Association of Median Width and Highway Accident Rates

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Data for two states have been extracted from the Highway Safety Information System and used to examine the effect of median width on the frequency and severity of accidents. Log-linear models for accident rates have been used to describe the effect of median width after adjusting for other variables. Effects have been estimated by the quasi-likelihood technique assuming a negative-binomial variance for the accident count per roadway section. Results for both states indicate that total accident rates and rates for specific types and severity decline rapidly when median width exceeds about 25 ft (7.6 m). Policy guidelines for median widths are somewhat nebulous, partly due to the lack of large well-conducted studies providing quantitative information on this topic. The results provide a basis for the development of more precise guidelines regarding median width.

Medians on divided highways provide a recovery area for out-of-control vehicles. The median should be wide enough to allow an out-of-control vehicle sufficient space to recover without crossing over the median into opposing traffic. In addition, divided highways with wide medians provide a safety zone at access points for turning vehicles and entering vehicles wishing to cross one or both directions of traffic. A variety of median types are in use, with narrow medians sometimes including barriers designed to positively prevent out-of-control vehicles from crossing the median into opposing traffic.

It has been suggested that the median width should be at least 60 ft (18.3 m) on rural highways and can be as low as 10 ft (3.1 m) on urban highways if median barriers are provided (*1*), but little research has been conducted providing quantitative measures of the effects of median width on the frequency and severity of related accidents. Early studies (*2–5*) were not able to establish definitive relationships between accident rates and median width; however, a subsequent study by Garner and Deen (*6*) has shown that wider medians have lower accident rates. The Garner and Deen study used 420 mi (676 km) of rural, four-lane, fully controlled access road sections [speed limit 70 mph (113 kph)] in Kentucky with median widths ranging from 20 to 60 ft (6.1 to 18.3 m) and involved a total of 2,448 accidents (1965–1968).

This paper examines the effect of median width on the frequency and severity of accidents on homogeneous highway sections with a traversable (nonbarrier) median. Highway sections with curbed medians or medians including barriers were also examined. However, there were insufficient sections of these types for meaningful statistical analysis.

Data extracted from the Highway Safety Information System (HSIS) for the states of Utah and Illinois are used. The Utah data involve 982 sections of highway for a total of 973.8 mi (1567.8 km) of roadway with 37,544 reported accidents over the period 1987 through 1990. The Illinois data involve 2,481 sections of highway for a total of 2,081.3 mi (3351 km) of roadway and 55,706 accidents over the period 1987 through 1989. Road sections with median widths ranging from zero (no median) to 110 ft (33.6 m) are examined.

METHODS

Data Base

HSIS developed and maintained for the Federal Highway Administration by the Highway Safety Research Center (HSRC) at the University of North Carolina, includes an accident data base, a road inventory data base, and a traffic volume file for five states (Illinois, Utah, Michigan, Minnesota, and Maine). All accidents reported to the police are included in the data base, and for each accident a variety of details are recorded, including date and location of accident, road and environmental conditions, accident type, and the number and severity of injuries. The road inventory data base contains the characteristics of homogeneous highway sections. The definition of homogeneous varies to some degree from state to state, but in most cases a new section is initiated any time there is a change in a major geometric or cross-section variable (e.g., lane width, pavement type, shoulder width or type, number of lanes, etc.). For this study, homogeneous sections of highway were defined as contiguous segments for which the following variables did not change: federal aid system, functional classification, rural/urban designation, predominant terrain type, average annual daily traffic volume (both directions), one- or two-way operation, number of lanes, average through lane width, posted speed limit, access control, median width and type, left shoulder width, and right shoulder type.

The traffic volume file contains the average annual daily traffic volume. Using route number and mile points, these three files can be merged to obtain the number, rate, severity, and type of accidents that have occurred on specific highway sections over a given period of time.

Extensive checking and preliminary investigation indicated that the accident and roadway data for two of the five states

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(Utah and Illinois) were of adequate completeness and reliability for an analysis investigating the effect of median width on accident rates. The Utah and Illinois data were described by Council and Hamilton (*7*) and Council and Williams (*8*), respectively.

Several roadway characteristics in addition to median width affect the frequency, severity, and type of accidents. To isolate the effect of median width, these other variables must be controlled either by restricting the road sections to have particular characteristics or through statistical adjustment. In this study both methods of control were used.

The analyses have for the most part been restricted to two-way, four-lane, rural and urban Interstate, freeway, and major highway road sections of length exceeding 0.07 mi (0.11 km), with posted speed limit at least 35 mph (56 kph) and with median widths ranging from zero (no median) to 110 ft (33.6 m). A section length of 0.07 mi (0.11 km) was chosen as the minimum length for which reported accident locations could be considered reliable for merging with the road inventory data base. Sections on minor roads were eliminated because many had missing data and virtually all had no median. After these were eliminated, there were very few sections with speed limit less than 35 mph (56 kph), so the remaining few were also eliminated. There were also a few sections with median width ranging from 111 ft (33.9 m) to 999 ft (304.7 m), and these were eliminated because they were possibly in error and would have a large influence on the median width coefficients in a regression model. In addition, the Utah analysis was restricted to road sections with lane width of 12 ft (3.7 m). There was no explicit lane width variable for Illinois, and it could not be reliably calculated from other variables; thus no such restriction was applied for Illinois.

Median width is defined as the width of the portion of divided highway separating the traveled ways for traffic in opposite directions (and includes the inside shoulder). Other variables considered in the statistical analyses were as follows: functional classification (categorized as rural–Interstate/freeway, rural–other major road, urban–interstate/freeway, urban–other major road), posted speed limit [35 to 40, 45 to 50, 55, and 65 mph (56 to 64, 72 to 81, 89, and 105 kph)], right shoulder width, access control (full, partial, none), curvature (value 1 if curvature greater than 1 degree, 0 otherwise), average daily traffic (average number of vehicles per day), and section length [in miles (kilometers)]. Access control data were not reliable for Utah (on the basis of information from state data experts) and were therefore not considered in the Utah analysis. Furthermore, 23 percent of the Utah sections did not have speed limit recorded and thus an additional category "missing" was used for this variable. Curvature was not considered in the Illinois analysis because the data were incomplete.

The Utah analysis was based on 982 sections of highway for a total of 973.8 mi (1567.8 km) of roadway [average section length 0.99 mi (1.6 km)], and the Illinois analysis involved 2,481 sections of highway for a total of 2,081.3 mi (3350.9 km) of roadway [average section length 0.84 mi (1.35 km)].

