Factors Affecting Speed Variance and Its Influence on Accidents

NICHOLAS J. GARBER AND RAVI GADIRAJU

One of the major factors that should be considered in selecting the speed limit for a stretch of highway is safety. It is generally accepted that the level of safety depends on certain characteristics of the traffic stream and the geometric alignment of the highway. However, in many cases speed limits are posted without adequate consideration given to these characteristics. For example, an important traffic characteristic that influences safety is speed variance. Currently, little is known about the factors that affect the variance of vehicle speeds in a traffic stream. Presented in this paper are the results of a study that investigated the influence of different traffic engineering factors on speed variance and quantified the relationship between speed variance and accident rates. A major influence on speed variance is the difference between the design speed and the posted speed limit. It was determined that speed variance will approach minimum values if the posted speed limit is between 5 and 10 mph lower than the design speed. Outside this range, speed variance increases with an increasing difference between the design speed and the posted speed limit. It was also found that drivers tend to drive at increasing speeds as the roadway geometric characteristics improve, regardless of the posted speed limit, and that accident rates do not necessarily increase with an increase in average speed but do increase with an increase in speed variance.

Highway safety is a vital concern of transportation engineers. Research and experience have shown that highway safety can be improved by implementing countermeasures in one or more of three areas: the vehicle, the driver, and the roadway.

Countermeasures to improve the safety of the vehicle include seatbelts, collapsible steering columns, and regular vehicle inspections. Some familiar countermeasures taken in the area of the driver include education, strict licensing procedures, and alcohol regulations. Countermeasures relating to the roadway include regulatory and warning signs, guardrails, breakaway signs and lighting supports, bridge and curve widenings, speed zoning, and various construction techniques.

A traffic characteristic that relates to both the driver and the roadway is speed. Although there have been studies relating accident rates with different speed characteristics, few of these are recent and varying results have been obtained with respect to the effect of speed on accident rates. Some related results are summarized under the following:

- Speed control,
- Accident rates and speed,
- Accident rates and speed variance, and
- Influence of geometric characteristics on speed.

School of Engineering and Applied Science, Department of Civil Engineering, University of Virginia, Charlottesville, Va. 22901.

SPEED CONTROL

Speed control is one of the most important tools to reduce speed-related accidents. However, speed control is a difficult and controversial issue, because criteria for establishing speed limits do not have the same degree of acceptability as do other traffic control tools such as no-passing zones or traffic signals. McMonagle (*1*), in one of the earliest studies on speed, stated, "It must be provided for and protected."

What speed is safe? Accidents occur at all speeds. Higher speeds may increase the chances of exposure to dangerous situations, and the rapidity at which these develop may reduce the ability of a driver to react properly and may lead to more accidents. The primary responsibility of traffic engineers is to identify safe speeds to reduce the probability of accidents occurring to a minimum. Only a few studies have developed recommendations for safe speeds on different highways. However, most of the recommendations were based on policy assessment or legislative requirements rather than traffic and geometric factors.

ACCIDENT RATES AND SPEED

Although it is assumed generally that speed is the greatest contributing cause to accidents, some studies have indicated that this may not be true. One investigation (*2*) concluded that speed is not necessarily an important cause of accidents, but it is an important determinant of severity. A study in Minnesota (*3*) considered 40,000 accidents in which data on speeds of vehicles involved were available. Nearly 75 percent of the accidents involved some violation other than speed. If every accident in which speed was the only violation could have been prevented, the number of accidents would have been reduced by less than 10 percent. A research study in Pennsylvania (*4*) found that speeds of drivers with accident records were only slightly higher than those for drivers with no accident records.

ACCIDENT RATES AND SPEED VARIANCE

Most research results show that higher speed variance is usually associated with higher accident rates. For example, Pisarski (*5*) pointed out that there is a significant statistical relationship between speed variance and accident rate. A study in Canada on speed and accidents (*2*) also found that speed variance may be an important factor in accidents. Cerrelli (*6*) concluded that accident rate increased as the speed of the vehicle deviated from the average speed of the traffic. A graph of accident rates by speed resulted in a U-shaped curve having the lowest value in the proximity of average speed. The risk of an accident appears to increase as vehicle speed varies from the average speed on the highway. Although these studies agree with the conclusion that speed variance significantly influences accident rates, few actually quantified the relationship between these variables.

