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ABSTRACT

A study was conducted to investigate the traffic engineering factors that influence speed variance and to determine to what extent speed variance affects accident rates. Detailed analyses were carried out to relate speed variance with posted speed limit, design speeds, and other traffic variables. The major factor identified was the difference between the design speed of the highway and the posted speed limit. It was determined that speed variance will be minimal if the posted speed limit is between 6 and 12 miles per hour lower than the design speed, and that outside this range, speed variance increases with increasing difference between the design speed and the posted speed limit. Other findings were that: (1) drivers tend to go at increasing speeds as roadway geometric characteristics improve, regardless of the posted speed limit; and (2) accident rates do not necessarily increase with increase in average speed but do increase with increase in speed variance. The results can be used to estimate changes in speed variance due to changes in traffic characteristics and, therefore, can provide traffic engineers with a means for controlling speed variance due minimize accidents. (Author/KC)

SPEED VARIANCE AND ITS INFLUENCE ON ACCIDENTS

By

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ABSTRACT

Safety should be one of the major factors considered when the speed limit is being selected for a particular stretch of highway. The level of safety on any highway is however related to certain characteristics of the traffic stream and the geometrics of the roadway. The geometric characteristics of a section of highway, e.g., maximum grade, minimum curvature, etc. are based mainly on the design speed. But in many cases, speed limits are posted without adequate consideration given to these characteristics. An important traffic characteristic which has been found to influence safety is speed variance, but currently little is known about the factors that affect variance of vehicle speeds in a traffic stream. The objective of this study was to investigate the traffic engineering factors that influence speed variance and to determine to what extent speed variance affects accident rates. Detailed analyses were carried out to relate speed variance with posted speed limit, design speeds and other traffic variables. The major factor identified is the difference between the design speed of the highway and the posted speed limit. It was determined that speed variance will be minimum, if the posted speed limit is between 6 and 12 mph lower than the design speed, and outside this range, speed variance increases with increasing difference between the design speed and the posted speed limit.

Other findings are:

* Drivers tend to go at increasing speeds as roadway geometric characteristics improve regardless of the posted speed limit.

* Accident rates do not necessarily increase with increase in average speed but do increase with increase in speed variance.

INTRODUCTION

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

Countermeasures to improve safety of the vehicle include installation of seat-belts, collapsible steering columns, and regular vehicle inspections. The vehicle driver is undoubtedly the most important single component of the driving process and also the most difficult to understand and control. Numerous studies have attempted to isolate the human traits that are apparent in individuals involved in accidents. Although certain psychological traits, such as aggressiveness, intolerance, and restraint of authority are apparent in chronic traffic violators and accident repeaters, it has been concluded that it would be difficult if not impossible to use human characteristics as reliable predictors of accident involvement. However, some familiar countermeasures taken in the area of driver characteristics include driver education, strict licensing procedures and alcohol regulations. Countermeasures relating to the roadway include the installation of safety features such as regulatory and warning signs, guard-rails, breakaway signs and lighting supports, bridge and curve widenings, speed zoning and various construction techniques.

Although some studies have indicated that the direct causal relationship between roadway characteristics and accident rates may be low, the roadway undoubtedly influences accident rate, because certain highway characteristics can require mental and physical responses beyond the abilities of the driver. The best evidence of such influences is the relatively low-accident rates on modern, well-designed, fully access-controlled highways compared with those on older, less expensive roadways.

A traffic characteristic that straddles the areas of driver characteristics and geometric characteristics is speed. It has long been known that while several speed characteristics may affect accident rates, speed variance is one of the most important. However, the factors that affect speed variance have not been widely studied. The main objective of this study is 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 will facilitate the development of countermeasures that will result in minimal speed variance levels which in turn will lead to reduction of accident rates.

PURPOSE AND SCOPE

The scope of the study was limited to Virginia highways. However, because of the different types of highways considered and the different topological features existing in Virginia, the results will be suitable for highways located in other parts of the country.

The specific objectives of the study are:

1. To determine the extent to which speed variance affects the accident risk on highways.

2. To determine the influence of traffic and geometric characteristics on speed variance.

3. To develop mathematical relationships relating speed variance with accident rates, traffic and geometric characteristics.

4. To develop guidelines for controlling speed variance, and thereby minimizing accident rates.

The results will provide valuable information that can be used to estimate changes in speed variance due to changes in traffic characteristics, and therefore provide traffic engineers a means for controlling speed variance to minimize accidents.

METHODOLOGY

The study methodology entailed the following tasks:

A. Literature Survey

B. Site Selection

C. Data Collection

D. Statistical Analysis

E. Model Development

F. Development of Guidelines

A schematic diagram of the tasks involved in the methodology is shown in Figure 1.

Literature Survey

A literature survey was conducted through the facilities of the University of Virginia and Virginia Highways and Transportation Research Council. Also a computer search was made through NTIS, to identify the relevant publications. A summary of information obtained through the literature survey is given later in another section.

