Access Spacing and Traffic Safety

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ABSTRACT

This paper reviews the many research studies that relate traffic safety to access spacing, presents results of specially conducted analyses of accident information obtained from eight states, and sets forth emergent guidelines for assessing safety impacts of access spacing. The literature review and safety analyses were performed as part of NCHRP Project 3-52, Impacts of Access Management Techniques. Accident rate indices, derived from the literature synthesis and safety analyses, show the relative increase in accidents that can be expected as the total driveway density in both directions increases. These indices suggest that doubling the access frequency from 10 to 20 access points per mile would increase accident rates by 40 percent. A road with 60 access points per mile would have triple the accident rate (200 percent increase) as compared with a spacing of 10 access points per mile. Each additional access point increases the accident rate by about 4 percent. The research results suggest a generally consistent relationship—the greater the frequency of driveways and intersections, the greater the number of accidents. While the specific relationships reflect variations in road geometry, travel speeds, and driveway and intersection volumes, the general relationship remains consistent. The access spacing implications are clear. Increasing the spacing between access points helps reduce the number and variety of events to which drivers must respond. In addition, wide access spacing gives drivers more time for perception, reaction and navigation.

INTRODUCTION

The spacing and locations of streets and driveways affect traffic safety and operations. These access points introduce conflicts and friction into the traffic stream. Vehicles entering and leaving the main roadway often slow the through traffic. The differences in speeds between through and turning vehicles increase accident potential.

There is a growing consensus that increasing the spacing between access points improves arterial traffic flow and safety by (a) reducing the number of conflicts per mile, (b) providing greater distance to anticipate and recover from turning maneuvers, and (c) providing opportunities for improved design of turning lanes. It is increasingly recognized that spacing standards for unsignalized access points should complement those for signalized access points. Potentially high-volume unsignalized access points should be located where they conform to traffic signal progression requirements.

This paper overviews research efforts relating to access spacing and accidents, presents the results of specially conducted analyses of accident information obtained from eight states, and gives the emergent guidelines for assessing safety impacts. The analysis were performed as part of NCHRP Project 3-52, Impacts of Access Management Techniques (*1*).

OVERVIEW OF SAFETY EXPERIENCE

The research linking access density and accidents spans many decades. More than 40 years of research efforts have documented the basic relationships between access and safety. The methods of analyses and the resulting relationships among individual studies vary, but the patterns are generally similar. Roadways with full control of access have lower accident rates than other roadways. Arterial roadways with many driveways and signals often have double or triple the accident rates of roadways with wide spacings between access points or of roadways where access is fully controlled. Accident rates generally increase with greater frequencies of intersections and driveways.

Full Control of Access

The safety benefits of access control have been long recognized and underlie the freeway systems that have been developed over the last half century. Access control reduces the number and variety of events, while increasing the spacing of events (and conflicts) to which drivers must respond. This translates into fewer accidents—roadways with full control of access consistently have lower accident rates than other roadways. Roadways with full access control generally had between 25 and 50 percent of the accidents per million vehicle miles traveled (VMT) of roads without any access control.

Early Studies

Almost a dozen research efforts between 1960 and 1980 investigated the correlation between accident rates and the number, frequency and type of roadside features and access points.

Recent Studies

Many studies since the mid-1980s have also shown that increasing the frequency of access points adversely affects safety. Most of these studies were conducted to demonstrate the benefits of access management. Some show aggregate relationships while others utilize analytical or regression models. A description of some key studies follows.

Arapahoe Avenue and Parker Drive, Denver (1985) (*17*)

A demonstration project conducted by the Colorado Department of Highways compared the three-year accident experience on two access-managed highways (Arapahoe Avenue and Parker Drive) with that of five regular arterials. The two highly access-managed arterials (with physical medians, full access generally limited to one-half-mile intervals, most left-turn access prohibited, and right turn access provided at quarter-mile intervals) had about 40 percent of the accident rate found along the roads with more frequent access (the range was 27 to 69 percent).

Oregon Coast Highway, Oregon (1995) (*25*)

A comprehensive accident analysis was conducted for 29 miles of the Oregon Coast Highway (US Route 101) by Portland State University in association with the Oregon Department of Transportation. The study area, located on the Oregon coast in and around Lincoln City, has tourist traffic as well as the usual urban and rural traffic. Seven hundred and fifty accidents were analyzed for the four-year period from 1990 to 1994.

The analysis showed a consistent relationship between access per mile and accidents per mile, except for the "Parkway" section where the low number of accidents per mile reflects the presence of a continuous non-traversable median. As expected, the higher accident frequencies were found within the city limits where urban development not only resulted in higher driveway densities, but probably higher driveway volumes as well.

Australian Experience (1997) (*28*)

Studies by ARRB Transport Research of Australia indicated the following safety impacts when intersection and/or driveway frequency was increased.