For each Utah road section, the number of accidents over the 4-year period 1987–1990 was obtained (giving a total of 37,544 accidents), whereas for Illinois the 3-year period 1987–1989 was used (giving a total of 55,706 accidents). The 1990 Illinois data did not yet exist in the HSIS files at the time of this analysis. Each accident had a severity code representing the most serious injury in the accident (K = fatal, A = incapacitating injury, B = nonincapacitating injury, C = possible injury, PDO = property damage only). The number of total accidents and the number of each severity type were determined for each section of road for use in total, A + K, C + B + A + K (i.e., all injury), and PDO crash rates.

The accident data from both states also provided numerous variables concerning the nature of the accident, including accident type, collision sequence (in Utah), and vehicle movements preceding and during the accident sequence. An attempt was made to define a smaller number of accident categories based on "potential median involvement"—the degree to which the presence and width of a median might potentially affect the crash rate. This categorization was based on the assumption that the basic goals of a median are (*a*) to separate opposing vehicles, (*b*) to provide a vehicle with a safe clearzone that can be used to avoid vehicles traveling in the same direction, (*c*) to provide a refuge for turning or crossing vehicles, and (*d*) to provide a safe clearzone to reduce the number of ran-off-road object impacts. In the resulting categorization, each accident was coded as a multivehicle collision or single-vehicle accident. In addition, head-on/sideswipe opposite direction collisions and single-vehicle rollover crashes were identified. If an accident involved a sequence of two or more events (as could be ascertained in the Utah data), collision with another vehicle took precedence over a single vehicle event, head-on/sideswipe opposite direction collision took precedence over other types of collisions, and rollover took precedence over other single-vehicle events. Counts of each of these types of crashes were made for each roadway section for use in calculating the rates.

Statistical Methods

The accident rate per 100 million vehicle miles traveled for an individual road section was calculated as

$$R = (Y/VM) * 10^8$$

where

R = observed rate,
Y = observed number of accidents,
VM = vehicle miles of travel calculated as $ADT * 365 * T * L$,
ADT = average daily traffic (vehicles per day),
T = number of years over which accidents were counted, and
L = section length (mi) (1 mi = 1.61 km).

Accident rates corresponding to all accidents, serious injury accidents (A or K), injury accidents (C, B, A, or K), PDO accidents, multivehicle accidents, head-on or sideswipe opposite direction accidents, single-vehicle accidents, and single-vehicle rollover accidents have been analyzed using regression models. The specific aims of the modeling process were to obtain standard errors and confidence intervals for estimated accident rates and to determine whether the observed reduction in the crude accident rates for wider medians persisted after adjusting for other roadway variables.

A log-linear regression model was used to simultaneously assess the effects of median width and several other roadway variables on the accident rate. This model may be represented algebraically as

$$\log(\lambda) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k$$

where

- λ = expected value of $R = E(R) = [E(Y)/VM] * 10^8$ (log denotes logarithm to base e), and
- X_i = indicator (dummy) variables for categorical roadway characteristics (e.g., functional class) or actual values for quantitative roadway characteristics (e.g., right shoulder width).

Note that $\exp(\beta_i)$ (i.e., e^{β_i}) represents the relative effect of a unit change in X_i on the accident rate.

Log-linear models assume that the effect of variables on the accident rate is multiplicative rather than additive as in linear models. Estimated rates from log-linear models cannot be negative. Log-linear models have been widely used in statistical analyses of count data [see McCullagh and Nelder (*9*) and references therein] and have recently been used in transportation studies by Joshua and Garber (*10*) for truck accident rates, Hauer and Persaud (*11*) for railway-crossing accident rates, and Zegeer et al. (*12*) for highway accident rates. Zegeer et al. (*12*) considered both additive and multiplicative (i.e., log-linear) models and concluded that the multiplicative models provided a better fit to the data.

To obtain estimates, standard errors, and confidence intervals, the negative-binomial variance function was assumed for the accident count per section, that is,

$$Var(Y) = E(Y) + K * [E(Y)]^2$$

where K has the same value for all sections and $Var(Y)$ and $E(Y)$ are the variance and expected value, respectively. The classical distribution for accident counts is the Poisson distribution for which the variance is equal to the mean. However, variances in excess of the mean are often observed (*13*), partly because not all relevant variables are included in the model. The negative binomial distribution is a natural extension of the Poisson, which accounts for this excess variability and has certain desirable theoretical properties (*14*). The negative-binomial distribution for accident counts has been used recently by Hauer and Persaud (*11*) and Hauer et al. (*15*), and these authors have validated its use for transportation studies. Maher (*16*) also used the negative binomial distribution to explain traffic accident migration and states that "it has become standard" to use this distribution. This assumption was validated in our study by calculating the mean and variance of Y (for total accidents) for homogeneous subgroups of road sections and plotting the variance against the mean.

The beta coefficients in the regression model were estimated by the method of quasi-likelihood, and the value of K was estimated by the method of moments (*9*). Others have used maximum likelihood estimation (*11,15*), but it has been suggested that quasi-likelihood estimation for the beta coefficients and the method of moments for K is a more robust estimation procedure (*14*) and therefore have been used here. The estimation procedures were carried out using the statistical package GLIM (*17*), and the GLIM macros (or procedures) for fitting these models are given by Breslow (*13*). For Utah, the estimated value of K was about 0.6 and for Illinois it was about 1.4, suggesting that accident rates for similar sections of highway are more variable in Illinois. This is most likely due to greater variability in driver and environmental conditions in Illinois than in Utah.

In the regression models, median width has been examined both as a categorical variable (six categories for Utah and eight categories for Illinois) and as a continuous variable in the form of a quartic (fourth-degree) polynomial function without a linear term, because this particular function closely resembled the observed rates. When median width has a categorical representation, no trend is assumed, whereas the continuous representation adopted in this study assumes a quartic polynomial trend on the log scale for the accident rates. As in all continuous forms of modeling, the data are "smoothed" by the assumed trend. By using both representations, comparison of the estimated rates (and confidence intervals) for the categories allows a check on the appropriateness of the form of the assumed trend in the continuous model. In all cases the trends were consistent with a quartic polynomial trend. For comparison purposes, in this paper results for both forms of representation are reported.

The purpose of the analysis was to determine the effect of median width on the accident rate after controlling or adjusting for other variables. Variables that have been controlled by design through restricting the analysis to particular (homogeneous) sections were listed earlier. Variables included in the regression models are functional classification (rural–Interstate/freeway, rural other, urban–Interstate/freeway, urban other), posted speed limit, right shoulder width (continuous), access control (none, partial, full—Illinois only), curvature (dichotomous as described above—Utah only), log (average daily traffic) (continuous), and log (section length) (continuous). Section length was included as a surrogate for other variables not included that may be correlated with section length. Because the sections were constructed to be homogeneous, shorter sections occur where the roadway characteristics are changing more rapidly.