Site Selection

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

Interstates

- Urban Interstate
- Rural Interstate
- Freeways & Expressways

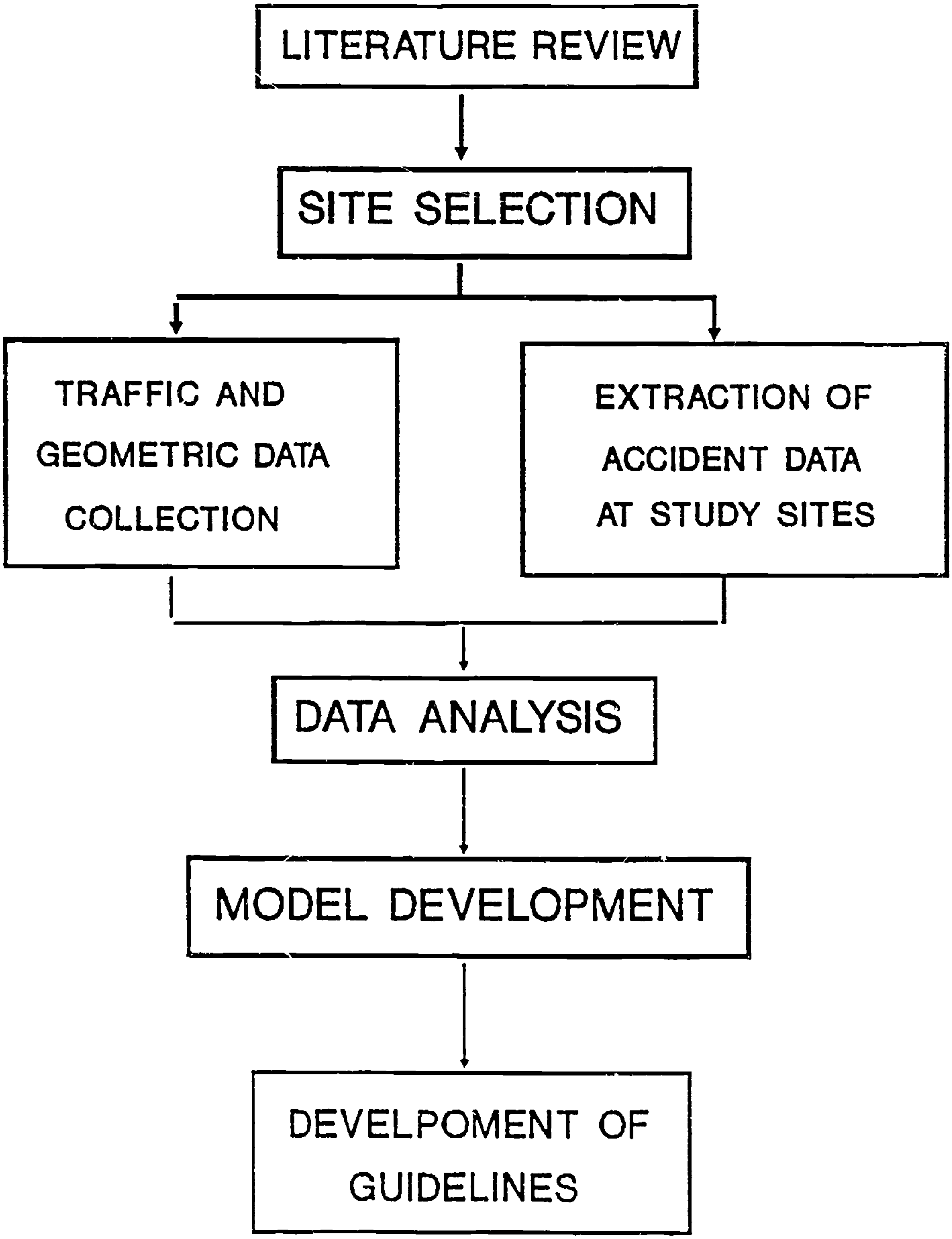

Figure 1 : Schematic Representation of the Study Tasks.

Arterials

- Urban Arterials
- Rural Arterials

Rural Major Collectors

Test sections were selected such that traffic volume and traffic characteristics remain practically constant within each section. The required test sections are located between interchanges on interstates, freeways and expressways and between major intersections on other roads.

A list of candidate sites was first identified for each highway type, such that they have geometric characteristics that are typical of the type of roads they represent. Consideration was given to horizontal and vertical alignments, the number of lanes, lane widths, access control, land use, traffic volumes and traffic control devices.

A final set of 36 locations (shown 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
* A good representation of different roads and terrains

Data Collection

Traffic Data Elements

Traffic data collected at the study sites included hourly volumes, 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. A sample output is shown in Appendix A

TABLE 1: LIST OF STUDY SITES

INTERSTATE

STAT	ROUTE	CITY	COUNTY	LOCATION	FROM	TO
				URBAN INTERSTATE		
2235	581	ROANOKE 128		0.02 MI.N.MI.MAR #3	RT 101 EBL	RT116&460 EB
1315	95		HENRICO 43	0.07 MI.N.MI.MAR #82	M RT 301 SB	RT 73 WBL
2325	195	RICHMOND 127		0.91 MI. S.RT.250/33 UP	RT 147	RT 6
1375	564	NORFOLK 122		0.40 MI.S.SE AIR.TERML	RT 460 WBL	RT 337
2393	64	VA.BEACH 134		0.80 MI.W.INC.RIVER RD UP	INDIAN RIV RD	FCL CHESAPEK
2461	95	FAIRFAX 151		1.30 MI.N.RT.613 UP	RT 613	RT 241
				RURAL INTERSTATE		
2225	77		CARROLL 17	0.53 MI.N.MI.MAR #23	RT 69 WBL	RT 52
1363	64		YORK 99	0.32 MI.E.MI.MAR #243	RT 199 EBL	W CONN RT 143
2455	95		PRINCE WILLM 76	1.33 MI.S.RT 234	RT 619	RT 234 NB
2497	66		FAUQUIER 30	1.90 MI.E.RT 17 N.B	E RT 175 NB	RT 245 NBL
1167	64		LOUISA 54	1.20 MI.E.RT 15	RT 15 NBL	RT 208
2571	81		ROCKBRID 81	0.13 MI.S.MI.MAR #179	S RT 11	M RT 11
2597	64		ROCKBRID 81	0.23 MI.W.MI.MAR #49	RT 780	RT 623
				FREEWAYS AND EXPRESSWAYS		
1191	23		SCOTT 84	0.82 MI.N.RT 23 BUS	RT 65	N RT 23 BUS
1283	150		CHESTERFIELD 20	0.56 MI.W.RT 60 C.P	RT 360 WBL	RT 60 WBL

TABLE 1 (CONTINUED)