1. Divided urban arterial roads with direct property access and frequent minor intersections had a 30 percent higher accident rate than those with few property access points and infrequent minor intersections. This difference increased to 70 percent for undivided roads.
2. In rural areas, each minor intersection added about 0.35 accidents per million entering vehicles for a 2-lane road and about 0.25 accidents per million entering vehicles for a 4-lane road.
3. Increasing minor intersection density in rural areas from zero to one per km (0 to 1.6 per mile) increased accident rates by about 25 percent on rural roads. An increase in minor intersection density in urban areas from 2 to 6 per km (3.2 to 9.7 per mile) increased accident rates by 20 to 100 percent on 4-lane roads and 50 to 100 percent on 2-lane roads.
4. Each additional private driveway per km in both urban and rural areas increased accident rates about 1.5 percent for 2-lane roads and 2.5 percent for 4-lane roads. These translate into 2.4 and 4.0 percent increases per private driveway on a per mile basis. In

urban areas, each commercial driveway had about 5 times the effect of a private driveway on accident rates.

5. In general, the effects noted above increased with decreasing standards of horizontal alignment and decreased if medians were present.

Synthesis of Experience

The various studies point to one consistent finding. An increase in the number of access points translates into higher accident rates. Thus, the greater the frequency of driveways and streets, the greater the number of accidents.

The specific relationships vary, reflecting differences in road geometry (e.g., lane width, presence or absence of turn lanes and physical medians), operating speeds, and driveway and intersection traffic volumes. Still, in every case, more access means more accidents. This upward trend in accident rates is apparent from experience in the United States and Canada.

A series of indices were prepared to correlate accident rates with access density by using the accident rates for 10 access points per mile as a base (total access points per mile on both sides of the road). The indices were then averaged for each access density. These indices suggest that doubling of access frequency from 10 to 20 per mile increases accident rates about 30 percent. An increase from 20 to 40 driveways per mile would increase accident rates over 60 percent. These increases are similar to those reported in Australia (*28*).

The access spacing implications are clear. Increasing the spacing between access points and providing greater separations of conflicts will reduce the number and variety of events to which drivers must respond. This, in turn, translates into fewer accidents.

SAFETY ANALYSES

Comprehensive safety analyses were performed for accident information obtained from Delaware, Illinois, Michigan, New Jersey, Oregon, Texas, Virginia, and Wisconsin. Overall, some 386 roadway segments were analyzed to establish the relationships between access and accidents for various spacings and median types.

Analysis Procedures

The accident database for the 386 road segments was stratified by the number of signalized and unsignalized access points per mile, the area type (i.e., urban/rural) and the median treatment (undivided, two-way left-turn lane, nontraversable median). The segments were further stratified by land use, number of lanes, and ADT range. In urban areas, 264 segments covered 254 miles, including 116 segments with medians, 95 segments with two-way left-turn lanes (TWLTLs) and 53 undivided segments. In rural areas, 122 segments covered 168 miles including 57 segments with medians, 14 segments with TWLTLs and 51 undivided segments.

The data screening and stratification process resulted in the elimination of 17 road segments without any access points or with sections less than 0.31 miles long and reduced the number of segments from 386 to 369 (252 urban and 117 rural road sections).

Exploratory analyses (e.g., frequency distributions, cross-classifications, means, etc.) were performed for key variables in the database to define appropriate stratifications and to screen outliers. These analyses revealed that area type was significant since accident rates for rural areas were significantly lower than those for urban/suburban areas. This is because as access density increases, the opportunity for conflicts is greater and the available space for maneuvering is less.

These analyses also found that the average accident rates for certain routes in urban/suburban areas in Texas, Virginia, and Oregon were almost 50 percent lower than comparable areas from the other states; Virginia segments exhibited twice as high average volumes per lane, compared to segments from the other states (excluding New Jersey); and the average access density and the average volume per lane for the urban/suburban segments in New Jersey were significantly higher than comparable segments from the other states.

Accordingly, Oregon, Texas and Virginia data were excluded from detailed analysis. The resulting database that was used for further analysis included 264 road segments—170 urban and 94 rural segments. Collectively, these sections contained about 37,500 accidents.

Urban and Suburban Areas

Detailed analyses were conducted for the urban/suburban database for Illinois, Michigan, Wisconsin, New Jersey, and Delaware. The first step was to screen segments for characteristics or accident rates that did not appear to be consistent with the rest of the data. Next, the accidents were stratified by geometric and access density variables. Finally, statistical analyses were performed for the accident rates in the various strata.

After the potential "outliers" were removed from the database, 152 of the 170 road sections remained. Frequency distributions and cross-classifications were prepared to identify potential strata and to explore relationships. Based on this analysis, four strata for total access points per mile and unsignalized access points per mile (0–20, 20.01–40, 40.01–60 and over 60) and four strata for signalized access points per mile (0–2, 2.01–4, 4.01–6 and over 6) were established. These stratifications avoid cells with few points.