INFLUENCE OF GEOMETRIC CHARACTERISTICS ON SPEED

A study by Elmberg (*7*) on a newly reconstructed highway investigated the effect of the posted speed limit on the speed of drivers. The drivers paid little attention to posted speed limits and chose a speed that they considered appropriate for the prevailing conditions. This strongly suggests that geometric characteristics influence operating speeds. For example, a low posted speed limit on a highway with good geometric conditions may result in a wide range of speeds on the highway, which in turn will lead to an increase in accident rates.

This summary of research results indicates that while several speed characteristics may affect accident rates, speed variance is one of the more important characteristics. However, the factors that affect speed variance have not been studied widely. To determine the factors that significantly affect speed variance, a study was sponsored by the AAA Foundation for Traffic Safety. The main objectives were to investigate the traffic engineering factors that influence speed variance and to determine to what extent speed variance affects accident rates. Identification of these factors should help develop countermeasures that will result in minimal speed variance levels, which in turn will lead to reduced accident rates.

METHODOLOGY AND RESULTS

Data Collection

Appropriate sites were selected from different highway types so that representative data could be collected for each type. Test sites were located on the following types of highways:

- *Interstates:* Urban interstate, rural interstate, and freeways and expressways having the same geometric standards as those for interstates;
- *Arterials:* Urban arterials and rural arterials; and
- *Rural Major Collectors.*

Test sections were selected so that traffic volume and traffic characteristics would be constant within each section. The test sections were located between interchanges on interstates, freeways, and expressways, and between major intersections on other roads.

Candidate sites with geometric characteristics typical of the type of roads they represented were identified first for each highway type. Consideration was given to horizontal and vertical alignments, the number of lanes, lane widths, access control, land use, traffic volume, and traffic control devices.

A final set of 36 locations (given in Table 1) was then selected using the following criteria:

- Availability of adequate accident data,
- Availability of adequate exposure data,
- Ease of collecting additional data, and
- Good representation of different roads and terrains.

Data on traffic geometric characteristics and accident characteristics were collected at the selected study sites. Traffic data included hourly volumes and individual vehicle speeds, from which other statistics such as average speed and speed variance were computed. The Leupold & Stevens traffic data recorder was used to collect data on traffic characteristics.

The data compilation was based on 24 continuous hours of monitoring on weekdays (Tuesday through Friday) at each test section. The data collected were also used to determine different characteristics of their distributions, for example, skewness and kurtosis.

Since the geometric characteristics of a section of highway are represented by its design speed, design speed was used as a surrogate for geometric characteristics in this study. Design speed usually depends on the type of highway, the topography of the area in which the highway is located, and the land use of the adjacent area. The design speed for each location was obtained from the highway log sheets provided by the Virginia Department of Transportation (VDOT).

Data on accident characteristics were obtained from computerized files prepared and stored by the VDOT and the Virginia Department of Motor Vehicles. The necessary data were extracted Tuesday through Friday in each week for 1983 through 1986.

Each study site was identified by route number, city or county in which it was located, and section number. The following data were extracted for each site:

- Fatal accidents,
- Injury accidents,
- Property damage accidents, and
- Total number of accidents.

Statistical Analyses of Data

A database was formulated suitable for use with available statistical packages. The database included the summary of accidents for 1983, 1984, 1985, and 1986 and the breakdown of accidents by type, class of highway, and traffic characteristics. This database was used to carry out the statistical analyses described below.

Traffic Characteristics

Table 2 presents a summary of the two main speed characteristics (average speed and speed variance) of the different types of highway. Although there was only a minimal difference in the posted speed limits for the different categories of roads, the average speed was much higher on interstate high-