Many of the variables included in the regression model were correlated with median width, and several combinations of median width and other variables had very few or no sections. For example, Interstate road sections had larger median widths, whereas other functional classes had smaller median widths, although there was some overlap. This made the fitting of interactions between median width and other variables difficult. Where possible, such interactions were examined, but no significant interactions were found.

The estimated effects of median width obtained from these models (especially those with a categorical representation) may be conservative, since when variables correlated with median width are included in the models, they will absorb some of the effect of median width. For example, if functional class is omitted from the model, the effect of median width increases and vice versa. Inclusion of such variables has been done deliberately so that any median width effects detected cannot be attributed to other confounding variables.

RESULTS

Table 1 gives the characteristics of the road sections that have been used in the accident rate analyses. Because there were fewer sections in the Utah data, only six median width categories were used rather than eight as for Illinois. Note also that there were very few sections in the Utah data with median width in the range 30 to 54 ft (9.2 to 16.5 m) and very few sections with functional classification as urban–Interstate/freeway.

The crude average accident rates by median width for total accidents and severity and collision types are given in Table 2. The total accident rate appears to decline steadily with increasing median width. For Utah it declines from 650 for sections with no median to 111 accidents per 100 million vehicle-mi (179 accidents per 100 million vehicle-km) traveled for sections with median width at least 85 ft (25.9 m). Thus the crude total accident rate is reduced by a factor of about 6 over this range of median width. The decrease in the total accident rate for Illinois declines by a factor of about 13.

Serious injury (i.e., AK), all injury (CBAK), and property-damage-only accidents also show many-fold reductions over this range of median width. The rate for multivehicle accidents declines steadily with increasing median width, and head-on/sideswipe opposite direction accidents in particular show a dramatic decrease with increasing median width. On the contrary, the rates for single-vehicle accidents (Utah) and single-vehicle rollover accidents in particular show little relationship to median width.

The many-fold reductions observed in these accident rates cannot all be attributed to the effect of median width because of confounding by other variables. It is for this reason that the models including these confounding factors are developed. The relative effect of median width on the total accident

TABLE 1 Number of Sections (N), Number of Roadway Miles (Miles) with Various Characteristics for Utah and Illinois

Utah			Illinois		
Category	N	Miles	Category	N	Miles
Overall	982	973.8		2481	2081.3
Median Width (ft)					
0	176	68.7	0	567	219.0
1-10	257	110.9	1-24	199	67.0
11-29	213	114.7	25-34	176	89.4
30-54	52	76.8	35-44	479	304.2
55-84	179	298.7	45-54	200	139.7
85-110	105	303.9	55-64	450	538.4
			65-84	239	424.6
			85-110	171	298.9
Functional Class					
rur_int	284	653.0	rur_int	846	1293.8
rur_oth	130	73.5	rur-oth	343	182.0
urb_int	64	43.9	urb_int	436	279.9
urb_oth	504	203.3	urb_oth	856	325.6
Speed Limit					
35-40	183	61.6	35-40	370	128.8
45-50	118	44.7	45-50	348	124.1
55	146	101.8	55	889	486.0
65	305	663.9	65	874	1342.4
missing	230	101.7			
Right Shoulder Width (ft)					
0	315	119.2	0	401	155.0
1-5	121	62.3	1-5	65	25.6
6-10	495	768.5	6-10	1406	1223.0
11-23	51	23.9	11-23	609	677.6
Curvature > 1 Degree					
no	756	605.6		NA	
yes	226	368.2			
Access Control					
none		NA	NA	872	356.8
partial				435	216.9
full				1174	1507.6

NOTE: 1 mi. = 1.61 km, 1 ft. = 0.305 m

TABLE 2 Crude Average Accident Rates per 100 Million Vehicle-mi and Estimated Relative Effects of Median Width on the Total Accident Rate [Median Width Is Represented Both as a Categorical Variable and as a Continuous Variable, Adjusting for Functional Class, Posted Speed Limit, Right Shoulder Width, Access Control (Illinois Only), Curvature (Utah Only), Log (ADT) and Log (Section Length)]

Median Width (MW)			Average Accident Rate (R)								Relative Effect on **Total Accident Rate**		
											Categorical		Continuous
Category	Mean	N	AK	CBAK	PDO	MVeh	SVeh	HO	Roll	Total	Estimate	95% Conf Int	Estimate
Utah													
0	0.0	176	48	220	430	522	127	10	14	650	1.00	(1.00, 1.00)	1.00
1-10	9.4	257	47	203	416	521	97	10	5	618	1.06	(0.89, 1.26)	0.96
11-29	14.9	213	45	159	303	373	89	8	7	462	0.97	(0.81, 1.17)	0.91
30-54	46.3	52	19	53	106	51	109	1	29	159	0.56	(0.36, 0.88)	0.61
55-84	71.7	179	20	42	95	31	106	1	22	137	0.51	(0.34, 0.78)	0.52
85-110	101.0	105	22	44	67	18	93	0	29	111	0.47	(0.30, 0.71)	0.47
ALL	32.0	982	38	142	282	321	103	6	14	424			
Illinois													
0	0.0	567	46	214	477	605	86	21	5	692	1.00	(1.00, 1.00)	1.00
1-24	12.8	199	40	194	452	578	69	12	8	647	1.05	(0.86, 1.28)	0.96
25-34	29.8	176	42	115	177	200	92	3	15	292	0.81	(0.62, 1.06)	0.84
35-44	39.7	479	16	48	82	78	51	2	6	129	0.77	(0.59, 0.99)	0.76
45-54	49.2	200	10	37	90	66	61	2	7	127	1.00	(0.74, 1.35)	0.69
55-64	63.8	450	5	14	31	18	27	1	3	45	0.62	(0.46, 0.83)	0.62
65-84	71.9	239	7	18	41	19	40	1	5	59	0.64	(0.46, 0.88)	0.60
85-110	88.9	171	6	20	34	18	36	1	6	53	0.68	(0.48, 0.96)	0.65
ALL	39.4	2481	22	91	193	226	58	7	6	283			

NOTE: 1 ft. = 0.305 m

Mean = average median width
N = number of road sections
Total = overall accident rate
AK = A+K rate
CBAK = all injury rate
PDO = property damage only
MVeh = multi-vehicle accident rate
SVeh = single-vehicle accident rate
HO = head-on/sideswipe opposite direct. rate
Roll = single-vehicle rollover rate

rate after adjustment for other variables via the log-linear regression model is also given in Table 2 and shown graphically in Figure 1. The estimate and standard error of the coefficients for fitted log-linear models showing the continuous effect of median width and the other independent variables are presented in Table 3.