ARTERIALS

STAT	ROUTE	CITY	COUNTY	LOCATION	FROM	TO
				RURAL ARTERIALS		
1185	80		RUSSEL 83	0.12 MI.S.RT 639	BUCHANAN CL	NCL HONAKER
2267	58		PITTSYLVANIA 71	1.40 MI.E.RT 62	HALIFAX CL	RT 729
2293	360		AMELIA 04	0.19 MI.W.RT 360 BUS	M RT 360 BUS	W RT 360 BUS
2381	13		ACCOMACK 01	0.28 MI.N.RT 180	NCL KELLER	S RT 180
2407	10		SURRY 90	0.65 MI.E.RT 660	W RT 31	RT 40
1115	17		ESSEX 28	0.90 MI.N.NCL TAPNOCK	N RT 624	NCL TAPPAHAN
1515	15		MADISON 56	0.34 MI.S.RT 634	CULPEPER CL	RT 230
2585	220		BATH 08	0.19 MI.N.RT 606	RT 658	ALLEGHANY CL
2043	460		BOTETOURT 11	0.10 MI.E.RT 652	RT 616	B R PKWY OP
2025	45		CUMBERLAND 24	0.65 MI.E.RT 633-S Int	S RT 60	N RT 636
2067	256		AUGUSTA 07	1.30 MI.E.RT 276	ROCKINGHAM CL	RT 276
1031	29		CAMPBELL 15	2.09 MI.S.SCL LYNCHBG	RT 24	RT 678
				URBAN ARTERIALS		
1303	360		HANOVER 42	RT 156 UP	RT 156	W RT 360 BUS
1487	7	FAIRFAX 151		0.40 MI.W.RT 702	RT 123 SBL	RT 193

RURAL MAJOR COLLECTORS

STAT	ROUTE	CITY	COUNTY	LOCATION	FROM	TO
2173	42		BLAND 10	0.07 MI.W.RT 604	RT 738	E RT 52
1273	56		NELSON 62	0.30 MI.E.RT 646	SE JAMESR BR	E RT 639
2131	156		HENRICO 43	0.19 MI.N.CHARLES CTY RD	RT 60	RT 5
2355	301		GREENSVILLE 40	0.29 MI.S.RT 639	SCL EMPORIA	RT 629
2507	55		FAUQUIER 30	0.34 MI.W.RT 726	W RT 17	WARREN CL
1565	42		SHENANDOAH 85	0.06 MI.S.RT 688	S RT 675	N RT 263
2431	201		LANCASTER 51	0.08 MI.S.RT 600	RT 3	N RT 600

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, e.g. skewness, kurtosis etc.

Geometric Data Elements

Another category of information needed for the purpose of analysis was the geometrics of the roadway. The characteristics associated with the study site were recorded.

However, since the geometric characteristics of a section of highway are represented by its design speed, we have used design speed as a surrogate for the geometric characteristics in this study. Design speed is defined as the "maximum safe speed that can be maintained over a specified section of highway when conditions are favorable such that the design features of the highway govern." Design speed 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).

Accident Data Elements

Data on accident characteristics were obtained from computerized files prepared and stored by the VDOT and the Virginia Department of Motor Vehicles (VDMOV). The necessary data were extracted for 1983 through 1986.

Each study site was identified by the route number, the city/county in which it is located, and its section number. Data were then extracted for each site for the following:

- Fatal Accidents
- Injury Accidents
- Property Damage Accidents
- Total Number of Accidents

Data Analysis

The first activity under this task was to formulate a database suitable for using available statistical packages. The database formulated included the summary of accidents for 1983, 1984, 1985 and 1986, the breakdown of accidents by type, class of highway and traffic characteristics. A data file for 1985 shown in Appendix B, is an example of the files used. This database was then used to carry out statistical analysis, described later in separate sections.

Development of Models and Guidelines

In order to determine the mathematical relationships existing among the variables, several models were developed using Regression Analysis. The first model relates average speed and design speed, the second shows the interaction of average speed and speed variance, the third explains how the difference between design speed and speed limit affects speed variance and the fourth shows the influence of average speed on accident rates. Another category of model gives the relationships between accident rates and speed variance for different types of roads. Guidelines for setting speed limits that will result in minimal accident rates were then developed based on the mathematical models obtained.

ANALYSIS AND RESULTS

The following subsections summarize the results of analysis performed on the data collected.

Literature Survey

The literature survey undertaken during the study revealed that although there have been studies relating accidents rates with different speed characteristics, varying results have been obtained with respect to the effect of speed on accident rates. The results of the literature survey are summarized under the following subheadings.

* Speed control
* Accident rates and speed
* Accident rates and speed variance
* Influence of geometric characteristics on speeds

Speed Control

Speed control has been identified as one of the most important tools used to reduce speed related accidents. Speed control has however been recognized as a difficult and controversial issue, due to the fact that 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, in one of the earliest studies on speed stated, "It must be provided for and protected." (1). The question may however be asked, What speed is safe? Drastically expressed, the only safe speed is 0 mph, as accidents occur at all speeds (2,3). Higher speeds however 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. Hence the main responsibility of traffic engineers is to identify a 'safe' speed to reduce the probability of an accident occurring to a minimum. Only a few studies have developed recommendations for safe speeds on different highways. However, most of these recommendations were based on policy assessment, and/or legislative requirements rather than traffic and geometric factors.

Accident Rates and Speed

Although it is generally assumed that speed is often the greatest contributing cause to accidents, some studies, have however indicated that this may not be entirely true. One investigation concluded that speed is not necessarily an important cause of accidents, but is an important determinant of severity (4). Another study in Minnesota considered 40,000 accidents in which data on speeds of vehicles involved in accidents were available, and showed that 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 (2). Nearly 75 percent of all accidents involved some violation other than speed. A research study in Pennsylvania (5) revealed 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 have shown that higher speed variance is usually associated with higher accident rates. Pisarski for example, pointed out that there is a significant statistical relationship between speed variance and accident rate (6). Study in Canada on speed and accidents also revealed that speed variance may be a more important factor in causing accidents (4). Cerrelli (7), summarized 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. Thus the risk of having an accident appears to increase, as the vehicle speed varies from the average speed on the highway. Although all of these studies are in agreement with the conclusion that speed variance significantly influences accident rates, very few actually quantified the relationship between these variables.

Influence of Geometric Characteristics on Speed

A study was conducted by Elmberg on a newly reconstructed highway to investigate the effect of posted speed limit on drivers' speed (8). The results revealed that the drivers paid little if any attention to posted speed limits and that drivers chose a speed which they themselves considered appropriate for prevailing conditions. This strongly suggests that geometric characteristics influence the operating speeds of the driver. A low posted speed limit on a highway with good geometric conditions, for example, may, result in a wide range of speeds on the highway, which in turn will lead to increase in accident rates.