Accident rates by total access density and type of median treatments are shown in Table 1. Means, coefficients of variation, Student's 't' distribution statistics and p-values are given. The p-values represent the probabilities of differences between means occurring due to chance; thus, a 0.05 p-value is similar to a 5-percent level of significance. The p-values are shown for changes in access density (top to bottom). They are for a one-sided, upper-tail 't' test (i.e., to determine if differences are significant).

Table 1 shows an increase in accidents for each type of median treatment as the *total* access density increases. The accident rate for access densities of over 60 per mile was more than 2.5 times higher than the accident rate for access densities of under 20 per mile.

The table also shows the accident reductions associated with various roadway median alternatives. Overall, two-way left-turn lanes had a 20-percent lower accident rate, and non-traversable medians had a 40-percent reduction compared with undivided road sections. These patterns were generally consistent across all access density ranges.

The effects of *signalized* access density on accident rates are shown in Table 2. The p-values are shown top to bottom. Accident rates increased as signalized access density increased. The rate for more than six signals per mile was more than 2.5 times that for signal densities of two or less per mile.

TABLE 1 Accident Rates by Total Access Density and Type of Median Treatment—Urban/Suburban Segments

Access Density [(1)]	Statistics	Median Treatment: Undivided	Median Treatment: TWLTL	Median Treatment: Non-traversable	Total
<20	Mean	3.82	--------	2.94	3.24
	C.V.	0.28		0.45	0.40
	Cases	5		10	15
20.01-40	Mean	8.27	5.87	5.13	5.90
	C.V.	0.72	0.43	0.60	0.53
	Cases	5	33	14	52
	t-statistic	1.64	NA	2.36	NA
	p-value	0.09	NA	0.02	NA
40.01-60	Mean	9.35	7.43	6.47	7.37
	C.V.	0.43	0.52	0.47	0.49
	Cases	7	23	17	47
	t-statistic	0.35	1.72	1.21	NA
	p-value	0.37	0.05	0.12	NA
>60	Mean	9.55	9.17	5.40	8.59
	C.V.	0.43	0.56	0.75	0.53
	Cases	21	9	8	38
	t-statistic	0.11	0.92	NA	NA
	p-value	0.46	0.19	NA	NA
Total	Mean	8.59	6.88	5.19	
	C.V.	0.52	0.52	0.61	
	Cases	38	65	49	152

Notes: Accident Rates = Accidents per Million Vehicle Miles Traveled.
p-values computed top to bottom and are not computed where inconsistencies in the accident rate trends exist.
(1) Access Density reflects both signalized and unsignalized access points per mile.
C.V. = Coefficient of variation.
NA = Not Applicable

TWLTL segments appeared to have lower accident rates than undivided road sections. The one exception may reflect the low sample size for undivided segments with less than two signals per mile. Non-traversable medians had lower accident rates than the other median treatments for all signal spacing frequencies.

Accident rates for various cross classifications of signalized and unsignalized access densities are shown in Table 3. The upper tail p-values are shown for changes in unsignalized access frequencies (left to right). The data showed an overall increase in accident frequency as unsignalized access density rises. Overall accident rates for access densities of over 60 points per mile were about 2.2 times that for densities of 20 or fewer access points per mile.

Table 3 provides guidance for estimating the effects of increasing unsignalized access density. However, signal density may be a surrogate for heavy cross street volumes; thus, the values for signal density may not apply where signals are added at lightly traveled cross roads.

TABLE 2 Accident Rates by Signalized Access Density and Type of Median Treatment—Urban/Suburban Segments

Signalized Access Density (1)	Statistics	Median Treatment			
		Undivided	TWLTL	Non-traversable	Total
<2	Mean C.V. Cases	4.01 0.41 4	4.13 0.72 15	2.75 0.52 14	3.53 0.66 33
2.01-4	Mean C.V. Cases t-statistic p-value	8.20 0.53 12 2.80 0.01	7.02 0.46 20 2.76 0.01	5.66 0.52 15 3.40 0.00	6.89 0.51 47 NA NA
4.01-6	Mean C.V. Cases t-statistic p-value	9.87 0.55 10 0.79 0.22	7.42 0.36 17 0.41 0.34	5.99 0.51 15 0.30 0.39	7.49 0.51 42 NA NA
>6	Mean C.V. Cases t-statistic p-value	9.45 0.38 12 0.21 0.42	9.13 0.46 13 1.30 0.11	8.26 0.40 5 1.22 0.14	9.11 0.41 30 NA NA
Total	Mean C.V. Cases	8.59 0.52 38	6.88 0.52 65	5.19 0.61 49	 152

Notes: Accident Rates = Accidents per Million Vehicle Miles Traveled.
p-values are computed top to bottom and are not computed where inconsistencies in the accident rate trend exist.
(1) Access Density reflects signalized access points per mile.
C.V. = Coefficient of variation.
NA = Not Applicable

Rural Areas

A similar analysis was performed for road segments located in rural areas. The accident rates were stratified by total access point density and median treatment, since the number of signalized access points in the database was small. Accidents rates for Michigan were recalculated to remove animal-related and rail-crossing accidents.

