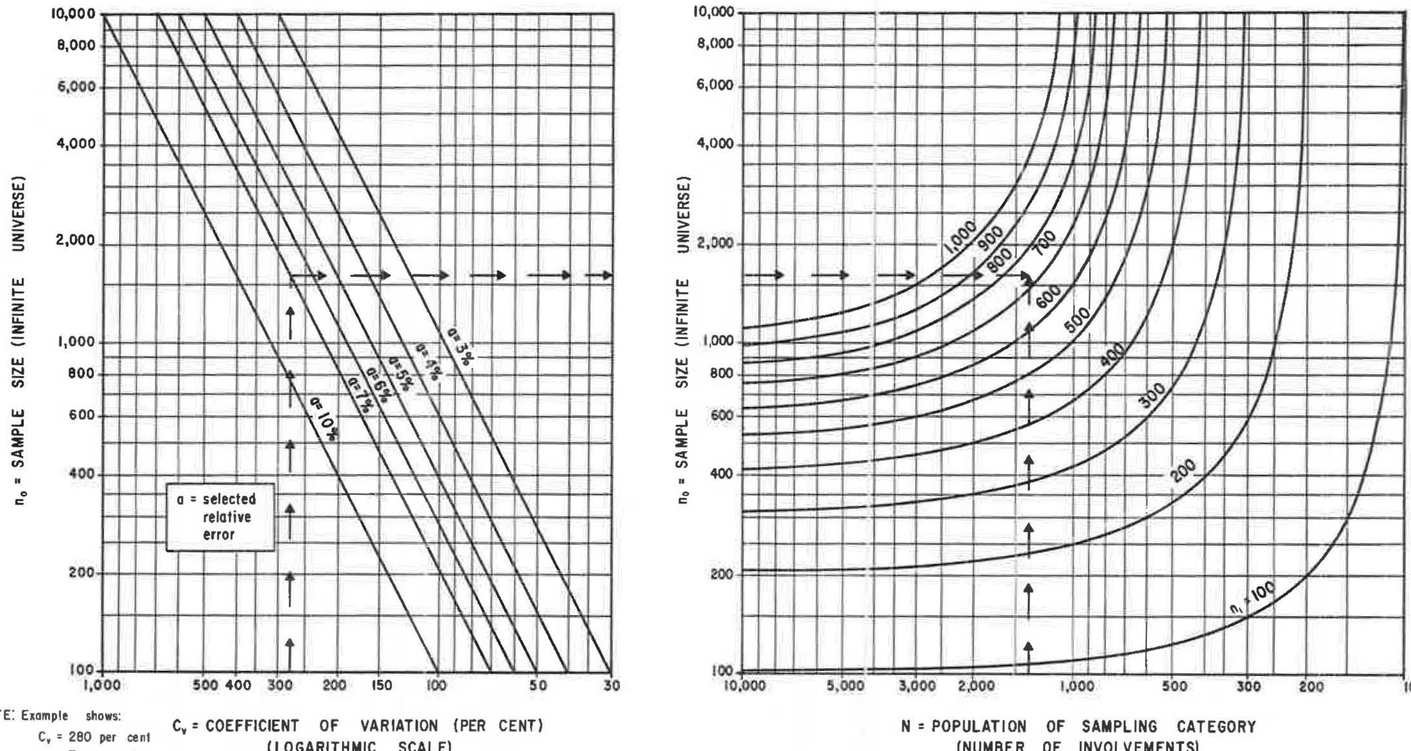
The net result of this categorization according to accident severity, class of vehicle, and special highway type was a matrix of 32 cells for each of the three vehicle registration jurisdictions, i.e., four classes of vehicles (passenger cars, single unit trucks, truck combinations, and taxicabs) according to eight categories of accident severity as follows:

1. Fatal injury;
2. Nonfatal injury to three or more persons;
3. High-cost property damage ($5,000 or more) with a nonfatal injury;
4. High-cost property damage ($5,000 or more) with property-damage-only;
5. Nonfatal injury on a freeway;
6. Property-damage-only on a freeway;
7. Other nonfatal injury; and
8. Other property-damage-only.

A 100 percent sample was selected for all involvements in accidents where (a) a fatal injury occurred, or (b) injuries occurred to three or more persons, or (c) property damage was estimated as $5,000 or more. The importance of these categories of accident involvements, and the relatively low numbers of cases expected in each, made complete sampling essential. The sampling ratios established for other involvement categories depended on selected confidence levels and accuracy requirements for cost determination. Prior experience suggested coefficients of variation in accident costs of 200 to 280 percent. Computation of the sample size for each involvement category was simplified by the use of the nomograph shown in Figure 2, which is based on a confidence level of 68 percent. A 7.0 percent relative error was specified as the desired level of accuracy in the cost determinations.[1] On this basis, a total of 13,881 samples (12.9 percent) was selected from 107,618 recorded involvements.

The same statistical techniques used in selecting reported accident involvement samples from police records were used in the selection of samples from the registration records. Of the 771,198 in-scope vehicles registered as of June 30, 1964, within the study area, 13,153 (1.7 percent) were selected for study.

[1]For this study, relative error represented the absolute error expressed as a percentage of the mean of the universe.



NOTE: Example shows:

C_v = 280 per cent

a = 7 per cent

n_0 = 1,600

N = 1,400

n_1 = 700

Figure 2. Sample size relationship, confidence level = 0.68.

TABLE 1

TOTAL COSTS OF ACCIDENTS AND INCIDENTS[1]

Category	Annual Cost ($)	Percent
Traffic accidents/incidents		
Reported	50,660,655	72.8
Unreported	18,922,020	27.2
Subtotal	69,582,675	100.0
Nontraffic accidents/incidents		
Reported	188,421	3.0
Unreported	6,099,470	97.0
Subtotal	6,287,891	100.0
Combined traffic and nontraffic accidents/incidents		
Reported	50,849,076	67.0
Unreported	25,021,490	33.0
Total	75,870,566	100.0

[1]Involving in-scope vehicles only.

TOTAL DIRECT COSTS

The total direct cost of motor vehicle accidents and incidents during the 12 months covered by the study amounted to \$81,870,000. This total consisted of \$75,870,000 (93 percent) related to in-area involvements and \$6,000,000 (7 percent) related to out-of-area involvements. The in-area cost was distributed as shown in Table 1 among reported and unreported traffic accidents and incidents, and nontraffic accidents and incidents. Unreported involvements resulted in one-third of the total cost (Fig. 3).

The costs of reported and unreported in-area accidents and incidents which occurred in each jurisdiction of the study area are given in Table 2. Whereas unreported involvements accounted for one-fourth of the total cost in the District (the central area of Washington), they accounted for more than one-third of the cost of all involvements in the suburbs. This relationship may provide a basis for expanding available cost data for other metropolitan areas where the data are similarly categorized.

COST ELEMENTS

The total cost of reported in-area involvements in traffic accidents relating to Washington area residents was \$50,660,655 for the study period (Table 2). Delineation of the various elements of direct cost associated with these traffic accidents was an important aspect of the project. One or more of 24 individual elements of direct cost were recorded where applicable. Ten of them pertain to property damage costs of an involvement, and 14 relate to personal injury costs. Differences in cost elements also were established according to accident severity.

Table 3 summarizes the number of reported involvements and direct costs associated with each of the applicable cost elements. Property damage costs represented only about 2 percent of the total cost in fatal injury involvements, whereas loss of future earnings accounted for 91 percent. In nonfatal injury cases, the costs were evenly divided between property damage losses and personal injury costs (Fig. 4).

TABLE 2

TOTAL COSTS OF ACCIDENTS AND INCIDENTS BY JURISDICTION OF OCCURRENCE[1]

Area	Annual Cost ($)	Percent
District of Columbia		
Reported	16,414,929	74.5
Unreported	5,606,480	25.5
Subtotal	22,021,409	100.0
Maryland		
Reported	21,690,188	66.3
Unreported	10,980,570	33.7
Subtotal	32,670,758	100.0
Virginia		
Reported	12,743,959	60.2
Unreported	8,434,440	39.8
Subtotal	21,178,399	100.0
Total reported and unreported		
District of Columbia	22,021,409	29.1
Maryland	32,670,758	43.0
Virginia	21,178,399	27.9
Total	75,870,566	100.0

[1]Involving in-scope vehicles only.

Considering all reported involvements regardless of severity, 45.2 percent (\$22,883,000) of the \$50,661,000 total cost concerned damages to vehicles, 26.7 percent (\$13,525,000) was the present value of loss of future earnings, and all other cost elements combined accounted for 28.1 percent (\$14,253,000). Of the latter amount, the value of work time lost accounted for \$3,651,000; legal and court costs amounted to \$2,475,000; doctor bills accounted for \$1,952,000; hospitalization costs added \$1,494,000; and all other costs amounted to \$4,681,000.

The Washington Area Motor Vehicle Accident Cost Study was the first study of its type to include in the cost determinations the present value of loss of future earnings for persons fatally injured or permanently impaired. Potential earnings based on age, sex, employment status, education level, the extent of

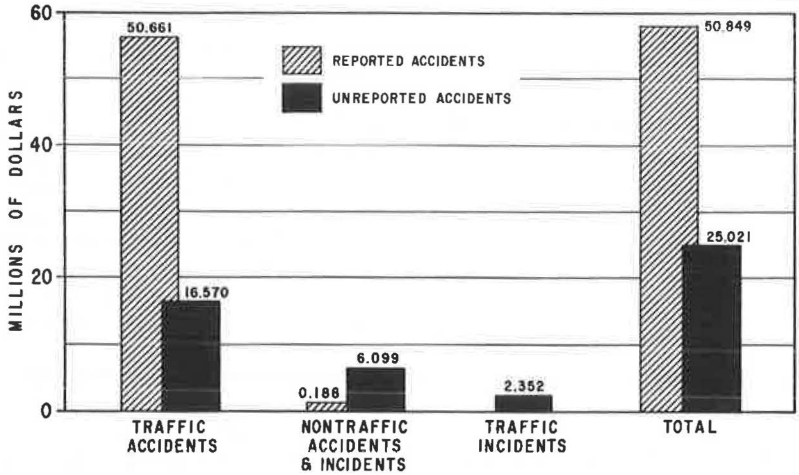


Figure 3. Distribution of direct costs of motor vehicle accidents and incidents, April 1, 1964 to March 31, 1965.

disability, and other factors were considered in these calculations. The procedure required that the potential earnings of the deceased person be considered had he or she enjoyed a normal work life; any reductions in long-term earning capabilities of injured persons also were considered. Anticipated earnings were based on Bureau of the Census data obtained from special tabulations prepared for the District of Columbia. Estimated 1964 wage and salary data related to education, race, and sex classifications of employed persons were utilized.

Loss of future earnings incurred by Washington area residents in fatal injury cases amounted to nearly $63,000 per involvement, and almost $36,000 per involvement in nonfatal injury cases. Damages to the case vehicle averaged $996 in fatal injury cases compared with $427 for nonfatal injury cases and $197 for cases involving property-damage-only. Considering all severity classes combined, damages to vehicles averaged $270 per vehicle.

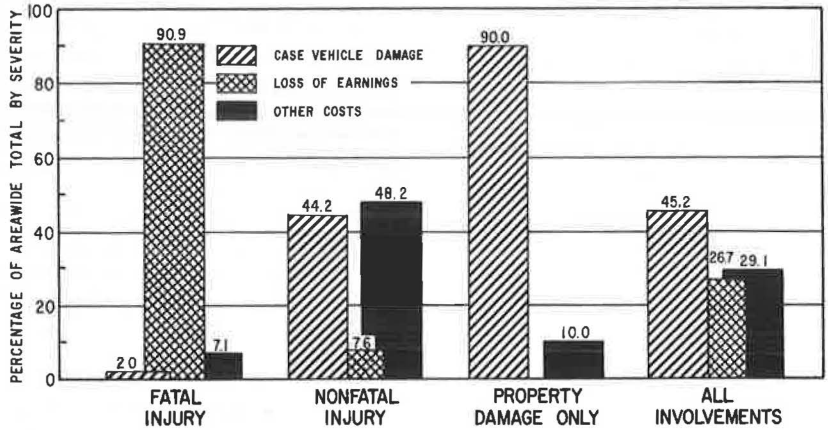


Figure 4. Percentages of direct costs by cost element and accident severity.