The continuous estimates given in Table 2 were obtained by inserting the average median width for each category into these equations. The interpretation of these relative effects is that, when all the other variables are the same and the only difference is the median width, the relative effect describes the proportional reduction in the total accident rate. For example, using the Illinois equation (continuous), the total accident rate for an average median width of 40 ft (12.2 m) is about 76 percent of the rate for median width zero (no median), and for an average median width of 64 ft (19.5 m) (see Table 3 for mean of interval) it is 62 percent. An estimate of the safety benefit of increasing the median from 40 to 64 ft (12.2 to 19.5 m) is obtained as $(0.62 - 0.76)/0.76 = -0.18$. Therefore, one would expect an 18 percent reduction in the

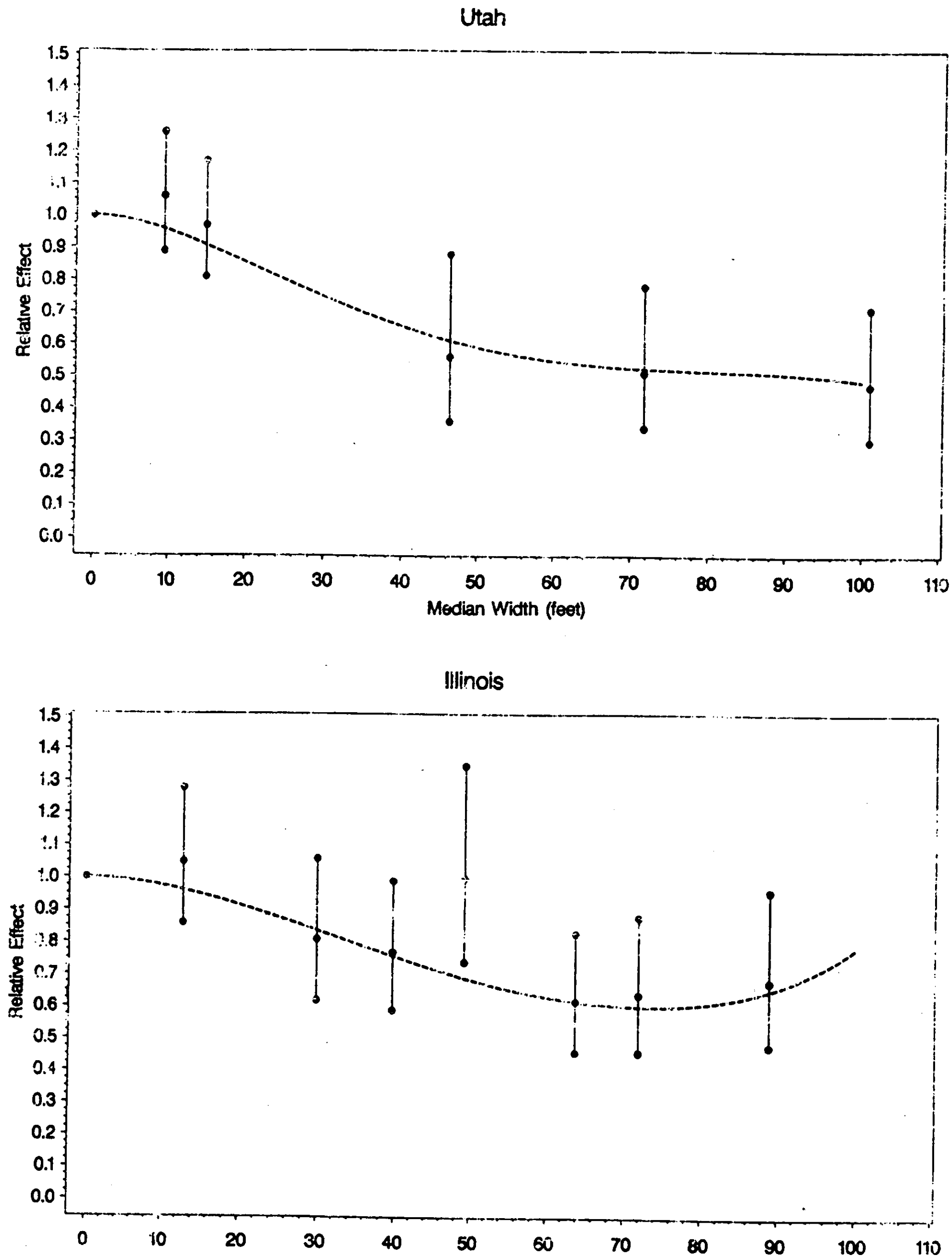

FIGURE 1 Estimated relative effects of median width on the total accident rate when median width is represented both as a categorical variable and as a continuous variable, adjusting for functional class, posted speed limit, right shoulder width, access control (Illinois only), curvature (Utah only), log (ADT) and log (section length). Note: 1 ft = 0.305 m.

TABLE 3 Fitted Log-Linear Regression Models for Total Accident Rate Showing Continuous Effect of Median Width and Other Variables

	Parameter	Estimate	Standard Error
UTAH			
	Constant	6.196	0.2943
	Median width^2	-5.589×10^{-4}	3.549×10^{-4}
	Median width^3	8.940×10^{-6}	7.083×10^{-6}
	Median width^4	-4.105×10^{-8}	3.716×10^{-8}
	Rural other vs rural interstate	-1.078	0.2757
	Urban interstate vs rural interstate	-0.2911	0.1714
	Urban other vs rural interstate	-0.5081	0.2782
	Curvature > 1 degree	0.0456	0.0754
	Right shoulder width	-0.0352	0.0082
	Speed limit 45-50 vs 35-40	0.5187	0.1097
	Speed limit 55 vs 35-40	0.4679	0.1149
	Speed limit 65 vs 35-40	-0.5417	0.2015
	Speed limit missing vs 35-40	0.6461	0.1041
	Log (average daily traffic)	-0.1389	0.0448
	Log (section length)	-0.1962	0.0308
Illinois			
	Parameter	Estimate	Standard Error
	Constant	4.587	0.1655
	Median width^2	-2.622×10^{-4}	2.397×10^{-4}
	Median width^3	2.062×10^{-6}	5.799×10^{-6}
	Median width^4	3.167×10^{-9}	3.740×10^{-8}
	Rural other vs rural interstate	0.4293	0.1308
	Urban interstate vs rural interstate	-0.0566	0.0975
	Urban other vs rural interstate	0.7921	0.1368
	Access control partial vs none	0.3723	0.1298
	Access control full vs none	0.4546	0.1280
	Right shoulder width	-0.0460	0.0110
	Speed limit 45-50 vs 35-40	0.5541	0.1140
	Speed limit 55 vs 35-40	0.5121	0.0962
	Speed limit 65 vs 35-40	-0.5434	0.1000
	Log (average daily traffic)	-0.2509	0.0495
	Log (section length)	-0.1232	0.0251

accident rate. On the other hand, if one reduced an existing median of 64 ft (19.5 m) to a median of 40 ft (12.2 m), one would expect a 23 percent increase in the total accident rate [(0.76 − 0.62)/0.62 = 0.23].