After the potential outliers were eliminated from the database, frequency distributions and cross-classifications were prepared to identify potential strata and to explore relationships. The number of strata was kept to a minimum to avoid cells with very few points. Accordingly, three strata for total access points were identified as less than 15, 15–30 and over 30.

TABLE 3 Accident Rates Stratified by Signalized and Unsignalized Access Density—Urban/Suburban Segments

Signalized Access Density (access points per mile)	Statistics	Unsignalized Access Density (Access Points Per Mile)				Total
		≤20	20.01-40	40.01-60	>60	
<2	Mean	2.63	4.33	3.01	3.80	3.53
	C.V.	0.49	0.69	0.51	0.68	0.66
	Cases	8	14	9	2	33
	t-statistic	NA	1.85	NA	0.41	NA
	p-value	NA	0.04	NA	0.37	NA
2.01-4	Mean	3.94	5.58	8.30	8.22	6.89
	C.V.	0.28	0.33	0.44	0.53	0.51
	Cases	5	16	12	14	47
	t-statistic	NA	2.45	2.35	0.05	NA
	p-value	NA	0.02	0.02	0.48	NA
4.01-6	Mean	4.83	6.91	8.37	8.54	7.49
	C.V.	0.36	0.52	0.43	0.58	0.51
	Cases	3	19	12	8	42
	t-statistic	NA	1.62	1.10	0.08	NA
	p-value	NA	0.08	0.14	0.47	NA
>6	Mean	8.61	8.06	11.30	9.53	9.11
	C.V.	NA	0.39	0.33	0.48	0.41
	Cases	1	14	5	10	30
	t-statistic	NA	0.98	1.75	0.44	NA
	p-value	NA	0.17	0.07	0.34	NA
Total	Mean	3.76	6.26	7.47	8.42	
	C.V.	0.51	0.51	10.55	0.53	
	Cases	17	63	38	34	152

Notes: Accident Rates = Accidents per Million Vehicle Miles Traveled.
p-values are computed left to right and are not computed where inconsistencies in the accident rate trend exist.
Separate Variance t-statistic to account for unequal Cell Variances.
C.V. = Coefficient of Variation.
NA = Not Applicable.

Accident rates are stratified by *total* access density and median treatment in Table 4. The upper tail p-values compare various access densities (top to bottom) on the table. P-values were not computed where inconsistencies in the accident rate trend exist.

The increase in access density from less than 15 access points to over 30 access points per mile resulted in a 65 percent increase in the overall accident rate. TWLTLs had about a 40 percent lower accident rate and non-traversable medians had a 60 percent lower accident rate than undivided road sections.

APPLICATION GUIDELINES

The generalized effects of access spacing on traffic accidents can be estimated by applying the accident rate indices shown in Table 5, that were derived from the literature synthesis and safety analyses. The suggested composite indices show the relative increase

TABLE 4 Accident Rates by Access Density and Type of Median Treatment Rural Segments

Access Density (1)	Statistics	Median Treatment			Total
		Undivided	TWLTL	Non-traversable	
≤15	Mean	2.54	2.06	0.90	1.64
	C.V.	0.63	NA	1.24	0.95
	Cases	24	1	30	55
15.01-30	Mean	2.60	1.26	1.18	1.79
	C.V.	0.62	NA	1.26	0.92
	Cases	11	1	14	26
	t-statistic	0.10	NA	0.64	NA
	p-value	0.46	NA	0.27	NA
>30	Mean	4.65	1.67	1.47	2.71
	C.V.	0.13	0.78	0.85	0.68
	Cases	3	2	3	8
	t-statistic	3.40	NA	0.35	NA
	p-value	0.01	NA	0.38	NA
Total	Mean	2.73	1.67	1.02	
	C.V.	0.59	0.49	1.20	
	Cases	38	4	47	89

Notes: Accident Rates = Accidents per Million Vehicle Miles Traveled.
p-values are computed top to bottom and are not computed where inconsistencies in the accident rate trend exist.

(1) Access Density reflects both signalized and unsignalized access points.
Separate Variance t-statistic to account for unequal Cell Variances.
C.V. = Coefficient of variation.
NA = Not Applicable.

TABLE 5 Suggested Accident Indices for Unsignalized Access Spacing

Access Points Per Mile*	(A) Literature Synthesis	(B) Safety Analysis	(C) Suggested Value
10	1.0	1.0	1.0
20	1.3	1.4	1.4
30	1.7	1.8	1.8
40	2.1	2.1	2.1
50	2.8	2.3	2.5
60	4.1	2.5	3.0
70	-	2.9	3.5

* Total for both directions.

in accidents that can be expected as the total driveway density in both directions increases. These indices suggest that doubling the access frequency from 10 to 20 access points per mile would increase accident rates by 40 percent. A road with 60 access points per mile would have triple the accident rate (200 percent increase) as compared with a spacing of 10 access points per mile. Each additional access point increases the accident rate by about 4 percent.