TABLE 3

AREAWIDE VEHICLE INVOLVEMENTS AND DIRECT COSTS CLASSIFIED BY COST ELEMENT

Cost Element	Involvements[1]	Direct Costs ($)	Avg. Cost[2] ($)	Percent of Total	Percent of Subtotal
(a) Fatal Injury Involvements					
Property damage					
Damage to case vehicle	244	243,036	996	2.0	85.5
Property in case vehicle	21	4,996	238	0.0	1.8
Outside vehicle/not other vehicle	23	3,962	172	0.0	1.4
Misc. costs with property damage	7	113	16	0.0	—
Vehicle rental fee/lost income	6	822	137	0.0	0.3
Rental income lost	—	—	—	—	—
Worktime lost (owner/driver)	71	18,498	261	0.1	6.5
Worktime lost by others	7	264	38	0.0	0.1
Legal and court costs	34	12,084	355	0.1	4.2
Surplus damages collected	4	700	175	0.0	0.2
Subtotal—property damage	—	284,475	—	2.2	100.0
Personal Injury					
Ambulance	206	5,326	26	0.0	0.0
Other transportation	56	2,056	38	0.0	0.0
Doctor/dentist	137	99,069	723	0.8	0.8
Private nursing	22	3,459	157	0.0	0.0
Hospitalization	149	103,595	695	0.8	0.9
Drugs, appliances, etc.	61	3,811	62	0.0	0.0
Miscellaneous items	67	4,285	64	0.0	0.0
Funeral expenses	178	189,232	1,063	1.5	1.5
Value of time lost by injured	70	63,456	907	0.5	0.5
Value of time lost by others	87	40,111	461	0.3	0.3
Special domestic services	3	434	145	0.0	0.0
Legal/court costs	104	353,772	3,402	2.8	2.9
Surplus damages	29	27,097	934	0.2	0.2
Loss of future earnings	185	11,639,841	62,918	90.9	92.9
Subtotal—personal injury	—	12,535,544	—	97.8	100.0
Total—all cost elements	—	12,820,019	—	100.0	—
(b) Nonfatal Injury Involvements					
Property damage					
Damage to case vehicle	25,725	10,984,997	427	44.2	89.2
Property in case vehicle	692	43,484	63	0.2	0.3
Outside vehicle/not other vehicle	1,021	143,921	141	0.6	1.2
Misc. costs with property damage	1,113	35,188	32	0.1	0.3
Vehicle rental fee/lost income	2,384	266,274	112	1.1	2.2
Rental income lost	387	80,058	207	0.3	0.6
Worktime lost (owner/driver)	7,260	495,104	68	2.0	4.0
Worktime lost by others	782	32,549	42	0.1	0.3
Legal and court costs	1,976	205,804	104	0.8	1.7
Surplus damages collected	309	30,676	99	0.1	0.2
Subtotal—property damage	—	12,318,055	—	49.5	100.0
Personal injury					
Ambulance	6,532	148,287	23	0.6	1.2
Other transportation	3,303	78,980	24	0.3	0.6
Doctor/dentist	12,300	1,853,129	151	7.4	14.7
Private nursing	237	43,119	182	0.2	0.3
Hospitalization	8,609	1,390,389	162	5.6	11.1
Drugs, appliances, etc.	4,853	153,973	32	0.6	1.2
Miscellaneous items	1,570	66,034	42	0.3	0.5
Funeral expenses	—	—	—	—	—
Value of time lost by injured	7,702	2,131,407	277	8.6	17.0
Value of time lost by others	1,661	184,810	111	0.7	1.5
Special domestic services	550	45,420	83	0.2	0.4
Legal/court costs	3,450	1,959,972	568	7.9	15.6
Surplus damages	4,896	2,630,546	537	10.5	20.9
Loss of future earnings	53	1,884,941	35,565	7.6	15.0
Subtotal—personal injury	—	12,571,007	—	50.5	100.0
Total—all cost elements	—	24,889,062	—	100.0	—
(c) Property-Damage-Only Involvements					
Property damage					
Damage to case vehicle	59,086	11,654,801	197	90.0	
Property in case vehicle	464	22,324	48	0.2	
Outside vehicle/not other vehicle	845	125,759	149	1.0	
Misc. cost with property damage	1,706	44,572	26	0.3	
Vehicle rental fee/lost income	2,390	205,373	86	1.6	
Rental income lost	621	39,708	64	0.3	
Worktime lost (owner/driver)	13,751	646,635	47	5.0	
Worktime lost by others	998	35,662	36	0.3	
Legal and court costs	1,588	161,252	102	1.2	
Surplus damages collected	315	13,488	43	0.1	
Total	—	12,951,574	—	100.0	

[1]Number of involvements associated with each cost element; several cost elements can be associated with a single vehicle involvement. In (a), there were 5 "fatal injury involvements" with no costs; 265 had one or more cost elements. In (b), there were 1,187 "nonfatal injury involvements" with no costs; 27,633 had one or more cost elements. In (c), there were 7,108 "property-damage-only involvements" with no costs; 59,902 had one or more cost elements.

[2]Average cost for involvements having that cost element.

Legal and court costs averaged about $100 per vehicle involvement for cases involving property-damage-only, but over $500 for nonfatal injury cases and $3,400 for those involving a fatal injury. Including all relevant cost elements, the average cost related to all 202 persons fatally injured in the involvements covered by this study was $59,200, and the average for all 21,477 nonfatally injured persons was about $600.

Doctor bills averaged $127 per person, and hospitalization costs averaged $136 for persons who incurred these costs. Funeral expenses averaged slightly less than $1,000 per person.

AVERAGE TRAFFIC ACCIDENT INVOLVEMENT COSTS

The $50,661,000 total direct cost of reported traffic accident involvements in the 12-month study period (involving in-scope vehicles) was the result of 96,100 individual vehicle involvements. Although only 0.3 percent of the total were classified as fatal injury involvements, these averaged over $47,000 per case and accounted for about one-fourth of the total cost. Nonfatal injury involvements accounted for almost one-half of the total cost and averaged $863 per case. Almost 70 percent of the cases involved property-damage-only; these accounted for one-fourth of the total cost and averaged $193 per case. The overall average cost was $527 per vehicle involvement. (As previously indicated, these are average costs associated with the case vehicles; they do not represent costs for all vehicles involved in the accidents.)

Of the 96,100 reported vehicle involvements, 88.5 percent pertained to passenger cars, and these passenger car involvements accounted for 92.0 percent of the total cost. The average cost of passenger car involvements was $548 compared with $402 for taxicabs and only $349 for trucks (Fig. 5). The differences were probably due to differences in vehicle occupancy rates, operating speeds, and relative vulnerability to damage.

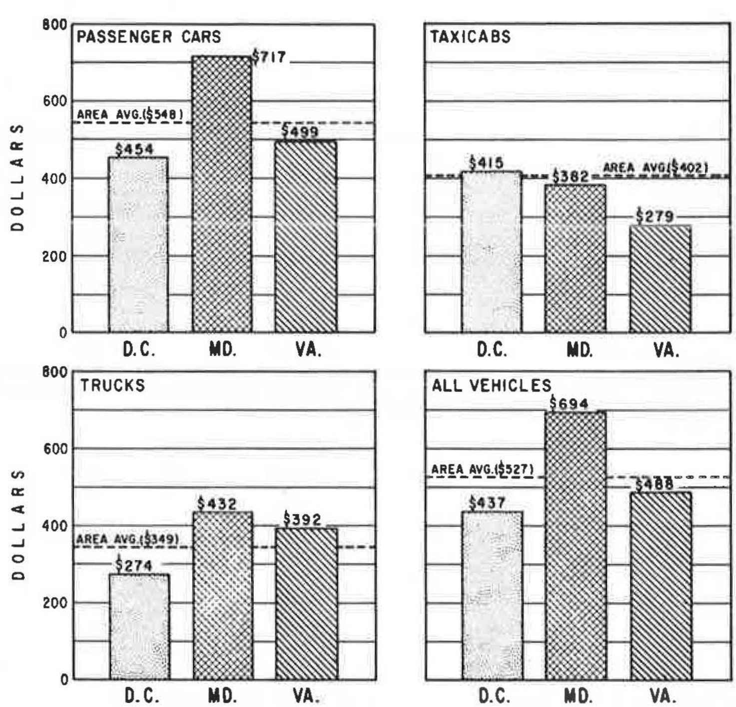


Figure 5. Average direct cost per involvement by vehicle class and sector of occurrence.

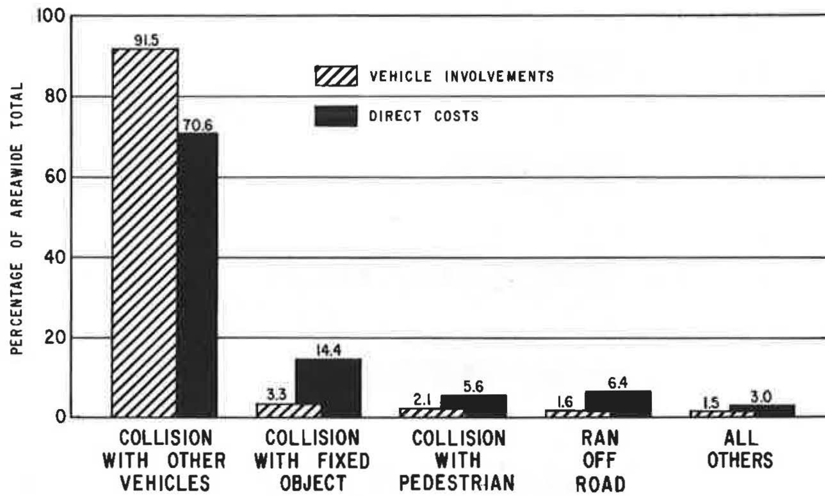


Figure 6. Percentages of vehicle involvements and direct costs by type of accident.

Other findings of the study relative to average involvement costs include the following:

1. Over 90 percent of the reported vehicle involvements were in multiple-vehicle collisions, the average direct cost of which was about $400 per involvement compared with the $527 overall average for all involvements (Fig. 6). The average costs of the relatively few collisions with pedestrians, bicyclists, or fixed objects were, of course, much higher.

2. The average direct cost of involvements on two-way divided highways with only partial control of access was substantially higher than where either full acess control or no access control was provided.

3. The average direct cost of involvements on one-way streets ($300) was substantially lower than that for either two-way divided or two-way undivided streets and highways in the study area ($500 to $600).

4. The average cost of involvements on express highways (freeways, expressways, or parkways) was much higher at $800 than the averages for arterial or local streets ($400 to $600), probably reflecting the higher speeds on the express highways.

5. The average cost of intersection involvements where stop signs were provided was somewhat higher than that where traffic signals were installed.

6. The average cost of involvements which occurred in portions of the area classified as rural was much higher ($1,400) than the average for involvements in the central urbanized portions ($500), probably reflecting the higher speeds attainable in the rural areas.

7. The average cost of involvements during the early morning hours between midnight and 6:00 a.m. ($800) was much higher than the averages for other periods of the day (Fig. 7).

8. The average cost of involvements which occurred during darkness ($700) was substantially higher than the average for those which occurred during daylight ($400). Where street lighting was provided, the average cost of involvements at night was less than one-half what it was for involvements where no street lighting was provided.

9. Rear-end collisions accounted for about one-third of the total direct cost of reported traffic accidents and averaged about $350 per involvement compared with the $400 average for all multiple-vehicle involvements. The vehicle that was struck incurred higher costs on the average than the vehicle that did the striking.

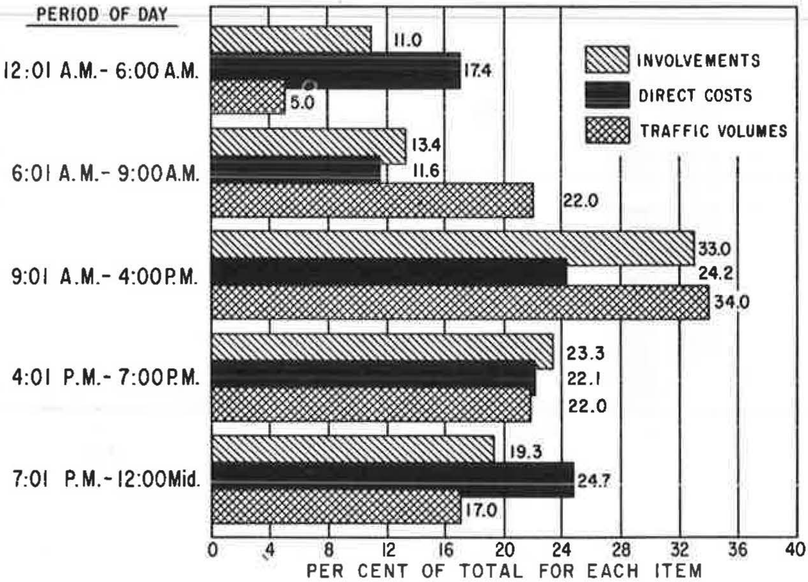


Figure 7. Percentages of vehicle involvements, direct costs and traffic volumes by period of the day.