Thus the decline in the crude total accident rates with increasing median width given in Table 2 persists, albeit it to a lesser degree, after adjustment for these other confounding variables. Similar trends are shown for Utah and Illinois. These results indicate that there is little reduction in the accident rate for median widths up to about 25 ft (7.6 m). Whereas this lack of decrease is not as apparent in the smoothed continuous models, the categorical estimates for the smaller median widths are a little greater than 1.0 (indicating no difference from a median width of zero). The decline in accident rate, particularly in the categorical model, is most apparent for median widths beyond about 20 to 30 ft (6.1 to 9.2 m). The decreasing trend seems to become level at median widths of approximately 60 to 80 ft (18.3 to 24.4 m), particularly for Illinois.

The estimated relative effects for serious injury, all injury, and property-damage-only accident rates are given in Table 4. Logic suggests that the effect should be stronger for more severe accidents because wider medians would reduce the likelihood of collisions between vehicles traveling in opposite directions, which tend to have serious injury consequences. However, although the effect of median width on the accident rate is slightly stronger for injury accidents (but not AK accidents) than for property-damage-only accidents for Utah, the effect appears to be much the same for all severity classes for Illinois.

The estimated relative effects (continuous model) for multivehicle, single-vehicle, head-on/sideswipe opposite direction, and single-vehicle rollover accident rates are shown in Figure 2. For Utah the effect of median width is very similar for multivehicle and single-vehicle accidents, whereas for Illinois the effect is larger for multivehicle accidents, as might be expected intuitively.

More specifically, one might expect that median width would have its most dramatic effect on head-on/sideswipe opposite direction accidents. This is demonstrated clearly by the Illinois data. However, for Utah, although median width appears to have a dramatic effect on head-on/sideswipe opposite direction accidents after about 40 ft (12.2 m), the size of the effect is somewhat similar to the effect for multivehicle accidents in general.

Median width had little effect on single-vehicle rollover accidents for Illinois but appeared to have a rather sizable effect for Utah.

TABLE 4 Estimated Relative Effects of Median Width on Serious Accident Rates (AK), Injury Accident Rates (CBAK), and Property-Damage-Only Accident Rates (PDO) [Uses Models in Which Median Is Represented Both as a Categorical (cat) and as a Continuous (cts) Variable, Adjusting for Functional Class, Posted Speed Limit, Right Shoulder Width, Access Control (Illinois Only), Curvature (Utah Only), Log (ADT), and Log (Section Length)]

	Median Width (Mean)	AK cat	AK cts	CBAK cat	CBAK cts	PDO cat	PDO cts
UTAH							
	0 (0.0)	1.00	1.00	1.00	1.00	1.00	1.00
	1-10 (9.4)	0.95	0.96	0.92	0.94	1.10	0.97
	11-29 (14.9)	1.01	0.91	0.91	0.86	0.99	0.92
	30-54 (46.3)	0.65	0.63	0.53	0.50	0.56	0.65
	55-84 (71.7)	0.62	0.57	0.48	0.46	0.51	0.52
	85-110 (101.0)	0.73	0.66	0.57	0.52	0.41	0.42
ILLINOIS							
	0 (0.0)	1.00	1.00	1.00	1.00	1.00	1.00
	1-24 (12.8)	1.00	0.97	1.04	0.98	1.07	0.95
	25-34 (29.8)	1.10	0.86	0.95	0.89	0.76	0.81
	35-44 (39.7)	0.88	0.77	0.84	0.80	0.72	0.74
	45-54 (49.2)	0.84	0.68	0.97	0.72	1.04	0.69
	55-64 (63.8)	0.60	0.57	0.60	0.61	0.63	0.64
	65-84 (71.9)	0.68	0.54	0.67	0.58	0.63	0.64
	85-110 (88.9)	0.58	0.57	0.64	0.64	0.70	0.67

NOTE: 1 ft. = 0.305 m

The results for head-on/sideswipe opposite direction and for rollover accidents should be interpreted with some caution, especially for Utah, because there were very few accidents of these types. For Illinois, 1,980 sections (out of a total of 2,481) and, for Utah, 699 sections (out of a total of 982) had no head-on/sideswipe opposite direction accidents, whereas 2,241 sections in Illinois and 907 sections in Utah had no single-vehicle rollover accidents.

CONCLUSIONS

This investigation represents an attempt to define the relationship between median width and accident rate while controlling for other confounding variables. Although there were some studies in the prior literature relating to median width, in general the literature on this subject is quite sparse. Thus, there is little available information on an issue that is even more critical today given the current movement toward adding lanes to multilane facilities to enhance capacity without purchasing additional right-of-way. Thus, even with the caveats stated below, this study is a beginning point in the development of much needed information related to median width and safety.

This study has the advantage of a more comprehensive data base than prior studies. In addition, the data used here are more current than the data in the older studies, and we were able to use data from two states rather than only one, which allowed us to look at consistency of findings between the states. Furthermore, there is greater mileage of four-lane divided highway and thus miles of median in each of the study states than had been the case in earlier studies, along with a wider range of median widths.

There are, however, some necessary caveats that must be stated. First, in any study that attempts to control for confounding variables through statistical means rather than through the design of the study (i.e., by actually assigning different median widths to similar sections of the highways), the validity of the results depends on how well the confounding variables are identified and measured. Whereas we attempted to control for major confounding variables in the analyses conducted here, there are clearly other variables that were either not measured in our data base or not used in the final model simply because of the need to limit the model to as few variables as possible. These possible confounding variables include vertical grade, median slope, type of traffic (e.g., percent heavy trucks), environmental factors, additional geometric variables related to details of curvature or sideslope design, and general exposure factors. Even with these caveats, the results are important.