Figures 1 and 2 present accident rates by median type and total access density (both directions) for urban-suburban and rural roadways, respectively. These are shown for the midpoints of the unsignalized access spacing groups, and they reflect adjustments to eliminate apparent anomalies in the reported data.

- In urban and suburban areas, each access point (or driveway) added would increase the annual accident rate by about 0.11 to 0.18 accidents per million VMT on undivided highways and by 0.09 to 0.13 on highways with TWLTLs or non-traversable medians.
- In rural areas, each access point (or driveway) added would increase the annual accident rate by about 0.07 on undivided highways and 0.02 on highways with TWLTLs or non-traversable medians.

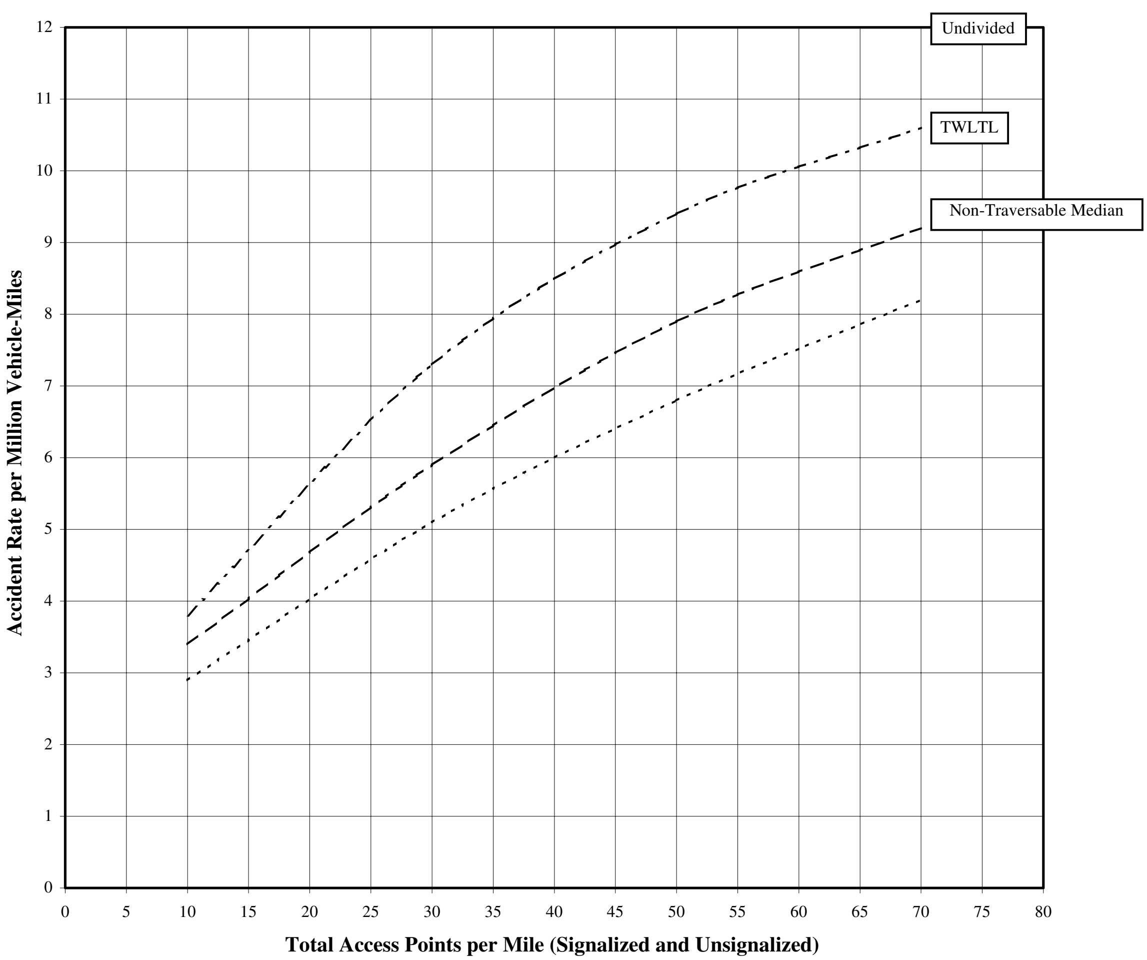

FIGURE 1 Estimated accident rates by type of median: urban and suburban areas.