10. The average cost of overtaking and passing involvements ($250) was much lower than either that for angle collisions ($450) or opposite direction collisions ($900).

ACCIDENT INVOLVEMENT AND COST RATES

During the study period, 0.12 of an involvement per registered vehicle occurred in the Washington Metropolitan Area—about one for every eight vehicles. The rate of involvement for passenger cars was 14.3 involvements per million in-area vehicle-miles of travel (Table 4). The comparable rate for trucks was only 11.4, but the rate for taxicabs was 16.7.

On a cost basis, the Washington area involvements studied cost 0.75 cent per vehicle-mile of travel; the rate for passenger cars (0.79 cent) was almost double that for trucks (0.40 cent) and about 20 percent higher than the rate for taxicabs (0.67 cent).

An earlier statewide study of accident costs in Massachusetts produced very similar results; the average direct cost of Massachusetts' accidents in urban areas was 0.76 cent per vehicle-mile. This figure compared with 0.11 cent per vehicle-mile for rural areas and a statewide average of 0.43 cent per vehicle-mile.

Although the average cost of involvements on the Interstate highways in the Washington area was relatively high, the involvement rate was very low. Whereas there were 14.2 reported traffic accident involvements per million vehicle-miles of travel on all

TABLE 4

INVOLVEMENT AND COST RATES BY VEHICLE CLASS[1]

Class	Involvements per Vehicle	Involvements per Million Vehicle-Miles	Cost per Vehicle-Mile (cents)
Passenger cars	0.12	14.3	0.79
Taxicabs	0.38	16.7	0.67
Trucks	0.13	11.4	0.40
All vehicle classes	0.12	14.2	0.75

[1]Related to involvements of in-scope vehicles and in-area vehicle mileage by in-scope vehicles.

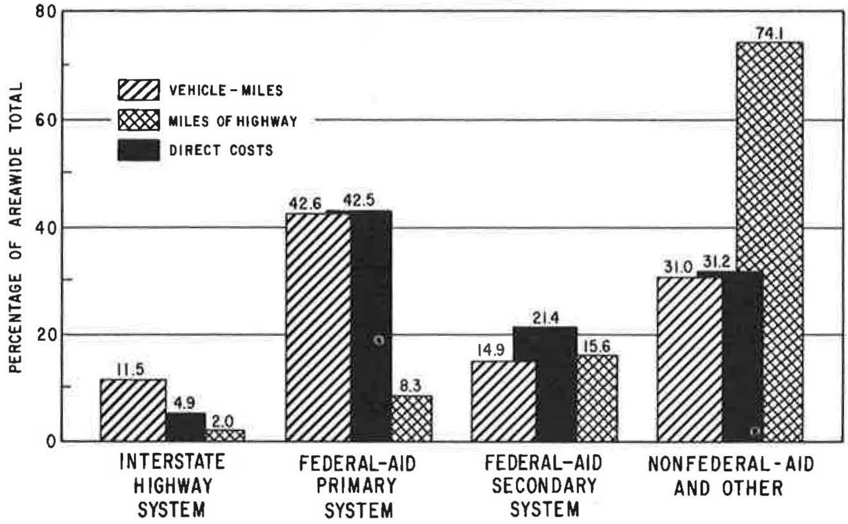


Figure 8. Percentages of direct costs, miles of highway and vehicle-miles of travel by administrative highway system.

TABLE 5

INVOLVEMENT AND COST RATES FOR ADMINISTRATIVE HIGHWAY SYSTEMS[1] (1964-1965)

Highway System	Involvements per Million Vehicle-Miles	Cost per Vehicle-Mile (cents)
Interstate	3.7	0.31
Federal-aid primary	12.7	0.75
Federal-aid secondary	19.7	1.08
Nonfederal-aid	16.2	0.70
All systems	14.2	0.75

[1]Related to involvements of in-scope vehicles and in-area vehicle mileage by in-scope vehicles.

streets and highways (related to in-scope vehicles), the rate was only 3.7 for the 133 miles of completed Interstate highways.

The Interstate highway system in the Washington area carried 11.5 percent of the total vehicle-miles of travel and was the location of only 3 percent of the accident involvements (Fig. 8). Involvements on the Interstate routes cost only 0.31 cent per vehicle-mile of travel compared with the 0.75 cent per vehicle-mile average rate for all streets and highways. The involvement and cost rates for highways on the Federal-aid secondary system were particularly high (Table 5). The apparent 0.44 cent per vehicle-mile accident cost saving from operations on freeways, expressways, and parkways as compared with conventional streets in the Washington area compares with freeway savings of 0.50 to 0.75 cent per vehicle-mile estimated previously by various analysts for general applications.

APPLICATIONS OF ACCIDENT COST DATA

This study established the dimensions of the problem of accident costs in a major urban area. The main elements of traffic accident costs were identified and the magnitudes of costs associated with various types of highways, vehicles, drivers, and general environmental factors were measured. Available data on accident exposure were used to calculate involvement cost rates. These findings should be valuable in many traffic safety applications in that they indicate areas where available financial and other resources should be spent to do the most good.

Further, there are indications that data of the type collected in this study can be used to quantify the accident cost savings to be expected from specific improvements.

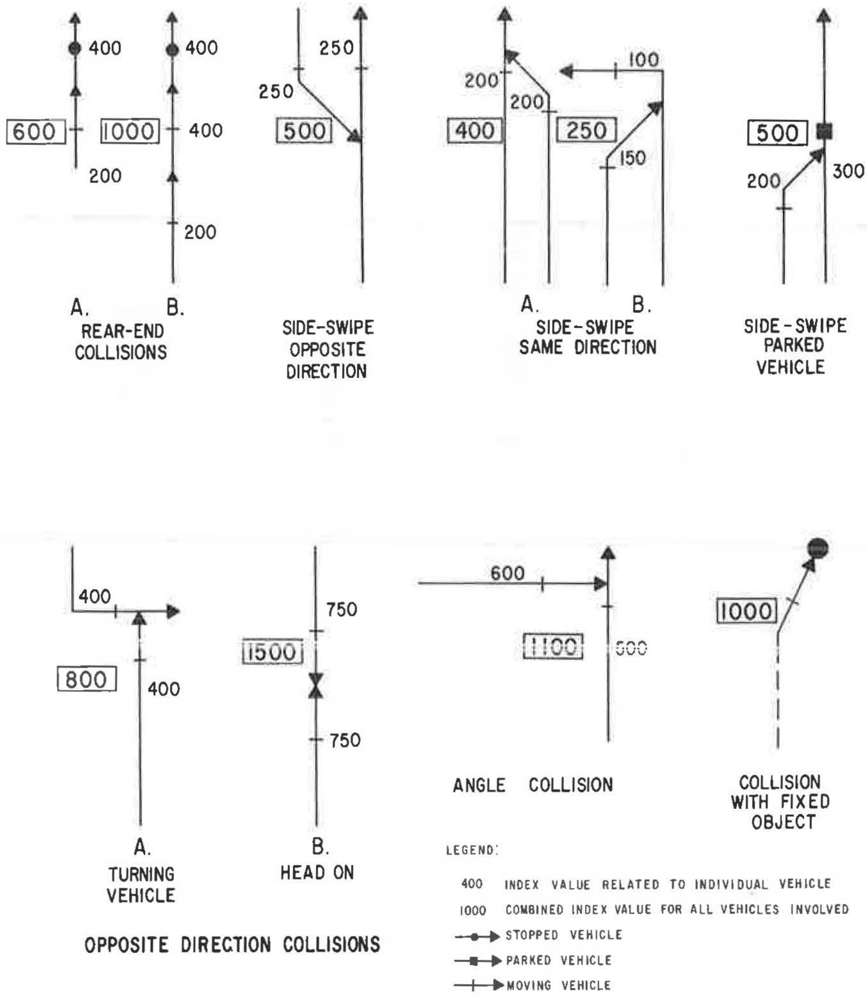


Figure 9. Representative cost-severity index values.

Improvement priorities can be established through the calculation of a cost-severity index based on mean costs of various types of accidents.[2]

For example, the mean cost of rear-end collisions involving two vehicles can be derived by summing the mean cost for vehicles struck from behind (about $400, excluding any loss of future earnings) and that for the striking vehicles (about $200), yielding a combined mean cost of $600. The combined mean cost of rear-end collisions involving three vehicles would be about $1,000. Similarly, an angle collision between two vehicles at an intersection would be valued at $1,100 with $600 derived from the vehicle which approached from the left and $500 from the vehicle which approached from the right. Unit index values (Fig. 9) can be developed by assigning one point for every dollar of mean cost.

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[2] Accidents were classified in this study according to type and with respect to the relative positions of the vehicles involved and related circumstances based on a classification system developed by the Project Director.

TABLE 6

APPLICATION OF THE COST-SEVERTIY INDEX CONCEPT

Type of Collision	Unit Value	Location 1[1]		Location 2[1]		Location 3[1]	
		Number of Accidents[2]	Cost-Severity Index[3]	Number of Accidents[2]	Cost-Severity Index[3]	Number of Accidents[2]	Cost-Severity Index[3]
Rear-end, 2 vehicles	600	20 (2)	14,400	16 (12)	24,000	8 (4)	9,600
Rear-end, 3 vehicles	1,000	2	2,000	4	4,000	–	–
Side-swipe, one vehicle turns	250	82 (4)	22,500	6 (2)	2,500	12 (1)	3,500
Side-swipe, one vehicle parked	500	–	–	2	1,000	–	–
Side-swipe, other	400	6	2,400	2	800	–	–
Angle	1,100	6	6,600	8 (2)	13,200	2	2,200
Opposite direction, head-on	1,500	2	3,000	2 (2)	9,000	2 (2)	9,000
Opposite direction, angle	500	–	–	–	–	–	–
Opposite direction, vehicle turns	800	–	–	–	–	6 (2)	8,000
Collision with fixed object	1,000	6 (2)	10,000	4 (2)	8,000	–	–
Total		124 (8)	60,900	44 (20)	63,500	30 (9)	32,300

[1]Hypothetical locations in the District of Columbia.
[2]Numbers in parentheses indicate nonfatal injury accidents; all others involved property-damage-only.
[3]Adjusted to reflect the incidence of personal injuries.

Table 6 gives unit values for various types of collisions based on data on the costs of collisions in the District of Columbia (excluding losses of future earnings), and shows cost-severity index ratings calculated for three hypothetical accident locations. For any type of collision, the personal injury cases were given three times the weighting of the property-damage-only cases. On this basis, Location 2 would be considered the location most in need of traffic safety improvements. The comparable costs of feasible improvements at each location would be needed, of course, to establish priorities based on accident benefit/cost relationships.

The application of point values to an accident location evaluation such as the above demonstrates a technique of great potential value but one that requires further refinement. For example, the comparative variability of mean cost values for individual types of collisions should be recognized. The technique should not be applied unless about 30 samples covering the same time period are available for the locations to be compared. Also, additional study needs to be given to differences in the average cost of fatal injury, nonfatal injury, and property-damage-only collisions of various types and to differences between the costs of accidents in central urban and outer suburban areas. Finally, the effects of other variables shown in this study which influence accident costs, such as time of day, highway classification, roadway type, and vehicle class, warrant further investigation as factors of potential importance in refining the cost-severity index technique for particular practical applications.

ACKNOWLEDGMENTS

The Washington Area Motor Vehicle Accident Cost Study was sponsored by the District of Columbia Department of Highways and Traffic, the Maryland State Roads Commission, and the Virginia Department of Highways in cooperation with the U. S. Bureau of Public Roads. Many individuals cooperated in this work; to list them all would be difficult. However, the special contributions of H. A. Mike Flanakin of the District of Columbia Department of Highways and Traffic, C. M. Billingsley of the U. S. Bureau of Public Roads, and other representatives of the study sponsors are gratefully acknowledged.