Traffic Characteristics

Table 2 shows a summary of the two main speed characteristics considered for the different types of highways. The results indicate

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 ANOVAs ON TRAFFIC CHARACTERISTICS

SUBSCRIPT VARIABLE	AVERAGE SPEED			SPEED VARIANCE		
	Computed F value	F Value at 0.05	result	Computed F value	F value at 0.05	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

that 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 highways. In order to test the extent to which different variables affect speed characteristics, Analysis of Variance (ANOVA) was performed on the main variables, speed variance and average speeds as shown in Table 3. The class variables are the highway type, design speed, and time (by year). Also the effect of average speed on speed variance was determined by segmenting the average speed into suitable classes, and performing the Oneway ANOVA test.

The statistical results are summarized in Table 3. The computer outputs for these analyses are shown in Appendix C.

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

Accident Characteristics

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

The results indicate that average speed, speed variance, design speed and highway type have a significant effect on accident rates. It should be noted however, that it has been shown that there is some correlation between design speed and average speed, and average speed and speed variance. The results therefore do not suggest that each of these variables independently affect accident rates.

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 ANOVAs ON TOTAL ACCIDENT RATES

	TOTAL ACCIDENT RATE		
SUBSCRIPT VARIABLE	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

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MODEL DEVELOPMENT

The results of the analysis of variance (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 significant difference existed between the speed variance for different categories of average speeds, and between accident rates for different speed variances. In order to quantify these observations, mathematical models were developed using regression analysis. The models obtained are discussed using appropriate figures under the following subheadings.

Average Speed and Design Speed

In order to have general indication of the mathematical relationship between average speed and design speed, the average speed at each site was plotted against the design speed. Figure 2a, shows this plot, and Figure 2b shows the plot of the mean of the average speeds for each design speed plotted against the design speed. The regression analysis indicates that the relationship between average speed and design speed can be given as:

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

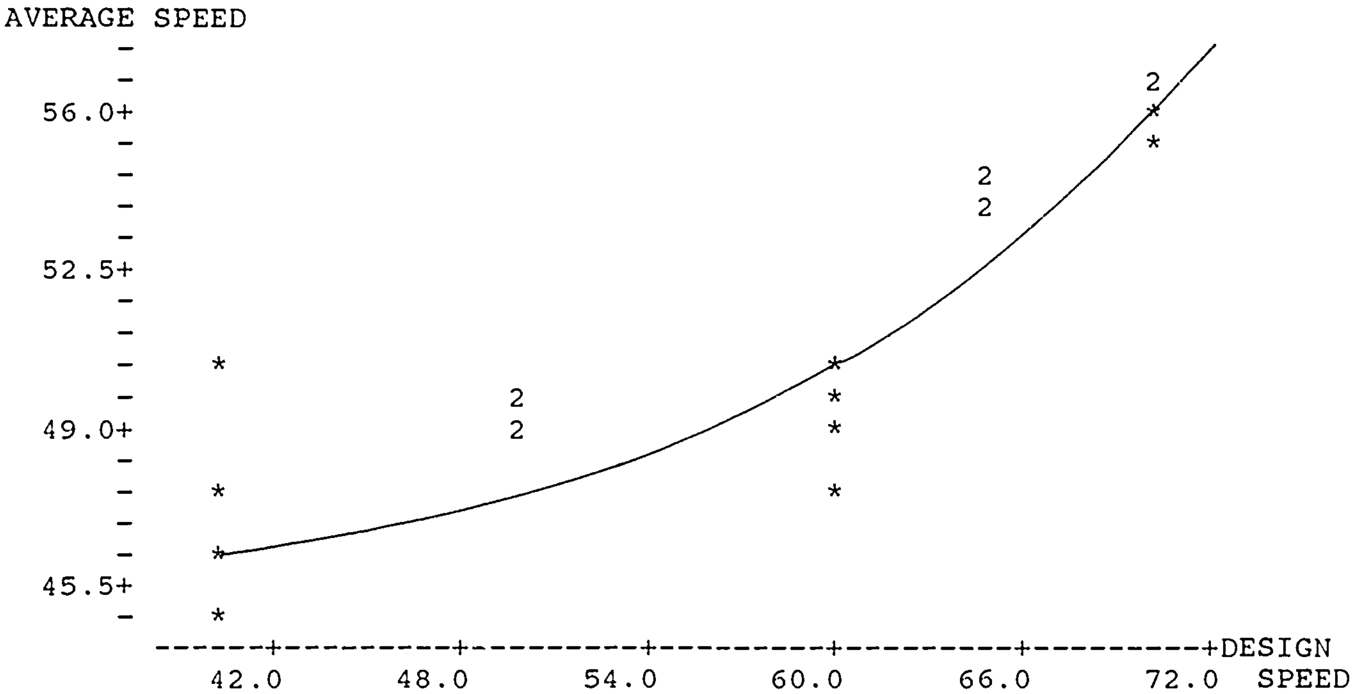
where

AVSPD = Average speed in mph,

DESPD = Design speed in mph, $40 < \text{DESPD} < 70$

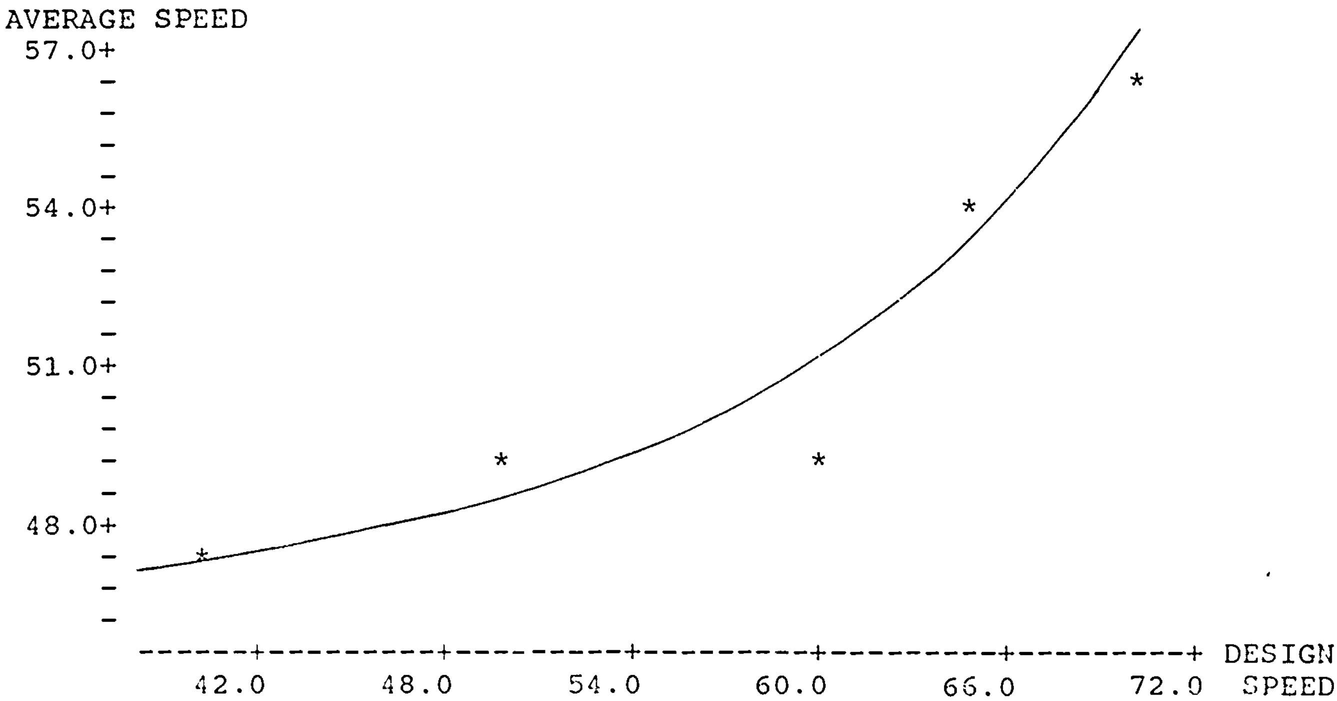
The output of the regression analysis is shown in Appendix D.

Since the design speed is a surrogate for roadway geometrics, and a higher design speed indicates better geometric characteristics, it is



(a)

MEAN DATA POINTS FROM ALL FOUR YEARS



(b)

MEANS OF DATA POINTS IN (a) FOR A GIVEN DESIGN SPEED

FIGURE 2 : AVERAGE SPEED VS. DESIGN SPEED

clear that drivers tend to travel at higher speeds on highways with better geometric characteristics regardless of the posted speed limit as all of the study sites considered for this model had a posted speed limit of 55 mph.

Speed Variance and Average Speed

Figures 3a and 3b show plots of speed variance and average speed for all highway types. It can be seen that speed variance decreases as average speed increases. The relationship is however non-linear, and resembles a second order function tapering off to a constant value. This is realistic, since speed variance can never go below a certain value even at higher average speeds. The relationship obtained from the regression analysis is given by

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

where

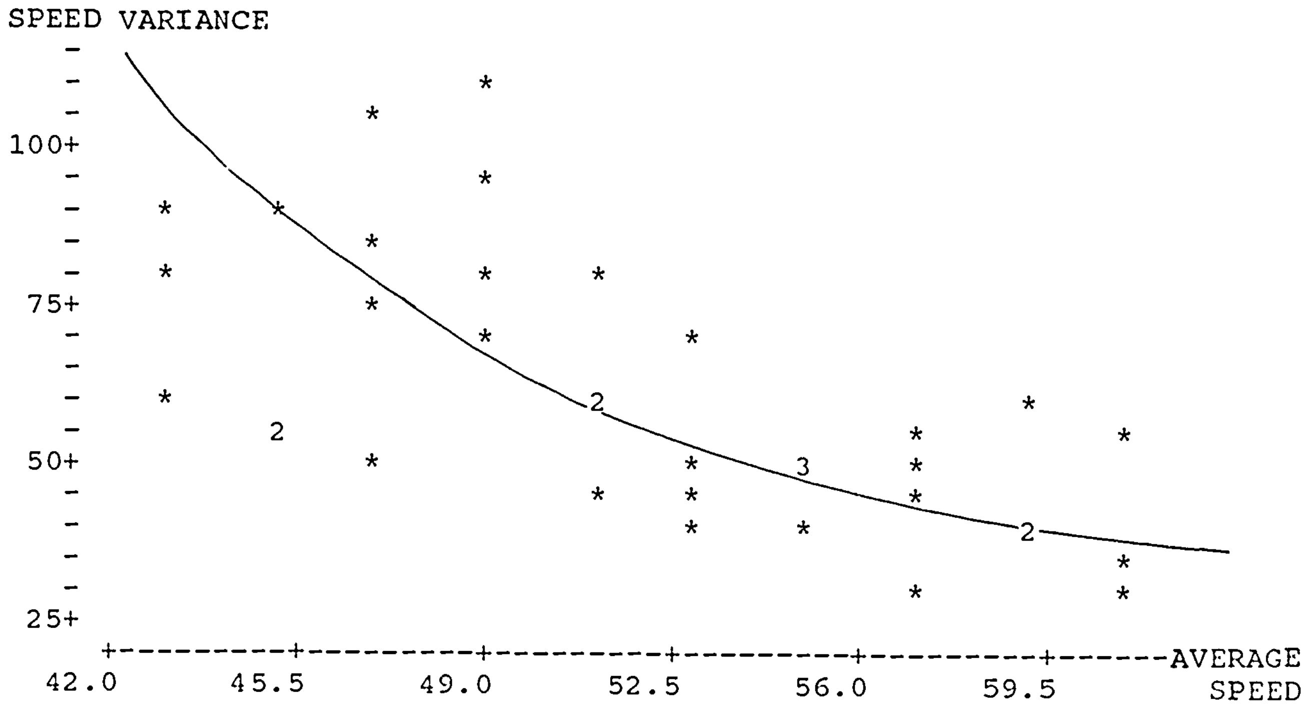
SPVA = speed variance

AVSPD = average speed, mph $25 < AVSPD < 70$ mph

Results of the regression analysis given in Appendix D show a coefficient of determination of 94% for this model.