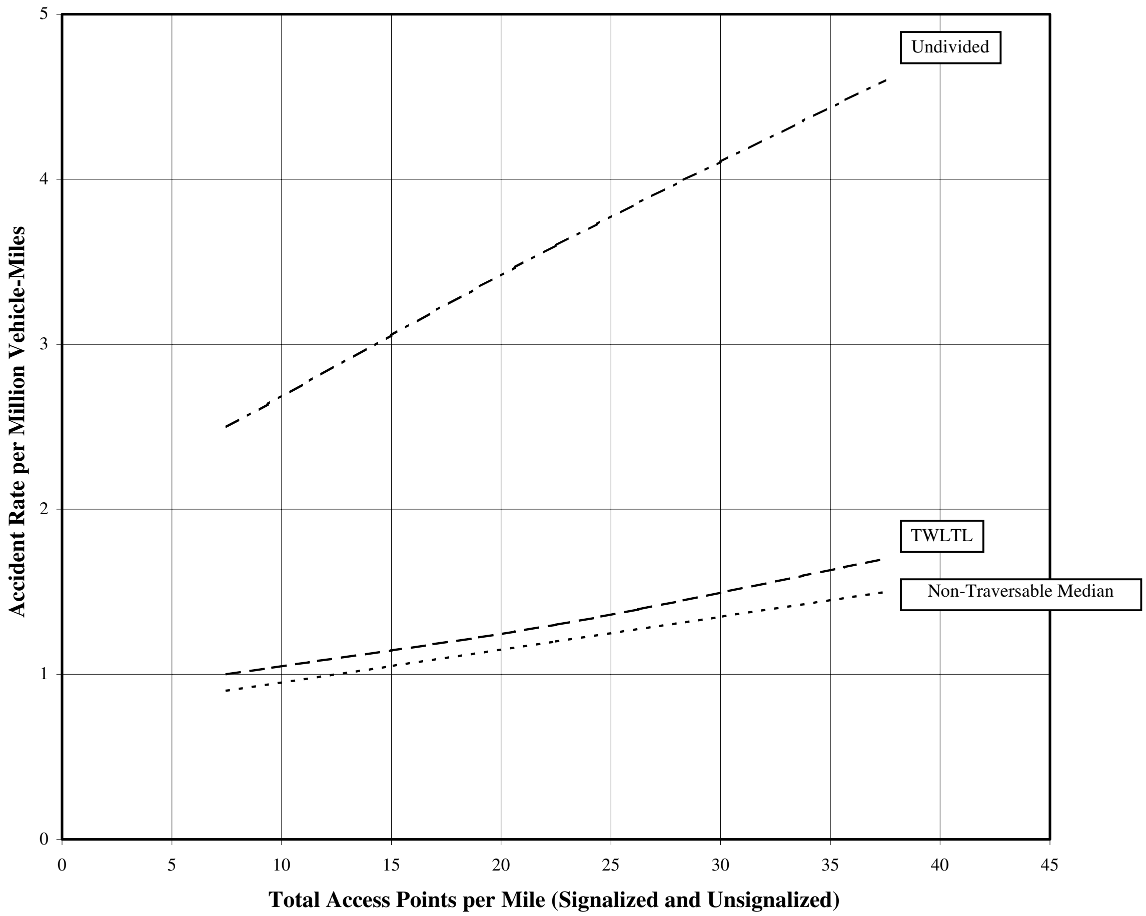

FIGURE 2 Estimated accident rates by type of median: Rural areas.

Representative accident rates by signalized and unsignalized access density are shown in Figure 3 for urban and suburban areas. These rates contain adjustments to account for apparent anomalies. Each unsignalized driveway may add about 0.02 to the accident rate at low signal densities, and from 0.06 to 0.11 at higher signal densities.

The rates in Figure 3 may be used to estimate the changes associated with increasing unsignalized access density at any given signal density (driveways to single-family residences should be excluded). However, the figure should not be used to estimate the effects of adding signals, since in deriving accident rates, signal density served as a surrogate for cross street traffic.

Accidents may be underestimated along sections of roadway with both heavy ADTs and driveway traffic since there is a greater proportion of non-reportable accidents. Therefore, care should be exercised when these rates are applied along heavily traveled roadways in large metropolitan areas. In such cases, basic accident rates should be obtained; the values in the table should be used to assess the differential cumulative impact of adding driveways.

Accordingly, the following procedure may be used to estimate the impacts of changing unsignalized access spacing along a section of road.