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Median Openings on Divided Highways: Their Effect on Accident Rates and Level of Service

P. D. CRIBBINS and J. W. HORN, Co-Technical Directors; and
F. V. BEESON and R D. TAYLOR, Graduate Research Assistants, Department of Civil Engineering, North Carolina State University, Raleigh

The purpose of this investigation was to attempt to determine quantitatively the optimum median opening spacing on multilane divided highways without access control when safety, level of service, and roadside access requirements were examined simultaneously.

The effect of certain roadway characteristics on the accident rate and level of service for every section of multilane divided highway (without access control and with non-crossable medians) in North Carolina were considered. Data were collected for 92 study sites, and accident records of over 6,000 accidents that occurred on these sites during a 21-month period in 1963 and 1964 were related by a distance measurement to a median opening and evaluated.

Data were stratified by accident type and location type and were analyzed by multiple-regression techniques. Prediction equations were also developed to estimate the accident rate and level of service for specific locations on multilane highways.

Findings of this investigation indicate that median openings, per se, are not necessarily accident prone under conditions of low volumes, wide medians, and light roadside development; however, as volumes increase and development increases commensurately, the frequency of median openings does have a significant effect on accident potential.

•THE increased construction of multilane highways without access control throughout the United States has created design and operational problems of growing complexity. Not the least of these is the need to provide median openings, or crossovers, at various locations throughout the length of such facilities to permit vehicles to reach abutting property or reverse their direction.

While the median opening satisfies many useful purposes, it may also serve as a possible point of increased congestion and accident exposure. Frequent interruptions in the flow of traffic, such as those created by vehicles turning on or off high-speed roadways, produce a variety of acceleration and deceleration maneuvers. Such turbulence in the traffic stream, particularly under high-volume conditions, may require a series of decisions that are simply beyond the capacity of the average driver. It is therefore obvious that judicious location of median openings is of paramount importance if traffic safety on multilane highways is to be maximized.

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Numerous standards and policies relating to the detailed geometric design of median openings are in common usage by highway engineers, but there is an almost total absence of policies concerning the longitudinal spacing or frequency of these openings. Correspondence (1) with other states revealed that 31 of 50 states have no written median-spacing policy; however, four are presently attempting to establish a median-spacing policy. Forty-eight states have no written median-width policy and there was general agreement that no rigid median-width policy could be established. Of those states with a written policy, enforcement in the face of political or other pressures was felt to be a difficult problem. The consensus of the states with a median-spacing policy was that median openings should be minimized with an absolute minimum spacing of 600 ft. Many states indicated a definite need for further research on this subject, although none had based a median policy on the findings of a research investigation.

There is a general consensus among highway designers that accident rates and traffic flow are adversely affected by frequent median openings and therefore the frequency of median openings should be minimized. As a result of such opinions, various minimum spacings have been recommended. For example, AASHO in "A Policy on Geometric Design of Rural Highways" (2) suggests that"... a minimum spacing of one-fourth to one-half mile is suitable in most instances."

On new highway facilities, movement of high volumes of traffic is usually given priority over access to adjacent land by permitting access only at specified locations. In actual practice, however, hundreds of miles of highway are being constructed in which provision of full control of access is just not practicable. Frequently, existing two-lane highways must be widened, improved, and divided under conditions of no access control. In such cases, acquisition of access rights is often economically prohibitive and median openings become a necessity.

The problems relating to the placement and/or addition of median openings are not unique to North Carolina but are common in all 50 states. Nevertheless, to date no satisfactory policy for treatment of such conditions is available.

OBJECTIVES AND SCOPE

The forces that bring about the controversy concerning the location of median openings are usually not within the control of the highway planner or designer. Consequently, without the aid of a satisfactory policy, highway engineers may find themselves yielding to demands for more and more median openings. In the past, such demands, and the resulting haphazard slicing of the median strip, have often fostered discontent and jealousy among owners of property contiguous to the roadway and increased the congestion and accident exposure to the driving public.

The objective of this research is to determine quantitatively the optimum median opening spacing when safety, traffic movement, and roadside access requirements are examined simultaneously. If spacing can be optimized, policies concerning longitudinal spacing of median openings for new roadway facilities and for the addition of median openings to existing facilities can then be formulated.

The North Carolina State Highway Commission is responsible for the construction, maintenance, and operation of 73,000 miles of paved highway, including 922 miles of multilane divided highway. Of these 922 miles, 388 are divided multilane facilities with no access control and non-mountable medians. Preliminary research involved the selection of 92 definite study sites, which were as nearly homogeneous as possible, from the 388 miles of divided highway. Site homogeneity was determined from physical characteristics obtained in preliminary field inventories.

In an effort to determine a suitable method for the collection and analysis of accident location data, pilot studies were organized during the summer of 1964. Data from 6,417 accidents which occurred between January 1, 1963, and September 30, 1964, were recorded. All accidents were located by distance to one of 1,727 median openings on the 92 sites. Of the 1,727 median openings, 112 were at signalized intersections and 850 were at unsignalized intersections, leaving 765 median openings excluding intersections. The combined accident and location data were coded and recorded on punch cards in a form suitable for statistical analysis at a later date.

DATA COLLECTION

The field work consisted of (a) inventorying all physical feature data, (b) locating each accident with respect to a median opening within the site where the accident occurred, (c) locating speed change lanes at median openings, intersections, and signalized intersections, (d) inventorying the roadside access along each individual site, and (e) recording a level of service index which is a reflection of the average travel time over a given site.

Accident Location

The location of every accident within each test section was recorded. The purpose of using all accident data rather than only those involving the median or median openings was twofold; it eliminated the possibility of biased data and it permitted the comparison of median accidents with non-median accidents.

Two teams, each composed of three men, were utilized to collect detailed field data. Each team was equipped with a Rol-a-tape for measuring short distances and an odometer calibrated to the nearest thousandth of a mile and mounted in their vehicle for measuring longer distances. Sketches or maps of each site were prepared in the field to record distances between median openings and distances to certain landmarks along the site necessary for the location of individual accidents.

Also, such features as plants and industries, intersecting streets, and shopping centers were located on the maps in order to evaluate access. Median openings were numbered within each site, and the distance ahead and behind for each accident was referred to a specific opening.

Relative Access-Point System

The access-point system serves as an indication of the number of conflicts introduced into the traffic stream along any one test section. While it is not intended to be a highly refined measure of the conflicts, it does provide an indication of the relative amount of access provided from one test section to another. The data for the access-point system were collected in the field as the teams measured distances to median openings. The number of private drives, city streets, public roads, plants and industries, commercial businesses, motel units, and shopping centers that had direct access to a site were actually counted and recorded. The number of parked cars in each plant or industry and in each shopping center was also counted. The time of visit to each plant, industry, and shopping center was recorded while the average daily volume of commercial vehicles at plants and industries was estimated and recorded.

In addition to the data gathered in the field, ADT volumes for the site and for intersecting streets and roads were obtained from traffic engineering departments in the larger cities and from culture maps or volume-count maps available at the North Carolina State Highway Commission.

After obtaining the field data and ADT volumes for each site, the access points per site were calculated. The ADT (total) was taken as the volume of all intersecting streets and roads along the site. The number of private drives was multiplied by a generation factor of seven to reflect the average daily number of trips to and from each dwelling unit (9). The number of cars parked at an industry or plant was multiplied by a factor of 2.5 to account for both work trips and industrial trips. The number of motel units was multiplied by a factor of two, and access points for commercial businesses were calculated by multiplying the site ADT by a factor designed to reflect trip generation to and from the business (8). This factor was calculated as the percentage of the total volume on a four-lane facility represented by turning movements for each type of commercial establishment. Commercial businesses were subclassified as restaurants, supermarkets, service stations, grocery stores, drive-in cafes, furniture and equipment stores, and miscellaneous businesses. Access points for shopping centers were also calculated for each site to reflect the maximum accumulation of parked vehicles which is then utilized to obtain the number of vehicles entering the shopping center each day. The access points were found to range from 50 to 132,000 points per mile indicating sizable differences in access service for different sites.

