Median Openings on Divided Highways: Their Effect on Accident Rates and Level of Service

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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			Access		Intersections				Median Openings Excluding Intersections		Total Openings per Mile	Medians		Speed limit (mph)	Volume	Land Use	Lanes		Level of Service (min/mi)	Accidents	
							Open/Mile														
Letter	No.	Length (mi)	Points	Per Mile	No.	Signalized	No.	Signalized	No.	Open/Mile		Type	Width (ft)				No.	Location		Per Mile	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	1483	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	45
One vehicle striking object off road	137	44	122	9	12	42	19	8	53	50	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	559	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 (36 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	0.50862	0.09385	0.56249	0.50543	0.04279	-0.02745	0.12218	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 $\bar{Y}$
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} = $(Access\ points)^2$.
x_{14} = ADT volume x access.
df = Degrees of freedom.

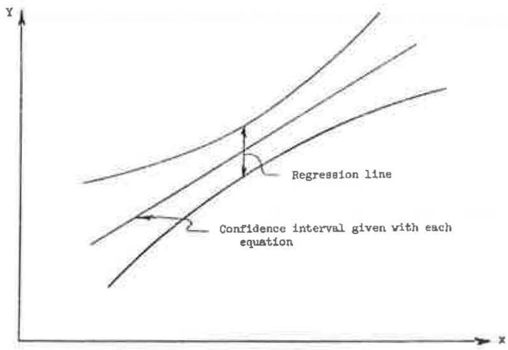

Figure 1.

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
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.

$$Y_T = -0.47946 + 0.00618\ x_2 + 0.00990\ x_3 + 0.05424\ x_4 + 0.16607\ x_5 + 0.2367\ x_6$$
$$T^* = \qquad (2.27) \qquad (1.74) \qquad (8.19) \qquad (2.70) \qquad (3.00)$$
$$+\ 0.02745\ x_8 + 0.06885\ x_9 + 0.07147\ x_{10} \qquad (1)$$
$$(1.54) \qquad (2.71) \qquad (3.29)$$

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.

$$\text{antilog}\left[Y_T + \text{"t"}\ \frac{s_{y.x}}{\sqrt{n}}\right] = \text{antilog}\left[1.06648 + 1.98\ \frac{0.29260}{\sqrt{92}}\right] = (10.141,\ 12.54)$$

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
$\text{antilog}_{10}\, \overline{Y}_4$	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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