The general findings indicate that accident rates decrease with increasing median width, even when other confounding variables are controlled for. Whereas the degree of improvement due to median width was not exactly the same in the Utah data as in the Illinois data, the same general trends were observed in the two states. Second, it was also apparent that there was very little decrease, if any, in the various accident rates for medians less than approximately 20 to 30 ft (6.1 to 9.2 m) in width in the two states. Thus, in terms of modification of existing roadways, this finding indicates that decreasing any median width that is greater than 20 to 30 ft (6.1 to 9.2 m) to 30 ft (9.2 m) or less to enhance capacity would probably be accompanied by a decrease in the level of safety on the roadway. [Unfortunately, we could not determine the exact "breakpoint" where the safety effect ends. Whereas the categorical data from both states indicated no safety effect

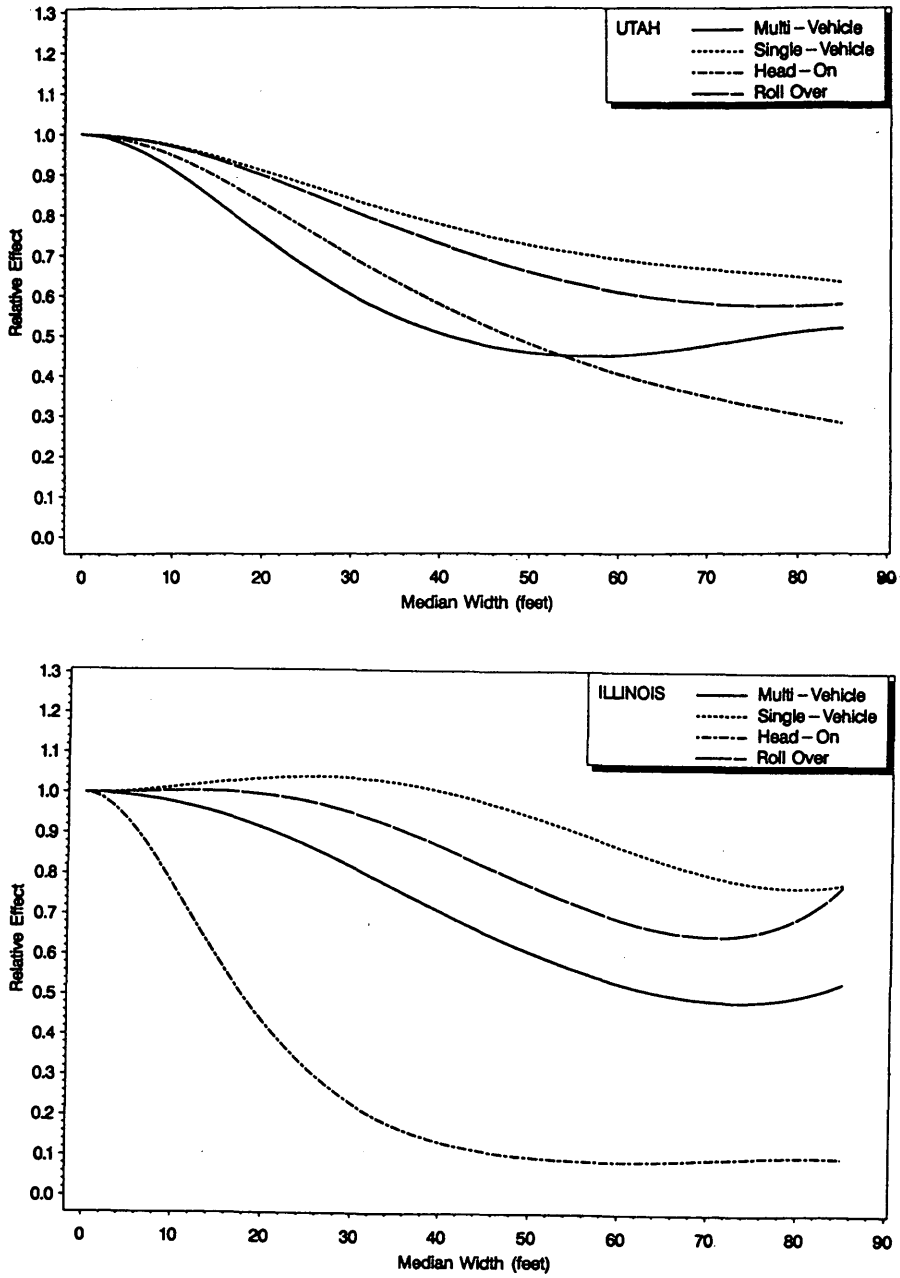

FIGURE 2 Estimated relative effects of median width on multivehicle accident rates, single-vehicle accident rates, head-on/sideswipe opposite direction accident rates, and single-vehicle rollover accident rates from models in which median width is represented as a continuous variable, adjusting for functional class, posted speed limit, right shoulder width, access control (Illinois only), curvature (Utah only), log (ADT), and log (section length). Note: 1 ft = 0.305 m.

for medians less than approximately 20 to 25 ft (6.1 to 7.6 m), there were not adequate numbers of 20-ft (6.1-m), 25-ft (7.6-m), or 30-ft (9.2-m) medians to allow separate analyses of these individual categories.]

There were also differences noted from what might have been traditionally hypothesized as the manner in which median width affects safety. For example, it might have been hypothesized that median width would be primarily related to decreases in "crossover accidents" involving head-on crashes between opposing vehicles. As a result of reducing these crossover accidents, changes in median width might have been expected to have a much greater effect on severe crashes than on less severe or property-damage-only crashes. We did not find either to be the case. As noted above, whereas we found significant changes in head-on crashes in both states, the changes in head-on crashes were only a small part of the overall decrease in total multivehicle accidents in each state. In addition, we did not find much difference in the effects of width on accident severity—the less severe crashes were affected as much as the more severe.

However, these results are not as surprising as first thought if viewed under the earlier-stated modified assumption of how medians affect safety. If instead of just acting as a buffer between vehicles that run off the road left toward each other, it is assumed that a median may well be serving as an escape area or clearzone for vehicles that are avoiding possible crashes with vehicles in their own lanes, one would see decreases in multivehicle crashes of all types (even rear-ends) and perhaps increases (or no change) in single-vehicle accidents due to the additional "roadside" to run off into. This is indeed what we found in the data—clear decreases in multivehicle crashes of all types and lesser or no decreases in the single-vehicle ran-off-road type crash.

Thus, in summary, it may be that we need to view the median differently, and this new view may affect median design. If the median is to "sell itself" to the driver as a safe escape area, it must clearly be wide enough to give the motorist the perception of safety. If the median is so narrow that heavy oncoming traffic on the opposing roadway reduces the perception of additional safety, it will not be used as much, and accident reductions will decrease.

A major point of interest is how these findings agree with design guidelines provided in the AASHTO *Policy on Geometric Design* (*1*). It is difficult to summarize AASHTO median-width and barrier-need guidelines, since material is found in a variety of sections of the *Policy* and because "hard" guidelines are not presented. This is due, of course, to the lack of hard data on the issue.