TABLE 1

TOTAL SITE AND ACCIDENT DATA

Site Letter	Site No.	Site Length (mi)	Access Points	Access Per Mile	Intersections No.	Intersections Signalized	Intersections Open/Mile No.	Intersections Open/Mile Signalized	Median Openings Excluding Intersections No.	Median Openings Excluding Intersections Open/Mile	Total Openings per Mile	Medians Type	Medians Width (ft)	Speed limit (mph)	Volume	Land Use	Lanes No.	Lanes Location	Level of Service (min/mi)	Accidents Per Mile	Accidents Total
A	1	2.5	49717	19899	10	3	4.00	1.20	4	1.60	5.60	3	30	55	14500	3	4	2	1.58	55.2	138
B	2	1.4	3332	2380	10	1	7.14	0.73	1	0.72	7.86	1	6	55	7600	3	4	2	1.36	15.0	21
C	3	1.4	35075	25054	16	2	11.43	1.43	0	0.00	11.43	2	27	35	12000	2	4	2	1.66	82.1	115
D	4	3.3	89189	27024	4	2	1.21	0.61	9	2.72	3.93	3	30	45	18000	2	4	2	1.43	47.6	157
E	5	2.0	17047	8523	6	0	3.00	0.00	0	0.00	3.00	3	30	55	9000	3	4	2	1.13	23.0	46
F	6	2.6	66335	25520	10	3	3.85	1.15	10	3.85	7.70	3	25	55	18000	2	4	2	1.27	63.8	166
G	7	1.5	9104	6069	3	0	2.00	0.00	12	8.00	10.00	2	15	60	8000	3	4	2	1.18	11.3	17
H	8	4.7	27013	5747	5	0	1.06	0.00	1	0.21	1.27	3	30	60	10000	1	4	2	1.08	7.0	33
I	9	2.1	29855	14217	17	0	8.10	0.00	4	1.91	10.01	2	30	45	10500	2	4	2	1.36	31.9	67
J	10	14.9	65619	4404	22	0	1.48	0.00	36	2.42	3.90	3	30	60	11000	1	4	2	1.00	10.2	152
L	11	1.1	34232	31120	7	2	6.36	1.82	3	2.72	9.08	2	30	35	10300	3	4	2	2.00	13.6	15
M	12	1.6	2000	1250	1	0	0.63	0.00	0	0.00	0.63	3	40	60	10000	1	4	2	0.95	1.3	2
N	13	14.1	24660	2182	23	1	1.63	0.07	56	3.97	5.60	3	35	60	6500	1	4	2	0.95	7.7	109
O	14	4.2	100000	23927	18	2	4.29	0.40	23	5.47	9.76	3	15	45	14400	3	4	2	1.36	45.1	189
P	15	12.4	20262	1630	21	0	1.69	0.00	20	1.61	3.30	3	40	60	7200	1	4	2	0.95	5.9	73
Q	16	0.8	12040	15100	6	1	7.50	1.25	3	3.75	11.25	1	2	45	7200	3	6	2	1.62	10.0	8
S	18	5.7	12521	2200	15	0	2.63	0.00	77	13.51	16.14	3	15	45	2400	1	4	2	1.50	1.2	7
T	19	2.6	2676	1015	4	0	1.54	0.00	10	3.85	5.39	3	35	60	3500	1	4	2	0.98	4.6	12
V	20	3.1	561	181	2	0	0.65	0.00	7	2.26	2.91	3	40	60	2450	1	4	2	0.97	1.3	4
W	21	4.6	19427	4223	8	1	1.74	0.22	12	2.61	4.35	3	15	45	6000	1	4	2	1.28	8.0	37
X	22	1.6	3759	2349	3	0	1.88	0.00	0	0.00	1.88	3	30	60	3400	1	4	2	0.97	4.4	7
Z	23	21.6	106113	4913	33	2	1.53	0.09	37	1.71	3.24	3	30	60	8000	1	4	2	1.03	1.5	33
CC	24	1.4	18983	13559	6	1	4.29	0.72	2	1.43	5.72	3	30	45	3350	1	4	2	1.20	8.6	12
DD	25	5.9	13174	2235	11	0	1.86	0.00	3	0.51	2.31	3	25	60	6500	1	4	2	1.04	11.2	66
GG	26	3.2	2081	650	6	0	1.88	0.00	9	2.81	4.69	3	30	60	1600	1	4	2	1.00	1.6	5
HH	27	11.3	48509	4293	19	3	1.68	0.27	4	0.36	2.04	3	30	60	6500	1	4	2	1.15	9.1	103
II	28	6.2	17124	2761	7	0	1.13	0.00	18	2.90	4.03	3	50	60	11000	1	4	2	1.00	9.2	66
JJ	29	7.5	184413	23588	32	7	4.27	0.93	16	2.14	6.41	1	14	45	18000	2	4	2	1.43	36.0	270
KK	30	6.5	345001	53077	27	20	4.15	3.08	2	0.31	4.46	1	2	45	25000	3	6	2	1.77	107.4	698
LL	31	2.2	82801	37637	19	4	8.64	1.82	6	2.73	11.37	2	25	35	11000	3	4	2	1.94	33.2	73
MM	32	1.4	16466	11754	13	2	9.29	1.43	0	0.00	9.29	1	3	45	11000	3	4	2	1.15	37.1	52
OO	34	2.0	19950	9975	10	1	5.00	0.50	0	0.00	5.00	3	3	55	7000	1	4	2	1.09	6.5	13
PP	35	1.6	212023	132000	7	3	4.38	1.88	1	0.63	5.01	3	30	45	17000	3	4	2	1.50	69.4	111
QQ	36	4.2	46480	11067	32	2	7.62	0.48	8	1.91	9.53	3	12	55	9000	3	4	2	1.50	14.3	60
TT	37	15.2	66048	4350	23	1	2.11	0.06	46	3.03	5.14	3	20	60	13000	1	4	2	0.97	23.6	358
UU	38	6.6	147676	22375	27	3	4.09	0.46	13	1.97	6.06	3	15	45	15000	3	4	2	1.46	45.3	290
VV	39	2.7	4181	1549	3	0	1.11	0.00	5	1.85	2.96	3	30	60	2800	1	4	2	1.09	1.5	4
WW	40	1.1	6281	5700	5	0	4.55	0.00	4	3.63	8.18	1	15	45	8300	3	4	2	1.33	13.6	15
YY	42	2.1	1127	540	3	0	1.43	0.00	2	0.95	2.38	3	30	55	2650	1	4	2	1.00	5.2	11
ZZ	43	0.8	1463	1854	2	0	2.50	0.00	0	0.00	2.50	3	30	45	7200	1	4	2	1.28	11.3	9
A-1	44	3.3	22489	6815	7	0	2.12	0.00	7	2.12	4.24	3	30	60	3500	1	4	2	0.97	14.2	47
E-1	45	4.7	226967	48200	22	2	4.68	0.43	27	5.74	10.42	3	30	45	20000	3	6	2	1.43	68.3	321
F-1	46	3.4	25726	7566	9	2	2.65	0.59	0	0.00	2.65	3	30	45	22000	1	4	2	1.43	9.1	31
G-1	47	0.7	72878	104111	7	0	10.00	0.00	1	1.43	11.43	2	25	35	22000	3	6	2	1.46	61.4	40
I-1	48	8.1	67118	8286	28	1	3.46	0.12	1	0.12	3.58	3	30	55	12000	1	4	2	1.00	20.5	166
J-1	49	2.4	120	50	3	0	1.25	0.00	6	2.50	3.75	3	30	60	2300	1	4	2	0.95	2.9	7
K-1	50	7.6	32254	4250	17	0	2.24	0.00	15	1.97	4.21	3	30	60	6100	1	4	2	0.92	15.8	120
L-1	51	4.7	11730	2495	14	0	2.98	0.00	3	0.64	3.62	3	30	60	5700	1	4	2	1.00	7.0	33
N-1	53	0.7	5662	8090	4	0	5.71	0.00	2	2.86	8.57	3	30	45	5600	3	4	2	1.25	4.3	3
C-2	54	2.5	21709	8684	17	3	6.80	1.20	5	0.00	8.80	2	30	35	18000	2	4	2	1.88	23.2	58
E-2	55	3.1	53649	17306	14	4	4.52	1.29	2	0.65	5.17	3	20	35	11000	1	4	2	1.71	11.3	35
F-2	56	11.6	24004	2069	5	0	0.43	0.00	10	0.86	1.29	3	30	60	8000	1	4	2	0.92	5.3	61
K-2	57	1.2	2224	1853	2	0	1.67	0.00	1	0.83	2.50	3	25	60	4200	1	4	2	1.00	5.0	6
M-2	58	5.6	8994	1606	5	0	0.89	0.00	17	3.04	3.93	3	35	55	2200	1	4	2	1.00	1.8	10
A-3	59	1.5	38029	26030	7	2	4.67	1.33	8	5.33	10.00	2	20	45	6500	3	4	2	1.20	26.7	40
B-3	60	2.8	25692	9175	2	1	0.71	0.36	6	2.14	2.85	3	20	60	3700	1	4	2	1.00	1.1	3
C-3	61	3.1	11619	3747	3	0	0.97	0.00	7	2.26	3.23	3	25	55	3800	1	4	1	1.00	3.9	12
D-3	62	1.1	5979	5430	4	0	3.64	0.00	2	1.82	5.46	3	30	60	3800	1	4	1	0.95	10.9	12
F-3	63	0.7	5126	7323	3	0	4.29	0.00	2	2.86	7.15	3	30	60	4600	1	4	1	1.09	7.1	5
G-3	64	0.9	16812	18680	3	0	3.33	0.00	6	6.68	10.01	2	25	45	7500	3	4	1	1.33	18.9	17
H-3	65	8.3	27867	3357	13	1	1.56	0.12	14	1.69	3.25	3	20	60	3000	1	4	1	0.92	3.6	30
I-3	66	16.2	23073	1425	34	0	2.10	0.00	5	0.34	2.44	3	20	60	6000	1	4	1	0.93	3.5	56
J-3	67	2.2	70506	32048	2	1	0.91	0.46	1	0.45	1.36	2	10	35	9000	2	4	1	1.72	1.4	3
K-3	68	0.9	181	201	1	0	1.11	0.00	2	2.22	3.33	3	25	55	5500	1	4	1	1.05	2.2	2
L-3	69	2.3	21641	9409	6	0	2.61	0.00	7	3.05	5.66	1	20	45	6500	3	4	1	1.20	11.3	26
M-3	70	3.6	34152	9487	25	2	6.94	0.56	3	0.84	7.76	3	40	35	6250	3	4	1	1.50	18.9	68
O-3	71	3.9	34988	8971	9	1	2.31	0.26	10	2.57	4.88	3	100	45	6000	1	4	1	1.20	29.0	113
Q-3	72	9.3	9626	1035	9	0	0.97	0.00	23	2.48	3.45	3	30	60	3800	1	4	1	1.02	6.8	63
S-3	73	0.9	17162	19069	6	1	6.67	1.11	3	3.34	10.01	2	20	45	2000	3	4	1	1.50	8.9	8
T-3	74	1.3	40828	31406	14	2	10.77	1.54	0	0.00	10.77	2	6	35	15500	2	4	1	2.40	92.3	120
U-3	75	1.0	50018	50018	14	3	14.00	3.00	0	0.00	14.00	2	10	35	12000	2	4	1	2.20	94.0	94
V-3	76	2.3	50515	22000	25	6	10.87	2.61	2	0.87	11.74	2	20	35	8500	2	4	1	2.22	55.7	128
A-4	77	0.8	26537	33171	5	3	6.25	3.75	2	2.50	8.75	1	15	35	10200	2	4	2	2.40	28.8	23
B-4	78	32.8	45604	1390	37	0	1.13	0.00	16	0.49	1.62	3	30	60	11000	1	4	2	0.95	8.5	278
E-4	79	4.2	36129	8211	10	0	2.38	0.00	3	0.72	3.11	3	25	55	15500	1	4	2	1.00	21.2	89
F-4	80	1.6	101162	63226	13	2	8.13	1.25	0	0.00	8.13	3	10	35	19000	3	4	2	1.56	30.6	49
H-4	81	0.9	18339	20377	7	2	7.78	2.22	0	0.00	7.78	2	10	45	5100	3	4	3	1.33	35.6	32
I-4	82	3.8	23004	6054	9	0	2.37	0.00	5	1.31	3.68	3	30	60	5500	1	4	3	1.07	9.7	37
J-4	83	2.6	2335	898	8	0	3.08	0.00	2	0.77	3.85	3	33	55	7900	1	4	3	1.25	5.4	14
K-4	84	1.9	189963	99980	4	3	2.11	1.58	8	4.21	6.32	3	25	35	26000	3	4	3	2.40	126.3	240
L-4	85	2.0	21369	10685	4	0	2.00	0.00	7	3.50	5.50	3	30	55	5000	1	4	3	1.09	8.5	17
N-4	86	1.3	383	295	1	0	0.77	0.00	5	3.85	4.62	3	3	60	8500	1	4	3	1.11	16.2	21
O-4	87	1.5	982	655	0	0	0.00	0.00	5	3.34	3.34	3	15	60	8000	1	4	3	1.09	4.7	7
P-4	88	2.9	15620	5386	3	0	1.03	0.00	7	2.41	3.44	3	18	60	7700	1	4	3	1.15	8.3	24
Q-4	89	2.7	6692	2480	7	0	2.59	0.00	0	0.00	2.59	3	30	55	4100	1	4	3	1.05	7.4	20
A-5	90	2.0	5328	2664	4	0	2.00	0.00	7	3.50	5.50	3	30	60	5550	1	4	2	1.00	9.0	18
D-2	91	0.7	19805	28293	5	1	7.14	1.43	0	0.00	7.14	2	30	35	3200	3	4	2	1.72	10.0	7
H-2	92	0.7	12275	17535	5	1	7.14	1.43	1	1.43	8.57	2	30	35	17000	3	4	2	2.00	30.0	21
C-4	93	0.9	1318	1464	2	0	2.22	0.00	2	2.22	4.44	3	30	55	3500	1	4	2	1.09	7.8	7
D-4	94	0.7	2027	2900	0	0	0.00	0.00	4	5.62	5.62	3	10	60	5800	3	4	2	1.09	18.6	13
B-5	95	9.5	55509	5819	5	0	0.53	0.00	28	2.95	3.48	3	35	60	7200	1	4	1	0.92	13.3	126
G-2	96	0.8	14799	18500	3	1	3.75	1.25	1	1.25	3.75	2	70	35	2835	3	4	2	1.71	8.8	7

DATA PROCESSING

Field data were transferred to 80-column IBM computer cards for processing. An all-numeric coding process, which divided the data into two major divisions—individual accident data and site data—was utilized and the coding format was divided accordingly. Gang punching of the site data was permissible because some sites had as many as 800 accidents during the study period while the physical features remained constant.

Coding Procedure

The accident data coded in columns 1 to 34 were taken from the accident forms provided by the North Carolina Department of Motor Vehicles and from field data collected by the research team. Each accident was given one of 10 location types which was coded in column 11. Each accident was also classified as one of 12 accident types and coded in columns 21 and 22. The data in the first 34 columns were punched separately for each of the 6,417 accidents. The site data, coded in columns 35 to 80, came from the inventory study and field data (Table 1) and were gang punched for each of the 92 sites.

Sorting Techniques

Before the data were analyzed statistically, several sorts were run to see what preliminary findings could be obtained. The cards were first sorted by site numbers and by the number of accidents per site so that the number of accidents at different location types (signalized intersections, median openings with storage, etc.) per site could be obtained. The accidents were then sorted by location type and by accident type to compare the two stratifications. The distance to each median opening ahead and the distance to each median opening behind was also sorted. Accidents which occurred within 200 ft of a median opening were classified as accidents which actually occurred at or were involved with the median opening. This required some changes in the previous sort on location type vs accident type. The results of the location type and accident type sort are given in Table 2. Additional sorting of the data failed to produce significant results.

STATISTICAL ANALYSIS

Because an optimum median opening spacing for specific highway segments with unique characteristics could not be determined from the data, the statistical analysis was directed toward the generation of models. Certain of these unique characteristics along with the frequency and type of median openings will be introduced into the model in a manner that will facilitate the observation of the corresponding accident rate or level of service.