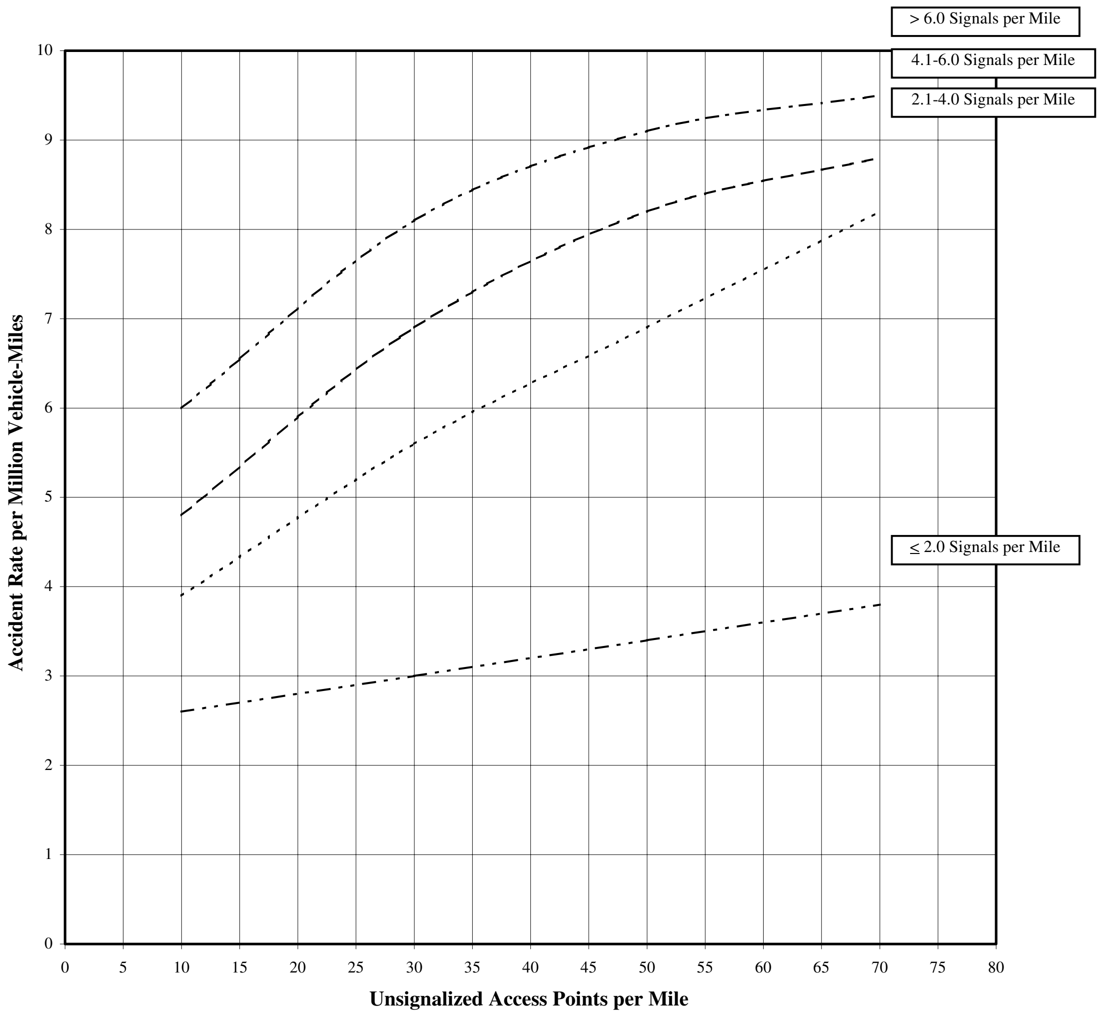

FIGURE 3 Estimated accident rates by access density: Urban and suburban areas.

1) Given:
   Actual Accident Rate = A
   Existing Driveways Per Mile = D_1
   Existing Signals/Mile = S_1
   Proposed Driveways Per Mile = D_2
2) Obtain the estimated existing and future accident rates (R_1 and R_2) from Figure 3.
3) Apply the ratio of R_2 / R_1 to the actual accident rate A.

Implications

The research results suggest a generally consistent relationship—the greater the frequency of driveways and intersections, the greater the number of accidents. While the specific relationships vary, reflecting variations in road geometry, travel speeds, and driveway and intersection patterns, the general relationship remains consistent.

The access spacing implications are clear. Increasing the spacing between access points helps reduce the number and variety of events to which drivers must respond. In addition, wide access spacings give drivers more time for perception, reaction and navigation. Access spacing, therefore, has become an integral part of contemporary access management actions.

It may also be noted that on urban/suburban segments, accident rates for a TWLTL are typically 20% less than for an undivided facility; and accident rates are 40% less for a divided facility compared to an undivided facility.