TABLE 1 STUDY SITES

ROUTE	CITY or COUNTY	LOCATION FROM	LOCATION TO
		URBAN INTERSTATE	
581	ROANOKE*	RT 101 EBL	RT 116 & 460 EB
95	HENRICO**	M RT 301 SB	RT 73 WBL
195	RICHMOND*	RT 147	RT 6
564	NORFOLK*	RT 460 WBL	RT 337
64	VA.BEACH*	INDIAN RIV RD	ECL CHESAPEK
95	FAIRFAX*	RT 613	RT 241
		RURAL INTERSTATE	
77	CARROLL**	RT 69 WBL	RT 52
64	YORK**	RT 199 EBL	W CONN RT 143
95	PRINCE WILLM**	RT 619	RT 234 NB
66	FAUQUIER**	E RT 175 NB	RT 245 NBL
64	LOUISA**	RT 15 NBL	RT 208
81	ROCKBRID**	S RT 11	M RT 11
64	ROCKBRID**	RT 780	RT 623
		FREEWAYS AND EXPRESSWAYS	
23	SCOTT**	RT 65	N RT 23 BUS
150	CHESTERFIELD**	RT 360 WBL	RT 60 WBL
		RURAL ARTERIALS	
80	RUSSEL**	BUCHANAN CL	NCL HONAKER
58	PITTSYLVANIA**	HALIFAX CL	RT 729
360	AMELIA**	M RT 360 BUS	W RT 360 BUS
13	ACCOMACK**	NCL KELLER	S RT 180
10	Surry**	W RT 31	RT 40
17	ESSEX**	N RT 624	NCL TAPPAHAN
15	MADISON**	CULPEPER CL	RT 230
220	BATH**	RT 658	ALLEGHANY CL
460	BOTETOURT**	RT 616	B R PKWY OP
45	CUMBERLAND**	S RT 60	N RT 636
256	AUGUSTA**	ROCKINGHAM CL	RT 276
29	CAMPBELL**	RT 24	RT 678
		URBAN ARTERIALS	
360	HANOVER**	RT 156	W RT 360 BUS
7	FAIRFAX*	RT 123 SBL	RT 193
		RURAL MAJOR COLLECTORS	
42	BLAND**	RT 738	E RT 52
56	NELSON**	SE JAMESR BR	E RT 639
156	HENRICO**	RT 60	RT 5
301	GREENSVILLE**	SCL EMPORIA	RT 629
55	FAUQUIER**	W RT 17	WARREN CL
42	SHENANDOAH**	S RT 675	N RT 263
201	LANCASTER**	RT 3	N RT 600

* City
** County

TABLE 2 TRAFFIC CHARACTERISTICS

HIGHWAY TYPE	AVERAGE SPEED	SPEED VARIANCE
Interstate		
Urban Interstate	55.73	73.68
Rural Interstate	57.60	36.75
Expressway and Freeways	52.79	50.02
Arterials		
Urban Arterials	53.92	49.02
Rural Arterials	51.82	62.23
Rural Collectors	44.69	73.06

TABLE 3 RESULTS OF ANOVA ON TRAFFIC CHARACTERISTICS

	AVERAGE SPEED			SPEED VARIANCE		
VARIABLE	Computed F value	F value at 0.05 Significance	Result	Computed F value	F value at 0.05 Significance	Result
Average Speed	Not Applicable			7.04	2.03	significant
Speed Variance				Not Applicable		
Design Speed	13.61	3.05	significant	2.42	2.29	significant
Highway Type	20.98	2.23	significant	5.62	2.29	significant
Time (By Year)	0.22	2.68	not significant	0.65	2.68	not significant
Traffic Volume	2.89	3.65	not significant	1.67	2.12	not significant

ways. Analysis of variance (ANOVA) was performed on the main variables, speed variance, and average speeds to test the extent to which different variables affect speed characteristics. The class variables were highway type, design speed, and time (by year). The effect of average speed on speed variance was determined by segmenting the average speeds into 3-mph ranges and performing the one-way ANOVA test. The results are given in Table 3.

The ANOVA tests confirmed that highway type has a significant effect on average speed and speed variance at the 5 percent significance level. Design speed (a surrogate for highway geometric characteristics) also has a significant influence on these variables. Both average speed and speed variance were not affected by time (year in which data were obtained). Another result obtained was that average speed affects variance. It is clear that these variables are interrelated and do not have independent influences on speed characteristics.

Accident Characteristics

Table 4 presents a summary of the total and fatal accident rates on the different types of highways. The results indicate that accident rates are much lower on interstate highways, although it was shown previously that speeds were much higher on these highways. The ANOVA test was performed to test the extent to which different factors affect total accident rates. The results are given in Table 5.

TABLE 4 ACCIDENT CHARACTERISTICS

HIGHWAY TYPE	TOTAL ACCIDENT RATE[1]	FATAL ACCIDENT RATE[2]
Interstate		
Urban Interstate	68.0	5.0
Rural Interstate	52.0	2.0
Expressways and Freeways	97.0	4.0
Arterials		
Urban Arterials	230.0	13.0
Rural Arterials	141.0	4.0
Rural Collectors	169.0	2.0

1. Number of accidents per 100 million vehicle miles of travel.
2. Number of fatal accidents per 100 million vehicle miles of travel.