The independent variables selected for investigation were as follows:

x_2 = Width of the median in feet,
x_3 = Speed limit posted (mph),
x_4 = ADT volume (1000's)
x_5 = Number of signalized intersections with left-turn storage facilities per mile,
x_6 = Number of signalized intersections without storage facilities per mile,
x_7 = Number of median openings with left-turn storage facilities per mile—excluding intersections,
x_8 = Number of median openings without storage facilities per mile—excluding intersections,
x_9 = Number of intersections with left-turn storage facilities per mile,
x_{10} = Number of intersections without storage facilities per mile,
x_{11} = Number of access points per mile (1000's),
x_{12} = x_4^2,
x_{13} = x_{11}^2, and
x_{14} = $x_4 \cdot x_{11}$

TABLE 2

NUMBER OF ACCIDENTS: ACCIDENT TYPE VS LOCATION TYPE

Accident Type	Location Type 1: Involving Median but Not at Opening	2: Intersection of 4-Lane With Primary Highway	3: Intersection of 4-Lane With Secondary Highway	4: At Median Opening Serving Private Drive	5: At Median Opening Serving Public Drive	6: At Opening With No Roadside Access	7: At Signalized Intersection	8: Median Openings Serving Public Drive With Storage Lane	9: Intersection With Storage Lane	10: Signalized Intersection With Storage Lane	11: Others	Total
Vehicle hit from rear while attempting left turn thru opening (not in storage lane)	1	4	144	4	30	82	4	4	18	13	4	308
Vehicle hit from front while turning thru opening	0	21	129	1	25	25	71	5	81	244	1	603
Vehicle hit from rear after making turn through opening	0	8	36	0	13	9	3	1	12	10	0	92
Vehicle hit from rear while turning from outside lane thru opening	3	19	194	3	44	92	10	9	41	32	6	453
Vehicle hit by oncoming traffic while attempting to cross four lanes	0	62	392	9	40	7	85	9	130	187	4	925
Head-on collision within opening by opposing traffic	1	2	12	0	3	1	4	2	1	7	0	33
Vehicle struck from rear while using left turn storage lanes at opening	0	0	0	0	0	0	0	2	8	12	0	22
Head-on collision within opening by vehicles crossing four lanes	0	1	7	0	0	0	6	0	0	25	0	39
Vehicle crossed median and collided with traffic in opposite lane	21	0	3	0	2	4	3	2	3	4	3	46
One vehicle striking object off road	137	44	122	9	12	42	19	8	53	60	273	769
Rear-end collision	48	80	329	35	33	56	204	23	104	336	328	1676
Other	171	101	358	20	59	88	74	19	108	212	344	1552
Total	382	342	1726	81	261	404	463	84	569	1132	963	6417

The variables x_{12}, x_{13} and x_{14} were created to introduce curvilinearity into a regression model which will be discussed later.

Simple correlations were computed between the accidents per mile at all locations and the above independent variables. These correlations are given in column 2 of Table 3. The absence of correlation between many of the independent and dependent variables seems to justify a more refined study using a multiple-regression model. The use of the multiple-regression method permitted the study of the effects on the dependent variable of each independent variable in relation to all other independent variables.

The accident data were sorted by location of accidents with emphasis on the type of median opening and the presence of left-turn storage facilities. This stratification of accident data by location types is given in Table 3. Separate regressions, with accidents per mile as a dependent variable, were fitted for each location as well as for all

TABLE 3

SIMPLE CORRELATIONS BETWEEN ACCIDENTS/MILE AND THE 13 INDEPENDENT VARIABLES

Independent Variable	All Location Types (92 sites)	Sig. Openings With Storage (38 sites)	Sig. Openings Without Storage (16 sites)	Median Openings With Storage (27 sites)	Median Openings Without Storage (78 sites)	Intersections With Storage (58 sites)	Between Openings (92 sites)	Primary and Secondary Roads (92 sites)
x_2	-0.20557	-0.23409	-0.13796	0.07428	0.00510	-0.11737	0.02792	-0.10603
x_3	-0.52572	-0.18107	-0.43659	-0.34533	-0.11868	-0.37148	-0.18692	-0.45964
x_4	0.73672	0.54940	0.24913	0.64813	0.52910	0.42803	0.48401	0.53344
x_5	0.46232	0.65390	-0.01928	0.12314	0.13163	0.05170	0.21699	0.17272
x_6	0.50882	0.09385	0.56249	0.50543	0.04279	-0.02745	0.12216	0.46390
x_7	0.17116	0.01232	-0.24834	0.47550	0.41316	0.00701	0.25474	0.09113
x_8	-0.17248	-0.14377	-0.25625	-0.19819	0.21758	-0.09462	-0.24914	-0.11338
x_9	0.04127	-0.03172	-0.27582	-0.05144	-0.03774	0.38349	-0.01791	-0.08154
x_{10}	0.45697	-0.06747	0.46343	0.24066	0.06168	0.09655	0.13668	0.61792
x_{11}	0.73302	0.58827	0.42593	0.30214	0.29075	0.55841	0.25058	0.49866
x_{12}		0.60474	0.17736	0.61472	0.55945	0.43697	0.47356	0.51586
x_{13}		0.54117	0.36133	0.13293	0.14596	0.47994	0.16080	0.36949
x_{14}		0.63541	0.31210	0.37899	0.34588	0.57319	0.31371	0.51041
M[a]	21.2033	8.1304	12.2136	0.7820	2.5240	3.2781	3.3597	7.0940
S[b]	12.1647	12.6200	11.1435	1.1621	4.0592	6.8456	3.5459	9.0868

[a]M = Mean value. [b]S = Standard deviation.

locations combined. Level of service, with travel time as the dependent variable, was also fitted using the data at all locations.

The wide range of values for accidents per mile on the various sites led the investigators to suspect that there would be non-normality and non-homogeneity of variance in the accident rates. Therefore, tests of normality (5) and homogeneity of variance (3) were made by classifying the accident data by volume and access points per mile. Results indicated that the errors were neither normal nor homogeneous. Various transformations were then made on the independent variable, and it was subsequently found that the $\log_{10}$ transformation not only reduced the difference among the error variances but also changed the distribution to normal.

On the basis of the foregoing preliminary analysis the multiple-regression model was as follows:

$$Y_K = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \epsilon$$

Where the particular independent variables (X's) included were chosen for each dependent variable (Y_K) by a stepwise regression procedure.

As a result of stratification and transformation, nine dependent variables were selected. These variables were defined as follows:

Location*	Variable	Definition
Total	Y_T	$\log_{10}$ of total accidents per mile
1, 11	Y_1	$\log_{10}$ of accidents between median openings per mile
2, 3	Y_2	$\log_{10}$ of accidents at primary and secondary roads per mile
4, 5, 6	Y_4	$\log_{10}$ of accidents per mile at median openings without left-turn storage facilities, excluding intersections
7	Y_7	accidents at signalized intersections without storage facilities per mile (Y_7 was left untransformed)
8	Y_8	square root of accidents per mile at median opening with left-turn storage facilities, excluding intersections (Y_8 was best transformed by taking the square root)
9	Y_9	$\log_{10}$ of accidents per mile at intersections with left-turn storage
10	Y_{10}	$\log_{10}$ of accidents per mile at signalized intersections with left-turn storage
Total	Y_{LS}	$\log_{10}$ level of service on a given section of highway

The selected approach was a stepwise multiple-regression analysis. In this procedure, single independent variables are entered one at a time into the multiple-regression equation. At each stage in the stepwise procedure the potential additional reduction in the variance of the dependent variable is computed. If the largest potential reduction is sufficient to be significant as tested by Students "t" at a chosen alpha level, the associated independent variable is added to the model. The alpha level selected was 0.10. As a result, independent variables are entered into the regression equation one after another and the best predictors (independent variables) are selected.

The stepwise procedure was completed for each of the nine dependent variables and the resulting equations are given in Table 4. Use of these equations is dependent on two major considerations: (a) new input data must be within the range of the data used to generate the equations and (b) the dependability of the prediction equations increases with the number of observations used in their computation.

The first eight equations were generated to predict accident rate per mile for specific locations on four-lane, nonaccess-controlled highways. In each of these equations the type of median opening was an important predictor and changes in the number of these median openings per mile were reflected by changes in accident rate.

*See columns in Table 2.

TABLE 4

PARTIAL REGRESSION COEFFICIENTS FOR EACH MODEL

0	Locations	Dependent Variable	R^2	Constant	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	b_{11}	b_{12}	b_{13}	b_{14}	Std. Error y.x	df	Mean of Transformed $\overline{Y}$
92	All location types combined	log accidents/mi	0.68	-0.47945	0.00618 (2.27)	0.00990 (1.74)	0.05424 (8.19)	0.16607 (2.70)	0.23676 (3.00)		0.02745 (1.54)	0.6885 (2.71)	0.0714 (3.29)					0.29260	81	1.06648
38	Sig. openings with storage	log accidents/mi	0.67	-0.51107			0.04852 (4.67)	0.49352 (5.67)	0.14416 (1.73)									0.37444	32	0.53601
16	Sig. openings without storage	Accidents/mi	0.78	-30.81846			2.63890 (2.74)		7.30204 (2.72)				1.87473 (2.33)		-0.04684 (-1.44)			6.24508	11	12.21358
27	Median openings with storage	sq ft accidents/ mi	0.78	-01.88702		0.02258 (2.05)	0.11439 (7.169)	-0.50902 -3.88		0.40825 (3.59)								0.35768	21	0.51674
78	Median openings without storage	log accidents/mi	0.51	-01.86762	0.00801 (2.43)	0.01755 (2.58)	0.05494 (4.55)			0.17612 (1.52)	(0.10494) (4.63)			0.02225 (2.54)		-0.00019 (-3.09)		0.36027	70	0.12543
58	Intersections with storage	log accidents/mi	0.54	-1.66931	0.01172 (2.58)	0.01613 (1.67)						0.16040 (4.82)		0.03629 (3.85)		-0.00022 (-3.10)		0.40693	51	0.14789
92	Between openings	log accidents/mi	0.35	0.04515			0.06414 (2.60)			0.20528 (2.36)	0.05478 (-2.75)	-0.03737 (-1.52)			-0.00150 (-1.52)			0.34762	86	0.35465
92	Primary and secondary roads	log accidents/mi	0.48	-0.99162	0.00579 (1.72)	0.00973 (1.52)	0.00025 (2.92)			0.17200 (1.76)			0.12512 (5.35)		-0.00295 (-2.129)		0.00035 (2.18)	0.41086	84	0.54830
92	Level of service	log travel time/ mi	0.844	0.43433		-0.00772 (-11.48)	0.00310 (2.85)	0.03544 (3.78235)	0.03842 (3.95)		0.00434 (1.656)					-0.33111×10^{-5} (-1.386)				

0 = Number of observations.
x_2 = Median width.
x_3 = Speed limit.
x_4 = ADT volume (1000's).
x_5 = Signalized intersection with storage.
x_6 = Signalized intersection without storage.
x_7 = Median opening excluding intersection with storage.
x_8 = Median opening excluding intersection without storage.
x_9 = Intersections with storage.
x_{10} = Intersections without storage.
x_{11} = Access points per mile.
x_{12} = $(ADT)^2$.
x_{13} = $(\text{Access points})^2$.
x_{14} = ADT volume x access.
df = Degrees of freedom.

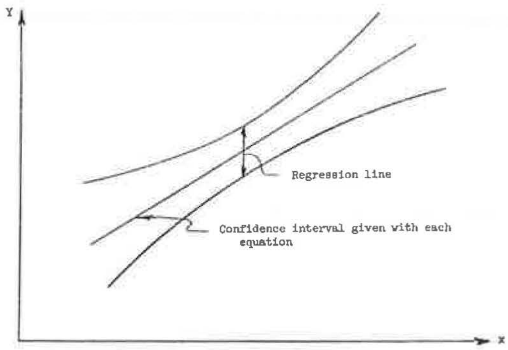

Figure 1.

Total Accidents per Mile

The dependent variable in Eq. 1 is $\log_{10}$ total accidents per mile, represented by Y_T. The purpose of this equation is to predict the number of total accidents per mile, whereas all the other equations were generated to predict accidents at specific median opening locations.