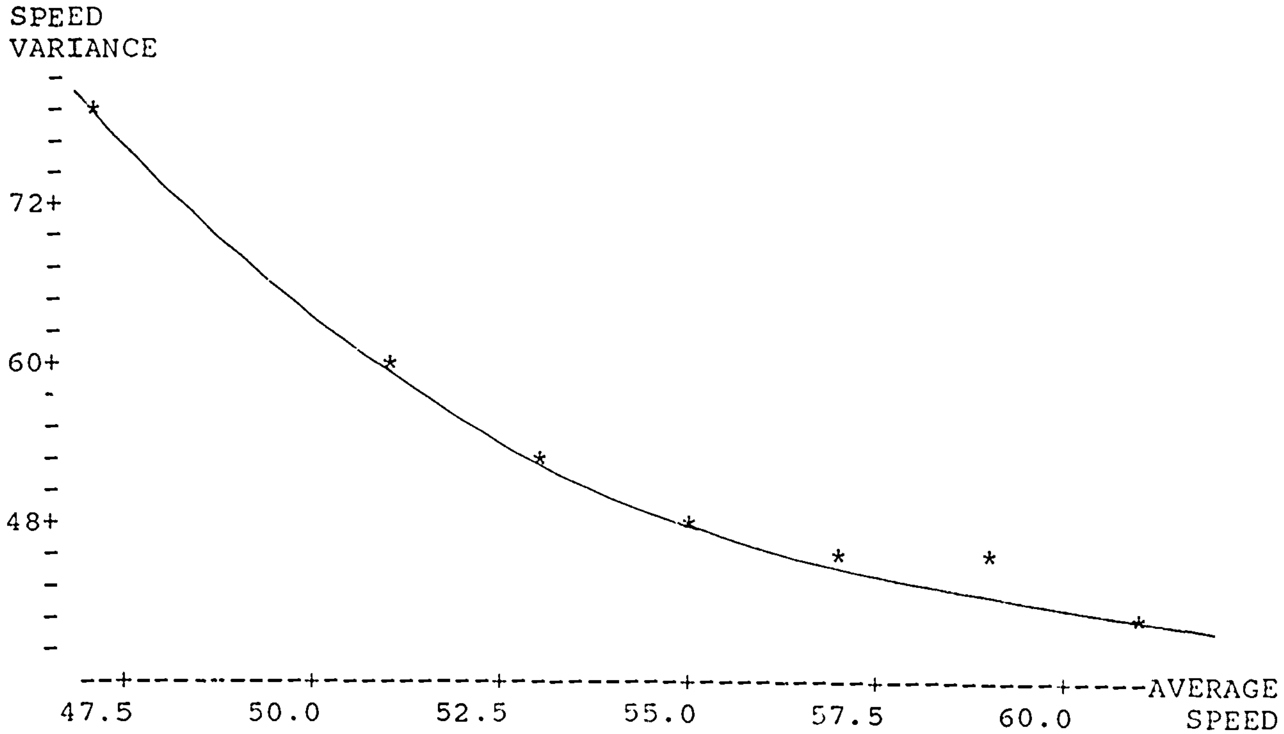
Speed Variance, Design Speed and Posted Speed Limit

The results of analyses presented in earlier sections of this report indicated that average speed is dependent 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. Also, since it has



(a)

MEAN DATA POINTS FROM ALL FOUR YEARS



(b)

MEANS OF DATA POINTS IN (a) FOR A GIVEN AVERAGE SPEED

FIGURE 3 : SPEED VARIANCE VS. AVERAGE SPEED

been shown in another study that average speed at a given location is also affected by the posted speed limit (3), it was decided to develop a model relating speed variance with design speed and posted speed limit. The independent variable selected for this model is the difference between the design speed and posted speed limit. This effectively considers the main factors influencing average speed. These include the type of highway and geometric characteristics which 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 4. It can be seen from these plots, that speed variance tends to be low, when difference is between 6 and 12 mph. In the application of this model however the range of this difference should be considered as between 5 and 10 mph since speed limits and design speeds are usually multiples of 5 mph. The model obtained from regression analysis is given as:

$$SPVA = 57 + 0.05\ (X - 10)^2 \quad \ldots\ldots\ldots (3)$$

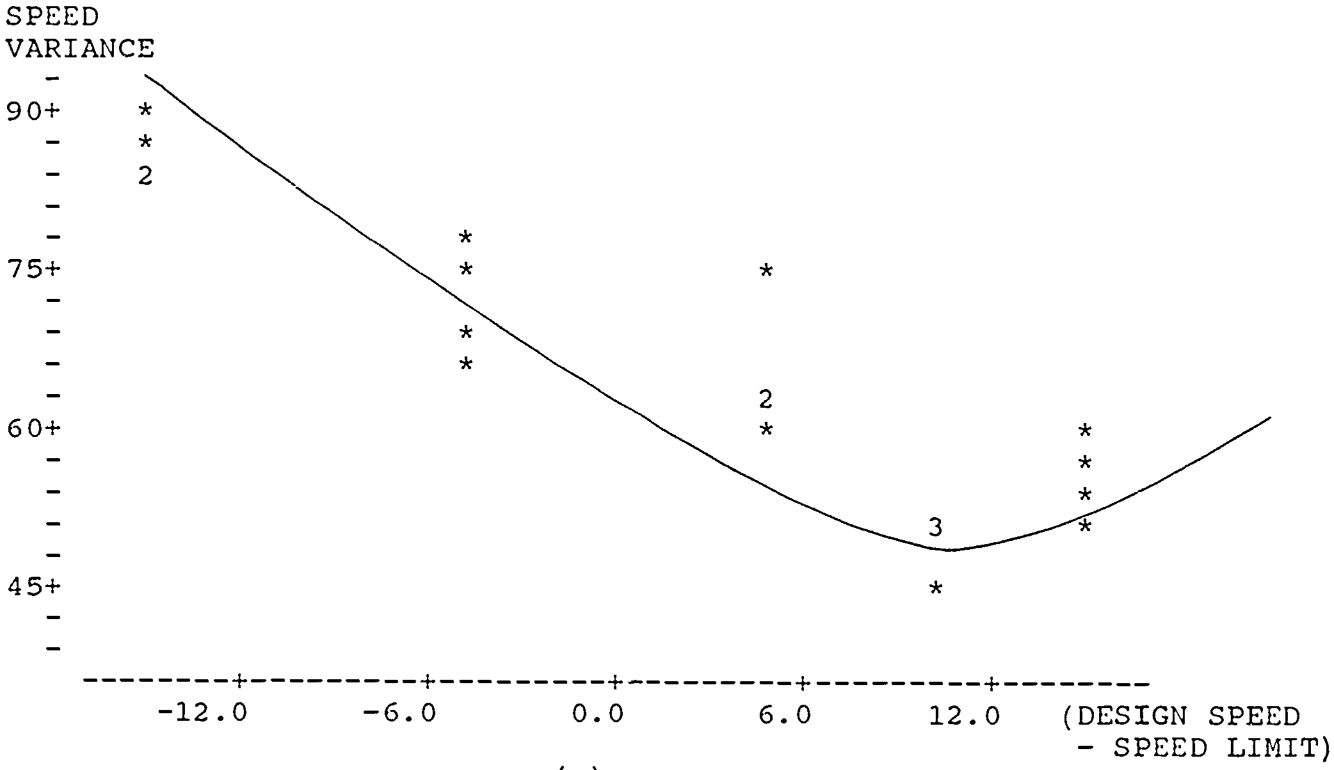
where

SPVA = speed variance

X = design speed minus posted speed limit, (mph).

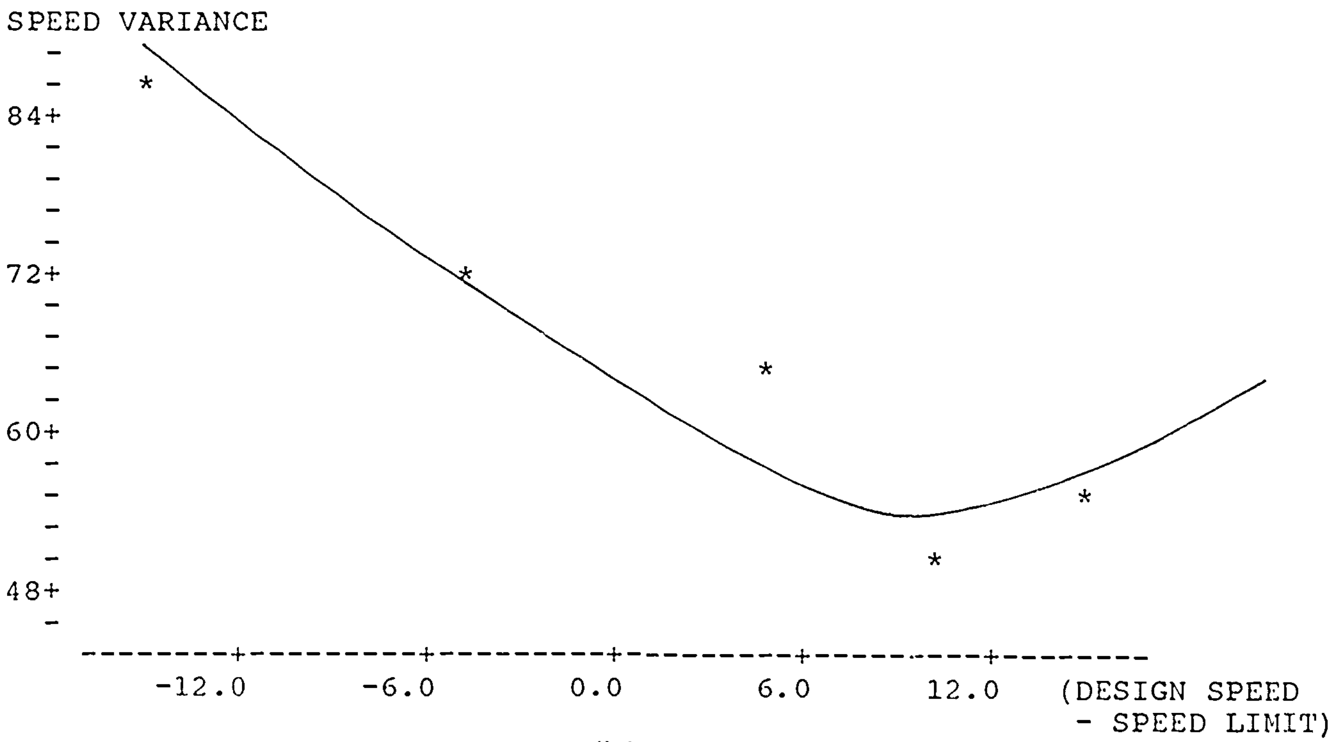
Table 6 shows computed values for speed variance using equation 3.

This model suggests that the minimum speed variance will occur when the difference between design speed and the posted speed limit is 10 mph. Results of the regression analysis are given in Appendix D, which shows that the model explains about 85 percent of the variation observed.



(a)

MEAN DATA POINTS FROM ALL FOUR YEARS



(b)

MEANS OF DATA POINTS IN (a) FOR A GIVEN (DESIGN SPEED - SPEED LIMIT)

FIGURE 4 : SPEED VARIANCE VS. (DESIGN SPEED - SPEED LIMIT)

TABLE 6. SPEED VARIANCE VS. (DESIGN SPEED - SPEED LIMIT)