TABLE 5 RESULTS OF ANOVA ON TOTAL ACCIDENT RATES

VARIABLE	TOTAL ACCIDENT RATE Computed F value	F value at 0.05	Result
Average Speed	4.46	2.02	significant
Speed Variance	2.35	1.84	significant
Design Speed	5.13	2.29	significant
Highway Type	8.22	2.29	significant
Time (By Year)	1.06	2.68	not significant

The results indicate that each of the variables (average speed, speed variance, design speed, and highway type) has a significant effect on accident rates. It should be noted, however, that there is some correlation between design speed and average speed, and average speed and speed variance. Therefore, it cannot be concluded that each of these variables independently affects accident rates.

Model Development

The results of the ANOVA indicated that the type of highway had some impact on speed and accident characteristics. The results also indicated that for all types of highways a statistically significant difference existed between the speed variance for different categories of average speeds and between accident rates for different speed variances. Mathematical models were developed using regression analysis to quantify these observations. The models obtained are discussed below using appropriate figures. The curves shown in the figures are graphic representations of the mathematical models obtained.

Average Speed and Design Speed

The average speed at each site was plotted against the design speed to indicate the general mathematical relationship. Figure 1 shows these plots. The regression analysis indicates that

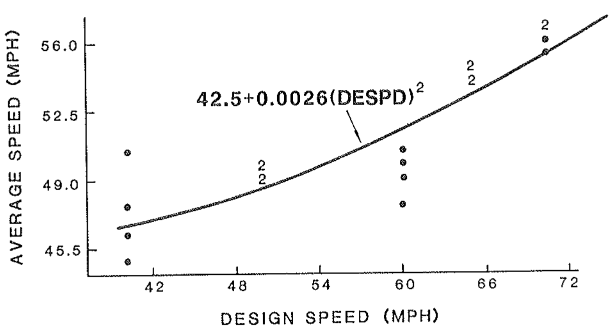

FIGURE 1 Average speed versus design speed.

the relationship between average speed and design speed can be given as

$$AVSPD = 42.5 + 0.0026\,(DESPD)^2 \tag{1}$$

where $AVSPD$ is average speed in miles per hour and $DESPD$ is design speed in miles per hour (40 mph $< DESPD <$ 70 mph). The coefficient of determination for this expression is 84.3 percent.

Since design speed is a surrogate for roadway geometrics and a higher design speed indicates better geometric characteristics, this model suggests that drivers tend to travel at higher speeds on highways with better geometric characteristics regardless of the posted speed limit. (All of the study sites considered for this model had a posted speed limit of 55 mph.)

Speed Variance and Average Speed

Figure 2 shows plots of speed variance and average speed for all highway types. It can be seen that speed variance decreases as average speed increases. However, the relationship is nonlinear and resembles a second-order function tapering off to a constant value. This is realistic because speed variance can never go below a certain value even at higher average speeds. The relationship obtained from the regression analysis is given as

$$SPVA = -16.7 + 204803\,(AVSPD)^{-2} \tag{2}$$

where $SPVA$ is speed variance and $AVSPD$ is average speed (25 mph $< AVSPD <$ 70 mph). Results of the regression analysis show a coefficient of determination of 94 percent for this model.

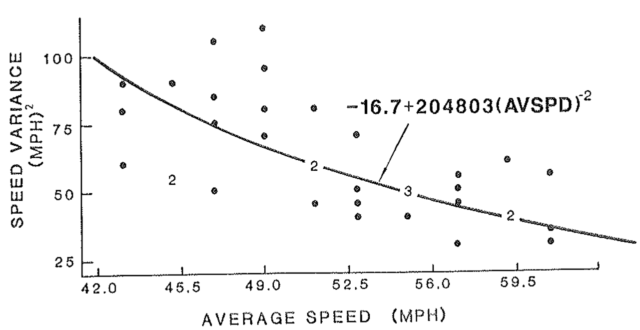

FIGURE 2 Speed variance versus average speed.

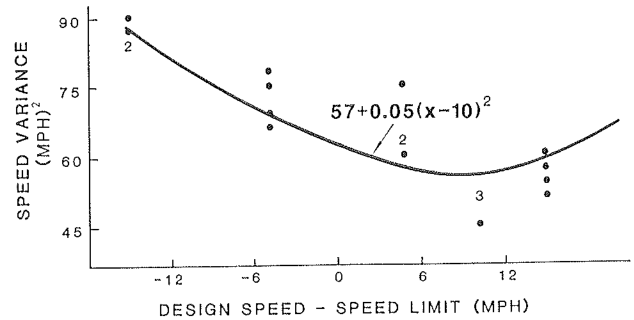

FIGURE 3 Speed variance versus design speed minus speed limit.