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BIBLIOGRAPHY

1. Gluck, J., Levinson, H. S., and Stover, V. *NCHRP Report 420: Impacts of Access Management Techniques*, TRB, National Research Council, Washington, D.C., 1999.
2. The Federal Role in Highway Safety. *Report to the 86th Congress*, House Document No. 95, February, 1959.
3. Gwynn, D. W. Accident Rates and Control of Access. *Traffic Engineering*, Institute of Traffic Engineers, Washington, D.C., November 1966, pp. 18–21.
4. Kihlberg, J. K., and Tharp, K. S. Accident Rates as Related to Design Elements of Rural Highways. In *Highway Research Record 41*, Highway Research Board, National Research Council, Washington, D.C., 1968.
5. *A Manual on Road User Benefit Analysis of Highway and Bus Transit Improvements.* American Association of State Highway and Transportation Officers, Washington, D.C., 1977.
6. McMonagle, S. C. Effect of Roadside Features in Traffic Accidents. *Traffic Quarterly*, ENO Foundation for Traffic Control, Westport, Conn., April 1952, pp. 228–243.
7. Staffeld, P. R. Accident Rates Related to Access Points and Advertising Signs - Minnesota Highway Study. *Traffic Quarterly*, ENO Foundation for Traffic Control, Westport, Conn., January, 1953.
8. Schoppert, D. W. Predicting Traffic Accidents from Roadway Elements of Rural Two-Lane Highways with Gravel Shoulders. *Highway Research Board Bulletin 158*, Highway Research Board, National Research Council, Washington, D.C., 1957, pp. 4–26.
9. Head, S. A. Predicting Traffic Accidents from Roadway Elements on Urban Extensions of State Highways. *Highway Research Board Bulletin 208*, Highway Research Board, National Research Council, Washington, D.C., 1959, pp. 45–63.
10. Cribbins, P. D., Aray, J. M., and Donaldson, J. K. Effects of Selected Roadway and Operational Characteristics on Accidents on Multi-lane Highways. In *Highway Research Record 188*, Highway Research Board, National Research Council, Washington, D.C., 1967, pp. 8–28.
11. Mulinazzi, T. C., and Michael, H. L. Correlation of Design Characteristics and Operational Controls with Accident Rates on Urban Arterials. *Engineering Bulletin*

of Purdue University, Proceedings, 53rd Annual Road School, March 1967, pp. 150–173.

12. Dart, O. K., Jr. and Mann, L., Jr. Relation of Rural Highway Geometry to Accident Rates in Louisiana. In *Highway Research Record 312*, Highway Research Board, National Research Council, Washington, D.C., 1970, pp. 1–16.
13. Fee, (Cirillo), J. A.; Beatty, R. L.; Dietz, S. K.; and Vates, S. G. *Interstate System - Study 1*, Bureau of Public Roads, U.S. Government Printing Office, Washington, D.C., October, 1970.
14. McGuirk, W. M. Evaluation of Factors Influencing Driveway Accidents, Joint Highway Research Project C-36-598. Purdue University, West Lafayette, Indiana, 1973.
15. McKotter, D. A. Analysis of Motor Vehicle Accidents at Commercial Driveway Locations. Purdue University, West Lafayette, Indiana, June 1974.
16. Glennon, J. C., Valenta, J. J., Thorson, B. A., Azzeh, and Wilton, C. J. Evaluation of Techniques for the Control of Direct Access to Arterial Highways, Report No. FHWA-RD-76-85; Technical Guidelines for the Control of Direct Access to Arterial Highways, Volume I: General Framework for Implementing Access Control Techniques, Report No. FHWA-RD-76-86; “Volume II; Detailed Description of Access Control Techniques,” Report No. FHWA-RD-76-87, Federal Highway Administration, August 1975.
17. *State of Colorado Access Control Demonstration Project*, Colorado Department of Highways, June, 1985.
18. *Waushara County Access Control Plan*, East Central Wisconsin Regional Planning Commission, September, 1986.
19. Sokolow, G. Access Management and Its Role in Congestion Management. Florida Department of Transportation, RA/International Conference Centre Amsterdam, The Netherlands, April 12–15, 1992.
20. Long, G., Gan, Cheng-Tin, and Morrison, B. S. *Safety Impacts of Selected Median and Design Features*, Transportation Research Center, University of Florida, Prepared in Cooperation with State of Florida Department of Transportation, May 28, 1993.
21. Li, Jian, *Study of Access and Accident Relationships*. Prepared for Highway Safety Branch, the Ministry of Transportation and Highways British Columbia, October 1993.
22. Millard, W. Accident Analysis Relating Crashes to Major Access Management Features - US 41, Lee County, Florida, 1993.
23. Urbitran Associates. Improvement Options. Prepared for Michigan Department of Transportation, 1994.
24. Fitzpatrick, K., and Balke, K. An Evaluation of Flush Medians and Two-Way Left Turns on Rural Four Lane Highways. Presented at 74th TRB Annual Meeting, Washington, D.C., January 1995.
25. Lall, B. K., et al. Analysis of Traffic Accidents within the Functional Area of Intersections and Driveways. Technical Report TRANS 1-95, Portland State University, 1995.
26. Urbitran Associates with I. K. Chann Associates and Herbert S. Levinson. Final Report. Route 7 Driveway and Access Management Plan. Prepared for Southwest Regional Planning Agency, Norwalk, Connecticut, June 1996.

27. Garber, N. J., and White, T. E. Guidelines for Commercial Driveway Spacing on Urban and Suburban Arterial Roads. In *Proceedings, 2nd National Conference on Access Management*, Vail, Colorado, August, 1996.
28. McLean, John. ARRB Transport Research Report 315, Practical Relationships for the Assessment of Road Feature Treatments - Summary Report, 1997.