The eight independent variables, which were selected by the stepwise regression process, and their mean values for Eq. 1 are as follows:

Variables	Means (per mile-per site)
$\bar{x}_2$	25.64130
$\bar{x}_3$	50.76086
$\bar{x}_4$	8.81467
$\bar{x}_5$	0.35672
$\bar{x}_6$	0.19922
$\bar{x}_8$	1.74386
$\bar{x}_9$	1.07636
$\bar{x}_{10}$	2.48801
$\bar{Y}_T$	1.06648
antilog $\bar{Y}_T$ =	11.65

The observations on these independent variables came from 92 different highway sites.

$$Y_T = -0.47946 + \underset{(2.27)}{0.00618\, x_2} + \underset{(1.74)}{0.00990\, x_3} + \underset{(8.19)}{0.05424\, x_4} + \underset{(2.70)}{0.16607\, x_5} + \underset{(3.00)}{0.2367\, x_6}$$

$T^* =$

$$+ \underset{(1.54)}{0.02745\, x_8} + \underset{(2.71)}{0.06885\, x_9} + \underset{(3.29)}{0.07147\, x_{10}} \qquad (1)$$

The R^2 value calculated for this equation is 68.1 percent, indicating that 68.1 percent of the variance of Y_T can be explained by the eight variables. For Eq. 1, the standard deviation of Y given these independent variables, $S_{y.x}$, is equal to 0.29260, and the coefficient of variation 100 $(S_{y.x}/\bar{Y}_T)$ is equal to 27.436 percent. This coefficient indicates the relative residual variations and can be used to compare the nine-regression situation. Higher percentages indicate high relative residual variations.

A 95 percent confidence interval about the mean was calculated for the prediction equation. It indicates the range of mean values within which there is a 95 percent certainty of the true mean value of accident rate.

The 95 percent confidence interval about the mean for Eq. 1 was calculated as follows:

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*"T" values with each equation rank the relative importance of the "x" predictors.

$$\text{antilog}\left[Y_T + "t" \frac{s_{y.x}}{\sqrt{n}}\right] = \text{antilog}\left[1.06648 + 1.98 \frac{0.29260}{\sqrt{92}}\right] = (10.141, 12.54)$$

The entire confidence band for the model may be represented schematically as shown in Figure 1. The confidence intervals which are given for each individual prediction equation are at the point where the band is narrowest.

Accidents Between Median Openings

The dependent variable in Eq. 2 is $\log_{10}$ accidents per mile at location types 1 and 11, represented by Y_1. The purpose of this equation is to predict accidents per mile occurring between median openings.

Five independent variables were selected by the stepwise regression process as the best predictors. The variables and their mean values are as follows:

Variables	Means
$\overline{x}_4$	8.81467
$\overline{x}_7$	0.20546
$\overline{x}_8$	1.74386
$\overline{x}_9$	1.07636
$\overline{x}_{12}$	108.22633
$\overline{Y}_1$	0.35465
antilog $\overline{Y}_1$	2.263

The observation on these independent variables came from 92 highway sites.

$$Y_1 = 0.04515 + 0.06414\ x_4 + 0.20528\ x_7 - 0.05478\ x_8 - 0.03737\ x_9 - 0.00150\ x_4^2 \quad (2)$$
$$T = \quad (2.60) \quad (2.36) \quad (-2.75) \quad (-1.52) \quad (-1.52)$$

For this equation, R^2 equals 35.0 percent, the standard deviation $S_{y.x}$ equals 0.34762, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_1)$ equals 98.018 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.35465 \pm 1.98 \frac{0.34762}{\sqrt{92}}\right) = (1.861, 2.751)$$

Accidents at Intersections Without Left-Turn Storage Facilities

The dependent variable in Eq. 3 is $\log_{10}$ accidents per mile at location types 2 and 3, represented by Y_2. The purpose of this equation is to predict accidents per mile occurring at the intersection of primary and secondary roads where no left-turn storage facility was provided.

Seven independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
$\overline{x}_2$	25.64130
$\overline{x}_3$	50.76086
$\overline{x}_4$	8.81467
$\overline{x}_7$	0.20546
$\overline{x}_{10}$	2.48801
$\overline{x}_{12}$	108:22633
$\overline{x}_{14}$	210.93548
$\overline{Y}_2$	0.54830
antilog $\overline{Y}_2$	3.534

The observations on these independent variables came from 92 highway sites.

$$Y_2 = -0.99162 + 0.00579\, x_2 + 0.00973\, x_3 + 0.09025\, x_4 + 0.17200\, x_7$$
$$T = \quad (1.72) \quad (1.52) \quad (2.92) \quad (1.76)$$
$$+ 0.12512\, x_{10} - 0.00295\, x_4^2 + 0.00035\, x_4\, x_{11} \qquad (3)$$
$$(5.35) \quad (-2.13) \quad (2.18)$$

For this equation, R^2 equals 48.0 percent, the standard deviation $S_{y.x}$ equals 0.41086, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_2)$ equals 74.93 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.54830 + 1.98\, \frac{0.41086}{\sqrt{92}}\right) = (2.907, 4.297)$$

Accidents at Median Openings Without Left-Turn Storage Facilities Excluding Intersections

The dependent variable in Eq. 4 is $\log_{10}$ accidents per mile at location types 4, 5 and 6 and is represented by Y_4. The purpose of this equation is to predict accidents per mile occurring at median openings without left-turn storage facilities, excluding intersections.

Seven independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
$\overline{X}_2$	27.07692
$\overline{X}_3$	51.60256
$\overline{X}_4$	8.27500
$\overline{X}_7$	0.18097
$\overline{X}_8$	2.05686
$\overline{X}_{11}$	13.61446
$\overline{X}_{12}^2$	683.83824
$\overline{Y}_4$	0.12543
antilog$_{10}$ $\overline{Y}_4$	1.335

The observation on these independent variables came from 78 highway sites.

$$Y_4 = -1.86762 + 0.00801\, x_2 + 0.01755\, x_3 + 0.05494\, x_4 + 0.17612\, x_7$$
$$T = \quad (2.43) \quad (2.58) \quad (4.55) \quad (1.52)$$
$$+ 0.10494\, x_8 + 0.02225\, x_{11} - 0.00019 \qquad (4)$$
$$(4.63) \quad (2.54) \quad (3.10)$$

For this equation, R^2 equals 51.3 percent, the standard deviation $S_{y.x}$ equals 0.36027, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_4)$ equals 287.228 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.12543 + 2.00\, \frac{0.36027}{\sqrt{78}}\right) = (1.106, 1.611)$$

Accidents at Signalized Intersections Without Left-Turn Storage Facilities

The dependent variable in Eq. 5 is accidents per mile at location type 7, represented by Y_7. The purpose of this equation is to predict accidents per mile occurring at signalized intersections without left-turn storage facilities.

Four independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
$\overline{X}_4$	13.21564
$\overline{X}_6$	1.14552
$\overline{X}_{10}$	5.36416
$\overline{X}_{12}$	219.09890
$\overline{Y}_7$	12.21358

The observations on these independent variables came from 16 highway sites.

$$Y_7 = -30.81845 + 2.63890\ x_4 + 7.30204\ x_6 + 1.87472\ x_{10} - 0.04684\ x_4^2 \qquad (5)$$

$$T = \qquad (2.74) \qquad (2.72) \qquad (2.33) \qquad (-1.4)$$

For this equation, R^2 equals 78.4 percent, the standard deviation $S_{y.x}$ equals 6.24508, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_7)$ equals 51.132 percent.

The 95 percent confidence interval about the mean is given as

$$\left(12.21358 \pm 2.201\ \frac{6.24508}{\sqrt{16}}\right) = (8.772,\ 15.650)$$

Accidents at Median Openings With Left-Turn Storage Facilities Excluding Intersections

The dependent variable in Eq. 6 is square root of accidents per mile at location type 8 and is represented by Y_8. The purpose of this equation is to predict accidents per mile occurring at median openings and having left-turn storage facilities provided, excluding intersections.

Four independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
$\overline{X}_3$	50.92592
$\overline{X}_4$	11.32592
$\overline{X}_5$	0.48741
$\overline{X}_7$	0.70010
$\overline{Y}_8$	0.59674
$\overline{Y}_8^2$	0.35610

The observations on these independent variables came from 27 highway sites.

$$Y_8 = -1.88702 + 0.02258\ x_3 + 0.11439\ x_4 - 0.50902\ x_5 + 0.40825\ x_7 \qquad (6)$$

$$T = \qquad (2.05) \qquad (7.17) \qquad (-3.88) \qquad (3.59)$$

For this equation, R^2 equals 76.6 percent, the standard deviation $S_{y.x}$ equals 0.36147, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_8)$ equals 60.5741 percent.

The 95 percent confidence interval about the mean is given as

$$\left(0.59674 \pm 2.08\ \frac{0.36147}{\sqrt{27}}\right)^2 = (0.20403, 0.54923)$$

Accidents at Intersections With Left-Turn Storage Facilities

The dependent variable in Eq. 7 is $\log_{10}$ accidents per mile at location type 9, represented by Y_9. The purpose of this equation is to predict accidents per mile occurring at intersections with left-turn storage facilities provided.

Five independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
x_2	25.67241
x_3	50.77586
x_9	1.07636
x_{11}	17.81656
x_{11}^2	988.98918
Y_9	0.14789
antilog$_{10}$ Y_9	1.3738

The observations on these independent variables came from 58 highway sites.

$$Y_9 = -1.66931 + 0.01172\ x_2 + 0.01613\ x_3 + 0.16040\ x_9 + 0.03629\ x_{11} - 0.00022\ x_{11}^2 \quad (7)$$

$$T = \quad (2.58) \quad (1.67) \quad (4.82) \quad (3.58) \quad (-3.10)$$

For this equation, R^2 equals 55.7 percent, the standard deviation $S_{y.x}$ equals 0.40963, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_9)$ equals 276.98 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.14789 \pm 2.01\ \frac{0.40963}{\sqrt{58}}\right) = (1.096, 1.803)$$

Accidents at Signalized Intersections With Left-Turn Storage Facilities

The dependent variable in Eq. 8 is log$_{10}$ accidents per mile at location type 10, represented by Y_{10}. The purpose of this equation is to predict accidents per mile occurring at signalized intersections with left-turn storage facilities provided.

Three independent variables were selected by the stepwise regression process as the best predictors. These variables and their mean values are as follows:

Variables	Means
$\overline{x}_4$	11.82236
$\overline{x}_5$	0.86365
$\overline{x}_6$	0.32697
$\overline{Y}_{10}$	0.54601
antilog$_{10}$ $\overline{Y}_{10}$	3.4357

The observations on these independent variables came from 38 highway sites.

$$Y_{10} = -0.51107 + 0.04852\ x_4 + 0.49352\ x_5 + 0.14416\ x_6 \quad (8)$$

$$T = \quad (4.57) \quad (5.67) \quad (1.73)$$

For this equation, R^2 equals 67.0 percent, the standard deviation $S_{y.x}$ equals 0.37442, and the coefficient of variation 100 $(S_{y.x}/\overline{Y}_{10})$ equals 69.85 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.53601 \pm 2.04\ \frac{0.37442}{\sqrt{38}}\right) = (2.582, 4.571)$$

With the use of Eq. 8, a sample prediction can be made. Given:

1. $Y_{10} = -0.51107 + 0.04852\ x_4 + 0.49352\ x_5 + 0.14416\ x_6$ (Eq.8).
2. Length of site = 2 miles.

3. Volume = 15,000 ADT.
4. Number of signalized intersections with storage = 5.
5. Number of signalized intersections without storage = 4.

Procedure:

1. Change volume to terms of 1000's (i.e., $x_4 = 15.00$).
2. Divide number of signalized intersections with storage by the length of the site (i.e., $x_5 = 2.5$).
3. Divide number of signalized intersections without storage by the length of the site (i.e., $x_6 = 2.0$).
4. Substitute x_4, x_5, x_6 into Eq. 8 from the given:

$$Y_{10} = -0.51107 + 0.04852\ (15.00) + 0.49352\ (2.5) + 0.14416\ (2.0) = 1.73885$$

5. Take the antilog of Y_{10} to get the actual accident rate (accident/mile) predicted antilog Y_{10} = 54.81.

This gives 54.81 accidents/mile occurring at signalized intersections with left-turn storage for the 21-month study period.

Level of Service

Eq. 9 was generated for the purpose of predicting the level of service, in minutes per mile, on a given segment of four-lane highway with respect to any changes in the independent variables. The dependent variable in this equation is $\log_{10}$ level of service (min/mile), represented by Y_{LS}.