Speed Variance, Design Speed, and Posted Speed Limit

The results of analyses presented earlier indicated that average speed depends on the design speed and that speed variance depends on the average speed. This suggests that the design speed has some effect on speed variance. Because another study showed that average speed at a given location is affected by the posted speed limit, a model relating speed variance with the design speed and the posted speed limit was developed. The independent variable selected for this model was the difference between the design speed and the posted speed limit. This effectively takes into account the main factors influencing average speed. These include the type of highway and geometric characteristics that are represented by the design speed and regulation, which is given in terms of the posted speed limit. The plots of speed variance against the difference between design speed and posted speed limit are shown in Figure 3. It can be seen from these plots that speed variance tends to be low when the difference is between 6 and 12 mph. In the application of this model, the range of this difference should be considered to be between 5 and 10 mph because speed limits and design speeds are usually multiples of 5 mph. The model obtained from regression analysis is given as

$$SPVA = 57 + 0.05\,(X - 10)^2 \tag{3}$$

where $SPVA$ is speed variance and X is design speed minus posted speed limit in miles per hour. Table 6 presents computed values for speed variance using Equation 3.

This model suggests that minimum speed variance will occur when the difference between the design speed and the posted speed limit is 10 mph. Results of the regression analysis show that the model explains about 85 percent of the variation observed.

Accident Rates and Average Speed

An attempt was made unsuccessfully to correlate accident rates with average speed for the different types of highways. Plots of accident rates against average speeds were very scattered. This indicates that there is no strong correlation between accident rates and average speed for any given type of highway based on the data used. This tends to support the theory that higher speeds do not necessarily result in higher accident rates.

When the data for all sites were pooled together and accident rates at the locations were plotted against the corre-

TABLE 6 SPEED VARIANCE VERSUS DESIGN SPEED MINUS SPEED LIMIT

Design Speed - Speed Limit X	Speed Variance Y
- 15	88.25
- 10	77.0
- 5	68.25
0	62.0
5	58.25
10	57.0
15	58.25
20	62.0

(Equation: $Y = 57 + 0.05(X - 10)^2$)

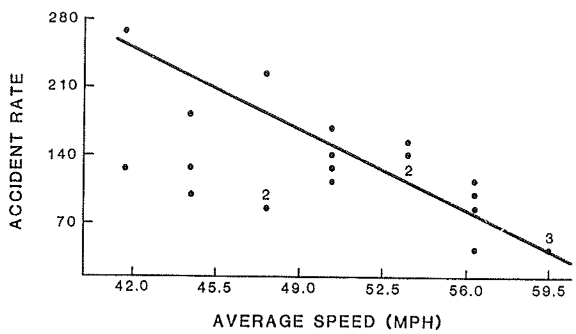

FIGURE 4 Accident rate versus average speed.

sponding average speeds observed, accident rates decreased with increased average speeds (see Figure 4). However, it would be inaccurate to make such a conclusion because average speeds on interstate highways tend to be higher than those on primary highways, and accident rates are lower on interstate highways because of better geometric characteristics. Therefore, Figure 4 shows the effect of the different geometric characteristics rather than the effect of speed. This also explains the result of the ANOVA test recorded earlier, which indicated that average speeds significantly affect accident rates.

Accident Rates and Speed Variance

Models were formulated to examine the influence of speed variance on accident rates on different categories of highways. Figure 5 shows plots of accident rates against speed variance for interstate highways.

These plots indicate clearly that accident rates increase as

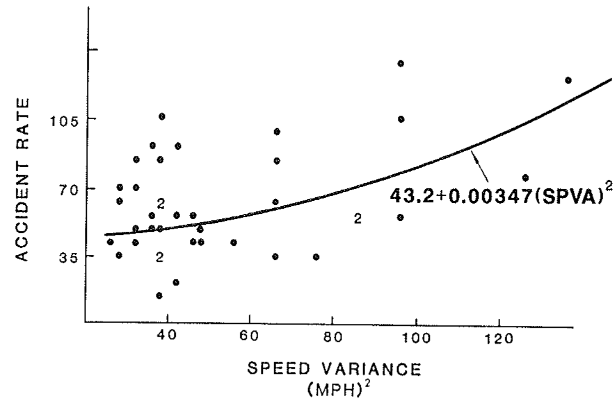

FIGURE 5 Accident rate versus speed variance for Interstate highways.