The general guideline provided is that careful study is needed of all locations. With respect to rural arterials, it appears that the policy suggests that medians of 60 ft (18.3 m) or more should be provided whenever feasible. In locations with restricted right-of-way, medians of 30 ft (9.2 m) or more are recommended. However, the additional information related to median width at intersections on rural arterials confuses the issue somewhat. Here, it is suggested that median widths of 12 to 30 ft (3.7 to 9.2 m) function quite well in that they provide room for turn lanes and, thus, protect turning vehicles; that median widths of 30 to 50 ft (9.2 to 15.3 m) may be suitable if detailed study of operational characteristics of the traffic are conducted; but that medians of 50 to 80 ft (15.3 to 24.4 m) ". . . have developed accident problems in some cases. . ." Thus, the designer is left with the impression that wider medians should not be used in places where at-grade intersections are present.

With respect to urban freeways, the general guideline is again to use medians that are as wide as possible. On four-lane facilities in areas of restricted right-of-way, it is suggested that 10-ft (3.1-m) medians are acceptable as long as a positive barrier is used. For six-lane facilities, a minimum width of 22 to 26 ft (6.7 to 7.9 m) is acceptable, again as long as a barrier is used. It is also interesting to note that a 50-ft (15.3-m) median is shown as a typical (nonbarrier) median width in a figure depicting a typical cross section with a median.

With respect to rural freeways, even less guidance is given. It is noted that 50- to 90-ft (15.3- to 27.5-m) medians are common. In sketches of typical cross section, a 50-ft (15.3-m) median is shown. It is further noted that in suburban areas, restricted right-of-way may lead to medians in the range of 10 to 30 ft (3.1 to 9.2 m) and that in these cases "median barrier is usually warranted as a safety measure."

Given the "softness" of the guidelines presented in the AASHTO policy, it is difficult to say whether the findings of this study support the design policy presented there. In this study, we find evidence that medians that are 50 ft (15.3 m) wide are indeed much safer than the no-median or narrow median condition. However, we also find that even wider medians [up to 80 ft (24.4 m) or more] appear to provide even greater safety benefits. If one takes literally the advice provided by the AASHTO guidebook concerning the need for barriers on either 10-ft (3.1-m) or 20- to 26-ft (6.1- to 7.9-m) medians, one might assume that four-lane medians greater than 15 ft (4.6 m) in width might be acceptable without barriers. Our findings do not support this at all. Indeed, the data here indicate that one needs to have a median at least 20 to 30 ft (6.1 to 9.2 m) in width before any safety effect is seen and that there are significant increases in the level of safety as one moves from 30 ft (9.2 m) to the wider median widths. Thus, in the design of new highways, our findings would support medians considerably wider than 30 to 40 ft (9.2 to 12.2 m).

This same information can be used in a slightly different way to provide information to the designer who is looking at the situation of potential lanes being added within the median. The conclusion from these data would be that safety benefits will indeed be lost by narrowing a median to any extent, and that if the median is narrowed to a width of between 20 ft (6.1 m) and 30 ft (9.2 m) (or less), essentially all of the safety benefit of the median may be lost unless a positive barrier is used. Unfortunately, because of the lack of barrier sections in the data set, we could not analyze the question of the benefit of placing positive barriers in the median.

In terms of needed additional research, it appears that these data have provided new information with respect to width of nonbarrier medians and the effects on safety—medians wider than approximately 25 to 30 ft (7.6 to 9.2 m) have a significant safety benefit, and the wider the median the better, up to approximately 65 to 80 ft (19.8 to 24.4 m). However, the most obvious remaining gap in knowledge is when to install positive barriers. At what width do the benefits of reductions in severe (cross-median) crashes outweigh the increase in less severe crashes? To conduct such a study will require a large sample of medians of various widths [at least in the range of 0 to 50 ft (0 to 15.3 m)] with and without barriers—clearly a multistate study.

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DISCUSSION

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The authors examined the effect of median width on vehicle accident rate for multilane divided highway sections with a traversable or nonbarrier median. Log-linear regression models with a negative-binomial variance function were used to study the effect. The authors should be commended for addressing a very important, yet difficult, problem. Overall, this is a well-written paper that presents some interesting empirical results. However, some of the results seem to be questionable:

1. This study failed to separate paved inside shoulders from the rest of the median. Paved inside shoulders are part of the roadway immediately contiguous with the traveled way and are important features of divided multilane highways. Failing to consider "paved inside shoulder width" in this study posted two potential problems: (*a*) the model results on the effect of median width are difficult to interpret in a design context and (*b*) it is entirely possible that the paved inside shoulder width was associated with the accident rate, not the rest of median width. To illustrate, let the paved inside shoulder width be X_1 and the rest of median width be X_2. In addition, let the total median width be X ($= X_1 + X_2$) and the number of accidents be Y. Furthermore, assume that X_1 is correlated with Y and X_2 is independent of Y. We can show that the correlation coefficient of Y and X, denoted by ρ_{xy}, does not vanish and can be computed as $\rho_{xy} = \mathrm{Cov}(X_1, Y)/[\mathrm{Var}(Y)\mathrm{Var}(X)]^{1/2}$.

2. (Table 1) Does "right shoulder width" include both the width of paved and unpaved shoulders? It does not seem reasonable to have road sections with a right shoulder width of 23 ft. Two related questions are as follows: How many road sections have a right shoulder width of 13 ft or more? Were these road sections particularly influential in estimating model coefficients?

3. (Table 2) Many rural Interstate road sections in the Utah roadlog file were coded as having a median width of 99 ft, which really meant that the road section's median width was equal to or greater than 99 ft. How did the authors handle these road sections?

4. (Table 4) The estimated coefficients for ADT having an algebraic sign contrary to expectation. The estimated coefficient for log(ADT) was -0.1389 in the Utah model and -0.2509 in the Illinois model. Thus, both models indicated that, for road sections of a particular functional class (and speed limit and access control), as ADT increased, total accident rate decreased. This result is apparently not acceptable. One possible reason for this to occur is that ADT alone did not give a good description of the traffic condition. Variables related to highway capacity, such as the number of lanes, should be considered in the model. Another possible reason is the collinearity problem to be discussed later.

5. (Table 4) The estimated regression coefficients for "median width" have very low *t*-statistics, indicating that the effect of median width on accident rate was poorly determined from the data. For the Utah model, the *t*-statistics of the estimated coefficients for $(\text{median})^3$ and $(\text{median})^4$ were about 1.26 and -1.10, respectively. For the Illinois model, *t*-statistics of the estimated coefficients for $(\text{median})^2$, $(\text{median})^3$, and $(\text{median})^4$ were about -1.09, 0.36, and 0.08, respectively. These low *t*-statistics were indications to the authors that they might have "oversmoothed" or "overinterpreted" the data. Therefore, the statements in this paper on the effect of median width, such as that the decreasing trend seems to become level at median widths of approximately 60 to 80 ft, particularly for Illinois, are questionable. Why not just consider the first- and the second-order terms [i.e., (median) and $(\text{median})^2$]?