Six independent variables were chosen by the stepwise regression process to be the best predictors. These variables are as follows:

Variables	Means
$\bar{x}_3$	50.76086
$\bar{x}_4$	8.81467
$\bar{x}_5$	0.35672
$\bar{x}_6$	0.19922
$\bar{x}_8$	1.74386
$\bar{x}_{11}^2$	716.65406
$\bar{Y}_L$	0.09525
antilog$_{10}$ $\bar{Y}_{LS}$	1.25

The observations on these independent variables came from 92 highway sites.

$$Y_{LS} = 0.43433 - 0.00772\ x_3 + 0.00310\ x_4 + 0.03544\ x_5 + 0.03842\ x_6 + 0.00434\ x_8 - 0.0000033\ x_{11}^2 \quad (9)$$

T = (-11.48) (2.85) (3.78) (3.95) (1.66)

For this equation, R^2 equals 84.4 percent, the standard deviation $S_{y.x}$ equals 0.04563, and the coefficient of variation 100 $(S_{y.x}/\bar{Y}_{LS})$ equals 47.905 percent.

The 95 percent confidence interval about the mean is given as

$$\text{antilog}\left(0.09525 \pm 1.98\ \frac{0.04563}{\sqrt{92}}\right) = (1.229,\ 1.272)$$

Use of Models

A model, such as that used in Eq. 8, serves the purpose of relating accident rate per mile to the number and type of median openings per mile. Taking the hypothetical situation used in this example, assume there is a suggested addition of one signalized intersection with left-turn storage provided. For such a situation the x_5 variable changes by one-half or 0.5 giving a new value of 3 for x_5 while all other x variables remain constant. This addition of one signalized intersection with left-turn storage lanes increases the accident rate from 54.81/mile to 96.74/mile at signalized intersections with left-turn storage. (Site length, volume, etc., remain constant.)

This procedure enables the prediction of an accident rate for given conditions on a specific segment of highway. Once the site data are substituted in the prediction equation, any of the x values can be altered and the change in accident rate examined.

Eq. 9, which is for the prediction of level of service, can be used in conjunction with the accident prediction Eqs. 1 through 8. By this combined usage, the change in travel time/mile and accident rate/mile due to a change in the number of median openings can be examined simultaneously.

All nine equations may be very useful in forming a policy for the addition or deletion of median openings on a given segment of highway. However, they do not yield any standard spacing for median opening placement.

SUMMARY

This study has investigated the possibility of determining an optimum median opening spacing for a four-lane undivided highway using safety (accidents), intensity of roadside development (access) and level of service (travel time) as dependent factors. A precise optimum spacing of median openings could not be derived. However, accident rates and level-of-service indexes could be predicted for the sites studied and can be applied to other sites with similar roadway characteristics.

A regression model utilizing all location types was generated to predict accidents. After stratifying the data with respect to location types and then generating additional models, it was ascertained that increased accuracy could be obtained in the predictions.

Findings

Nine multiple-regression equations, which can be utilized to predict accident rates and level of service at different roadway locations, were presented. Because regression equations indicated that, in most cases, average daily traffic was the predictor of greatest magnitude (with respect to Student "t" value) and most frequent occurrence, traffic volume was recognized as the most significant predictor. The frequency of median openings, which corresponded to the accident rate predicted by the model for a specific location type, also ranked high in significance as a predictor.

These findings indicate that the average daily traffic volume and roadside access combined with the frequency and type of median openings account for most of the variation in accident rates. As a result, if these quantities and the other somewhat less significant factors investigated as independent variables are measured in the prescribed manner, accident rates can be forecast for given conditions. The most significant finding was that changes in these accident rates due to changes in the addition and type of median openings can be determined and evaluated relevant to safety and level of service.

During the preliminary investigation of characteristics on four-lane, nonaccess-controlled highways several auxiliary findings were made.

1. Roadside access increases as (a) the level of service index increases, (b) the number of median openings increases, or (c) the ADT volume increases.
2. Rear-end collisions account for 33 percent of all accidents on four-lane, nonaccess-controlled highways.
3. Unsignalized intersections and signalized intersections rank first and second as high-frequency locations for rear-end collisions.
4. The number of rear-end collisions is less where storage lanes are provided.

The principal results of this investigation are given in the regression equations shown previously. However, statements based on simple correlations may be made as to the effect of each of the independent variates acting alone.

These findings are as follows:

Simple Correlation Coefficients		Findings
(0.69883)	a.	As volume increases, accidents at all location types increase.
(0.66104)	b.	As volume increases, accidents at median openings with storage lanes increase.
(0.60117)	c.	As access points increase, accidents of all types increase.
(0.59287)	d.	As the number of signalized intersections with storage lanes increases, average travel time increases.
(0.57475)	e.	As the number of intersections without storage increases, travel time increases.
(0.57264)	f.	As volume increases, accidents at signalized intersections with storage increase.
(0.57087)	g.	As access points increase, travel time increases.
(0.53215)	h.	As access points increase, accidents at signalized intersections with storage increase.
(-0.53004)	i.	As speed limit increases, accidents of all location types decrease.
(0.50431)	j.	As volume increases, travel time increases.
(0.50256)	k.	As the number of signalized intersections without storage increases, travel time increases.
(0.49145)	l.	As volume increases, accidents at median openings without storage increase.
(0.47149)	m.	As volume increases, accidents between openings increase.
(0.47266)	n.	As access points increase, accidents at intersections with storage increase.
(0.46343)	o.	As the number of intersections without storage increases, accidents at signalized intersections without storage increase.
(0.46134)	p.	As the number of signalized intersections without storage increases, accidents at median openings with storage increase.
(0.45992)	q.	As volume increases, accidents at primary and secondary roads increase.
(0.45955)	r.	As the number of signalized intersections with storage increases, accidents at all location types increase.
(0.45570)	s.	As the number of intersection openings without storage increases, accidents at all location types increase.
(-0.43659)	t.	As the speed limit increases, accidents at signalized intersections without storage decrease.
(0.42593)	u.	As access points per mile increase, accidents at signalized openings without storage increase.
(0.42513)	v.	As the number of signalized intersections without storage increases, accidents at all location types increase.
(-0.41632)	w.	As speed limit increases, accidents at signalized intersections with storage decrease.
(0.41017)	x.	As access points increase, accidents at primary and secondary roads increase.
(-0.40896)	y.	As the speed limit increases, accidents at intersections with storage decrease.
(0.40490)	z.	As the number of signalized intersections without storage increases, accidents at primary and secondary roads increase.

5. Due to the difficulty of predicting many future independent variables, accident data on existing facilities do not furnish a basis for predicting accident rates on facilities to be constructed in the future; however, predictions on existing facilities can be made with the use of the regression equations.

6. Accident rates and level of service can be predicted for given sections of existing highways with the use of regression models. These models will show a change in the accident rate of the facility due to changes in given characteristics of the highway such as volume, number and type of median openings.

CONCLUSIONS

1. As traffic volumes increase, usage of median openings rapidly becomes hazardous. When combined with intensive roadside development, usage of median openings under high-volume conditions becomes very hazardous.

2. The signalization of median openings does not necessarily reduce the hazard of using openings under high-volume conditions, but merely tends to make the traffic flow more orderly by offering a more equitable distribution of time for movement by each driver.

3. As roadside development increases, and crossovers of any type are permitted, accidents will increase.

4. Fewer accidents were found on sections with higher speed limits only because higher speed limits were permitted on locations with low volume and low intensity of roadside development. In contrast, the mere reduction in speed limit, when volumes are high and roadside development is intense, does not suffice to keep the accident rate at a low level. The increased hazards associated with turning movements under high-volume conditions far exceed the benefits occasioned by reducing the speed limit.

RECOMMENDATIONS

1. All state highway departments should give serious consideration to the adoption of a policy or policies which would permit the predetermination, prior to actual need, of the specific location of all openings in the median on all future construction of divided highways. Following such an approach, the approximate spacing and location of future traffic signals would be preplanned to assure a travel speed and signal progression along the route compatible with the desired level of service. This plan would also designate the location of all future openings and would prohibit any appreciable altering of such locations and spacing in the future.

2. Roadside businesses must be encouraged to design their development in accord with the most efficient and safe use of the public highway. When a highway is continually altered to specifically serve roadside businesses, the accident potential will rapidly increase and the level of service will deteriorate. Consequently, roadway function must be defined prior to the intensive development of roadside business, and throughout its functional life a divided highway must continue to serve the general public, not principally by providing access to abutting property, but by satisfying its primal function—safe and efficient movement of traffic.

3. On existing four-lane, divided, nonaccess-controlled highways, prediction equations for accident rate and level of service may be most helpful in deriving a policy for the justification of either closing or adding median openings. However, each facility by virtue of its unique characteristics such as volume, roadside development, and number of existing openings, will have its own individual prediction criteria.

4. Whereas many states permit close spacing of median openings, such a procedure will usually result in a higher accident experience for the facility under consideration. Because many of these openings become potential points of signalization as land uses change and traffic volumes increase, it is strongly recommended that the spacing of median openings be rigidly controlled to accommodate efficient and safe traffic movement. Specifically, the opening should be so spaced as to permit efficient two-way progression of traffic movement. Knowledgeable traffic engineers are well aware that such spacing of signals depends primarily on the average operating speed of the traffic, which in turn reflects the level of service provided by a facility.

5. It is recommended that steps be taken toward the establishment of a firm policy in North Carolina whereby new facilities of the type described here would have median openings pre-located prior to actual need. The exact spacing must first be commensurate with the desired operating speed on the specific facility under consideration, and secondly must be compatible with anticipated roadside ingress and egress needs. Furthermore, it is recommended that no additional openings should be permitted at locations other than those satisfying the predetermined spacing.

6. It is recommended that highway-design concepts be reviewed in an attempt to derive improved ways of providing roadside access along highways with intensive

roadside development. Because of its inherent characteristics, roadside development along high-volume highways will inevitably attract vehicles from the traffic stream. If the most common means—median openings and crossovers—of facilitating access for these vehicles are not permitted at other than predetermined locations, it is readily apparent that currently accepted standards of geometric design will have to be revised in order to bring about compatibility of roadside development and highway function.

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Motor-Vehicle Accident Rates as Related to Design Elements of Rural Highways

K. J. THARP and JAAKKO K. KIHLBERG, Cornell Aeronautical Laboratory, Inc., Buffalo, New York

ABRIDGMENT

•THE results obtained from Phase 2 of the National Cooperative Highway Research Program Project 2-3 are summarized.

The study utilized highway and accident data from Ohio, Connecticut and Florida. The highway network of each state was subdivided into segments, each 0.3 mile long, each with known ADT, each homogeneous with respect to number of lanes, access control, and median, and each containing known geometric elements (curvature, gradient, intersections, and structures). Data of accidents occurring on the highway were affixed to the segment containing the site of occurrence. Proper grouping allowed calculation of accident rates for the various geometric elements.

The results showed that access control had the most powerful accident-reducing effect; one-vehicle accident rates (MVM) decreased with increasing ADT and multi-vehicle accident rates increased with increasing ADT; with no median and no access control, four-lane highways had higher accident rates than two-lane highways; medians tended to decrease the number of accidents, although the effect was not clear-cut; presence of curvature, gradients, intersections, and structures increased accident rates—intersections being the dominant element; presence of combinations of these elements generated higher accident rates than the presence of individual elements; the effect of grades and curves appeared to be constant for all gradients above 4 percent and for all curvature sharper than 4 degrees.

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Statistical Analysis of Accident Rates and Geometry of Highway

JAAKKO K. KIHLBERG and K. J. THARP, Cornell Aeronautical Laboratory, Inc., Buffalo, New York

ABRIDGMENT

•STATISTICAL aspects of the National Cooperative Highway Research Project 2-3 are summarized and discussed.

In the first phase of the study, accident data on individual highway segments were studied in terms of the equation log* $A = a + b_1 \log L + b_2 \log T$, where A = number of accidents on the segment, L = segment length, and T = ADT on the segment. The variable segment length was found to have an adverse effect on statistical analysis, presumably because the determination of the segment length often is based on the properties of the roadway itself, and length therefore is not a measure of exposure only.

In the second phase, segment length was made constant, and data, arranged in ADT classes, were analyzed by the equation log* $\bar{A} = a + b_1 \log \bar{T} + b_2 \log^2 \bar{T}$, where $\bar{A}$ and $\bar{T}$ are averages within each ADT class. Accident-rate curves were determined for four geometric features and their combinations. Generally, a good fit was obtained, and detailed analysis of effects of roadway geometry was made possible.

Possibilities for future research are discussed.

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