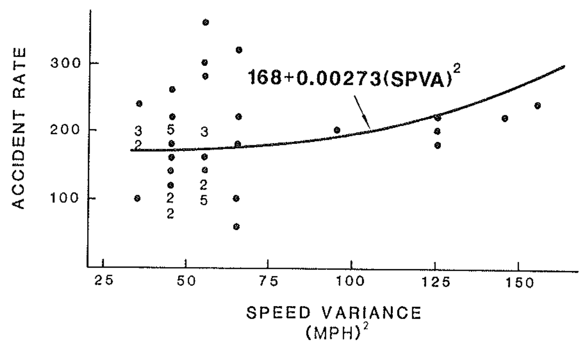

FIGURE 6 Accident rate versus speed variance for arterial highways.

speed variance increases. The model obtained from the regression analysis for interstate highways describes about 70 percent of the variation observed, and is given as

$$ACCRT = 43.2 + 0.00347\,(SPVA)^2 \quad (4)$$

where *ACCRT* is accident rate in number of accidents per 100 million vehicle miles of travel and *SPVA* is speed variance.

The corresponding plots for arterial highways are shown in Figure 6. These plots also indicate that as speed variance increases accident rates also increase. The model explains about 82 percent of the variation and is given as

$$ACCRT = 168 + 0.00273\,(SPVA)^2 \quad (5)$$

TEST OF MODELS

To test the validity of the models, a detailed analysis was carried out to identify sections of highways that have significantly higher accident rates than the critical values for their specific highway type. The following equation was used to determine critical accident rates for a given section of a highway:

$$C = A + K(A/M)^{1/2} + \frac{1}{2M} \quad (6)$$

where

C = critical accident rate,
A = average accident rate for the category of highway being tested,
M = average vehicle exposure for the study period at the location (million vehicle miles),
K = a constant, the Z-value for 95 percent confidence (1.96).

Sites with accident rates significantly higher than the critical value usually are considered hazardous locations.

Traffic and accident data files from the four study years were sorted by highway category and mean accident values were computed for each category. The critical accident value for each location then was computed. Sites at which accident rates were higher than the corresponding critical values were identified and 31 sites were selected randomly for testing the models. This resulted in 124 observations for the 4-yr study period. The difference between the design speed and the posted speed limit for each site was compared with the range of 5 to 10 mph, which the model suggests for minimum accident rates, using the following hypothesis: Speed variance will be higher on either side of a desirable zone of 5 to 10 mph for the difference between the design speed and the posted speed limit. This, in turn, will result in higher accident rates. This hypothesis can be restated as follows: If the location is hazardous, in the sense that its accident rate is higher than the critical value, then the difference between the design speed and the posted speed limit is either less than 5 or greater than 10 mph. This can be mathematically stated as follows: if $ACCR > CRIT$, $x < 5$, $x > 10$, then the hypothesis is true; if $ACCR < CRIT$, $x > 5$, $x < 10$, then the hypothesis is true; otherwise, the hypothesis is false. The test was applied to the 124 observations. The results validated the hypothesis. About 80 percent of the observations satisfied the conditions of the hypothesis.

The next hypothesis tested was: Accident rates at hazardous sites can be reduced by selecting an appropriate posted speed limit at those sites. In testing this hypothesis, appropriate speed limits within the desirable zone were selected for different sites based on their design speeds. The resulting speed variance was computed using Equation 3. The expected accident rates were computed for the respective sites using either Equation 4 or 5. Accident rates were reduced at 73 percent of the sites considered, which supports the hypothesis. The results indicate that at a relatively small percentage of the sites the hypothesis was not confirmed. However, the hypothesis was substantiated at a significantly larger percentage of the sites. These results suggest that the models given in Equations 3, 4, and 5 reasonably describe the respective relationships.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions are made based on the results of the study:

- Accident rates increase with increasing speed variance for all classes of roads.
- Speed variance on a highway segment tends to be at a minimum when the difference between the design speed and the posted speed limit is between 5 and 10 mph.
- For average speeds between 25 mph and 70 mph, speed variance decreases with increasing average speed.
- The difference between the design speed and the posted speed limit has a statistically significant effect on the speed variance.
- Drivers tend to drive at increasing speeds as the roadway geometric characteristics improve, regardless of the posted speed limit.
- The accident rate on a highway does not necessarily increase with an increase in average speed.

Recommendations

In order to reduce speed-related accidents, speed limits should be posted for different design speeds as follows:

Design Speed (mph)	*Posted Speed Limit (mph)*
70	60 or 65
60	50 or 55
50	40 or 45

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