6. (Table 4) Some of the variables considered in the model were extremely collinear (e.g., functional class, speed limit, and access control were highly correlated with one another). This collinearity problem may have made the interpretation of the fitted log-linear regression models difficult and the results questionable.

Some examples of Item 6 are as follows:

- Unreasonable speed limit effect?—If we use the fitted models to shed some light on the effect of speed limit change (from 55 to 65 mph) in 1987 on accident rates for rural Interstate highway sections, we would find that the models suggested a 64 and a 65 percent reduction in total accident rate for Utah and Illinois, respectively. These results cannot be supported by any highway statistics. This is probably a result of the distortion produced by the collinearity of some of the covariates. The computation of these reductions can be carried out as follows: Take Utah for example. Let the accident rates of any rural Interstate road section before and after the speed limit change be λ_{55} and λ_{65}, respectively. Provided that everything else was the same, the fitted model suggested that the ratio of these two accident rates would be $\lambda_{65}/\lambda_{55}$ = exp(−0.5417)/exp(0.4679) = exp(−1.0096) = 36 percent. Therefore, according to the model, the drop in accident rate on a rural Interstate section as a result of the speed limit change would have been 64 percent.

- Unexpected signs in coefficients for functional class variables?—For Utah, the estimated coefficients for functional class variables (i.e., "rural other versus rural Interstate," "urban Interstate versus rural Interstate," and "urban other versus rural Interstate") were negative (i.e., −1.078, −0.2911, and −0.5081, respectively). The negative sign also appeared in the Illinois model for "urban other versus rural Interstate." If we disregard other variables and focus on functional class variables alone, the Utah model suggests that rural other highways, urban Interstates, and urban other highways had a lower total accident rate than that of rural Interstates, which was contrary to what one would usually expect. But because functional class, speed limit, and ADT are highly correlated with one another, it may not be appropriate to examine functional class variables alone. The authors should make this clear in the paper.

Now, consider two hypothetical road sections in Utah: one rural and one urban Interstate section. Assume that these two road sections have the same geometric design characteristics, section length, and speed limit. Furthermore, assume that the rural and urban road sections have an ADT of 5,000 and 50,000 vehicles, respectively. Then, according to the model, the ratio of the accident rate between these two road sections is $\lambda_{\text{urban}}/\lambda_{\text{rural}} = \exp\{-0.2911 - 0.1389 \times [\log_e(50{,}000) - \log_e(5{,}000)]\} = \exp(-0.611)$ = 54 percent. That is, the total accident rate of the urban road section is 46 percent lower than that of the rural road section. It is arguable that this ratio does not seem to be reasonable. More information will be needed for the readers to make a better judgment on this. For example, the authors may want to (*a*) cross-classify the number of road sections by functional class, speed limit, access control, and ADT in Table 1 and (*b*) tabulate the accident rate by functional class, speed limit, access control, and ADT.

- Unexpected signs in coefficients for "access control" variables?—For Illinois, the estimated coefficients for "access control partial versus none" and "access control full versus none" were 0.3723 and 0.4546, respectively. This implies that for any road section, the tighter the access control we apply to it, everything else being the same, the higher the accident rate would be, which is unreasonable. Again, to make a better judgment on the reasonableness of this result, functional class, speed limit, access control, and ADT will have to be considered simultaneously. Therefore, more detailed information, such as that mentioned above, will be required.

AUTHORS' CLOSURE

We very much appreciate the interest of the discussant and quite a number of other reviewers of our paper examining the relationship of median width and highway accident rates. Obviously this is a subject area of considerable interest.

The first issue raised by the discussant was that "it is entirely possible that the paved inside shoulder width was associated with the accident rate, not the rest of median width." As pointed out, we did not separate the inside shoulder width from the remainder of the median width in the analyses, primarily because of the difficulty of determining where the median/shoulder "begins" for unpaved shoulders (approximately 43 percent of the data). Although it is an interesting hypothesis, we continue to believe that the effect seen is from the total median width rather than just the paved shoulders. Unfortunately, we are not able to reanalyze the data at this time.

After the question was raised, we reexamined the available Illinois roadlog file. (Utah data were unavailable at this time.) In the first place, as noted above, nearly half of the sections in the study file (43 percent) were not paved (i.e., earth, sod, aggregate, surface treated, or no shoulder). Of those that were paved, virtually all were 8 ft (2.5 m) or less and most often (54 percent of the time) were found on roads with median widths of 64 ft (19.6 m) or greater. Less than 10 percent of the sections with paved inside shoulders had median widths of less than 40 ft (12.3 m), where we also saw significant effects of total width.

In short, we find it hard to imagine in this case that paved inside shoulders could account for the effects found in the analysis. However, it is an interesting hypothesis that could be explored further.

With regard to the question about right shoulder widths, only 3 of 982 Utah sections had right shoulder widths exceeding 15 ft (4.6 m) and none of 1,481 Illinois sections had right shoulder widths exceeding 13 ft (4.0 m).

With regard to the comment that "the estimated coefficients for ADT have an algebraic sign contrary to expectation," we do not see why the result that sections of freeways with higher ADTs have lower accident rates is not acceptable. Whereas lower accident frequencies would not be expected, lower accident rates may be. Is it not conceivable that sections with a higher ADT may have slower traffic speeds due to congestion, for example? It should be noted that the number of lanes is the same for all sections in this analysis, meaning higher ADT sections are more congested by definition.

The discussant notes that "the estimated regression coefficients for 'median width' have very low *t*-statistics, indicating that the effect of median width on accident rate was poorly determined from the data." The individual *t*-statistics for the median width terms are not especially relevant to whether median width has an effect. Overall, the effect of median width is significant. However, we agree that we could be more sure of the shape of the trend if the individual coefficients were significant as well. Note that median width was examined in greater detail (i.e., quadratic, cubic, and quartic functions) than other variables because it was the primary variable under investigation in this study.

Finally, the problem of collinearity is discussed in the section on statistical methods starting with the paragraph that begins with "Many of the variables included in the regression model were correlated with median width. . ." The available data do not allow clear resolution of the problem. Interactions representing the simultaneous effect of two variables at a time were investigated, but, as stated in the paper, none were found to be significant. Simultaneously cross-classifying sections by median width, functional class, speed limit, access control and ADT is not practical because there would be too few sections in each cell of such a cross-classification. The regression approach adopted appears to be the only practical method of adjusting for other variables in this case.

Again, we appreciate these thoughtful comments and suggestions by the discussant and others and believe that the paper has generally addressed them to the extent practicable with the available data.

Publication of this paper sponsored by Committee on Operational Effects of Geometrics.