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

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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

		Independent Variable						
Accident Variable	Dependent 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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