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

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

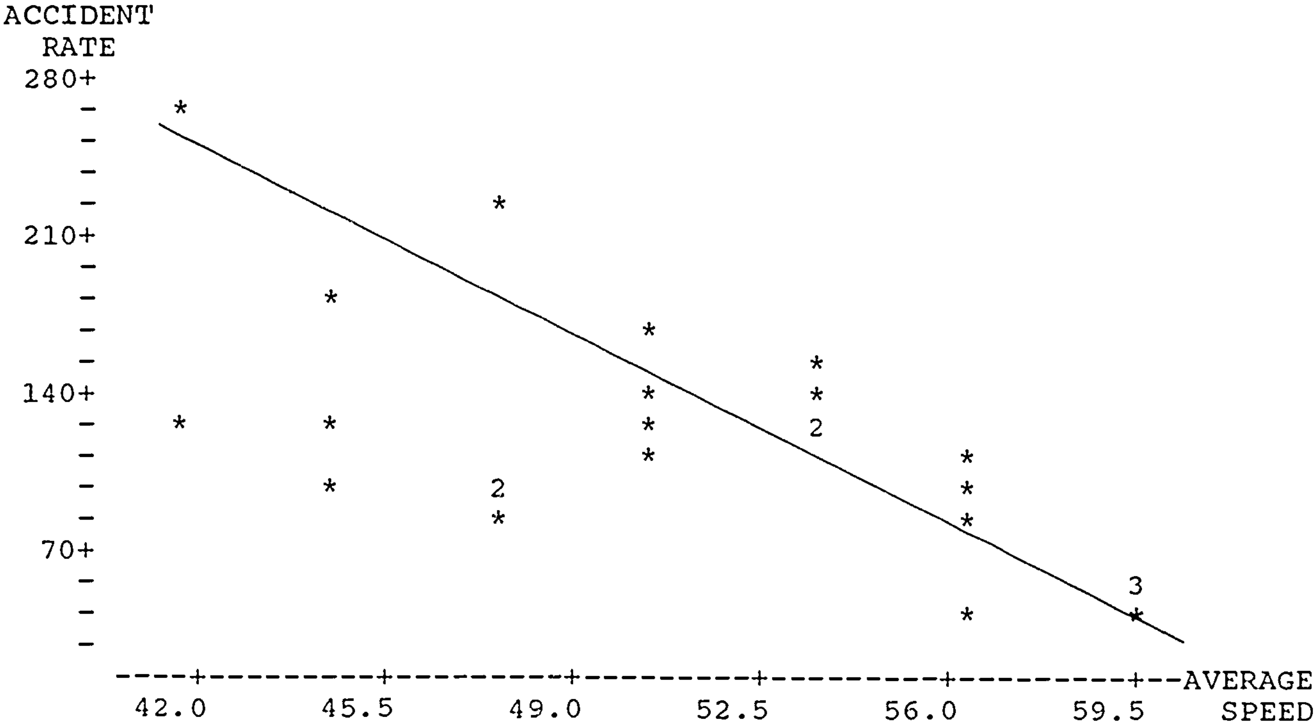
Accident Rates and Average Speed

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

However, when the data for all sites were pooled together and accident rates at the locations were plotted against the corresponding average speeds observed, the results obtained are shown in Figure 5. The plots suggest that accident rates decreased with average speeds. It will however be inaccurate to make such a conclusion, as average speeds on the interstate highways tend to be higher than those on the primary highways, and accident rates are lower on the interstate highways because of their better geometric characteristics. Figure 5 therefore, depicts the effects of the different geometric characteristics rather than the effect of speed. This also explains why the result of the ANOVA test recorded earlier indicated that average speeds significantly affects accident rates.

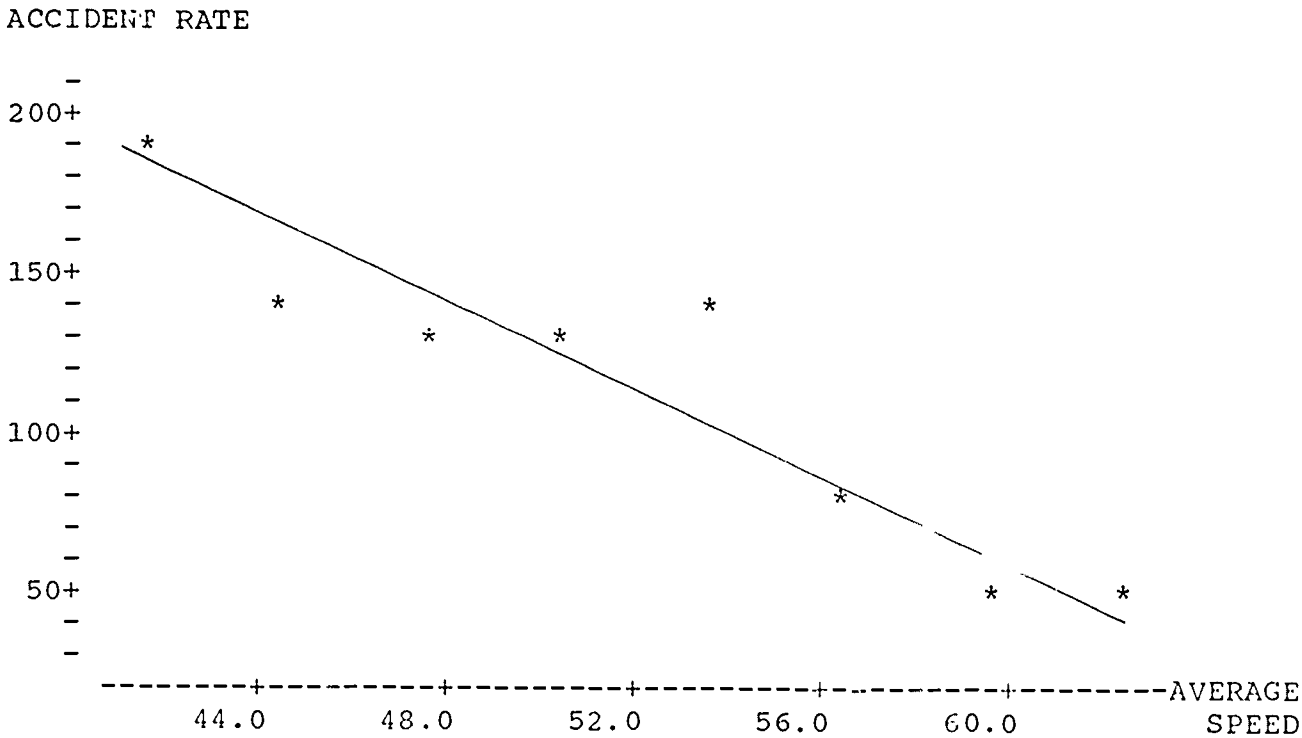
Accident Rates and Speed Variance

Models relating accident rates and speed variance were formulated to examine the influence of speed variance on accident rates on different categories of highways. Figure 6 shows plots of accident rates against speed variance for interstate highways.



(a)

MEAN DATA POINTS FROM ALL FOUR YEARS



(b)

MEANS OF DATA POINTS IN (a) FOR A GIVEN AVERAGE SPEED

FIGURE 5 : ACCIDENT RATE VS. AVERAGE SPEED

These plots clearly indicate that accident rates increase as variance increases. The model obtained from the regression analysis describes about 60% of the variation observed, and is given as:

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

where

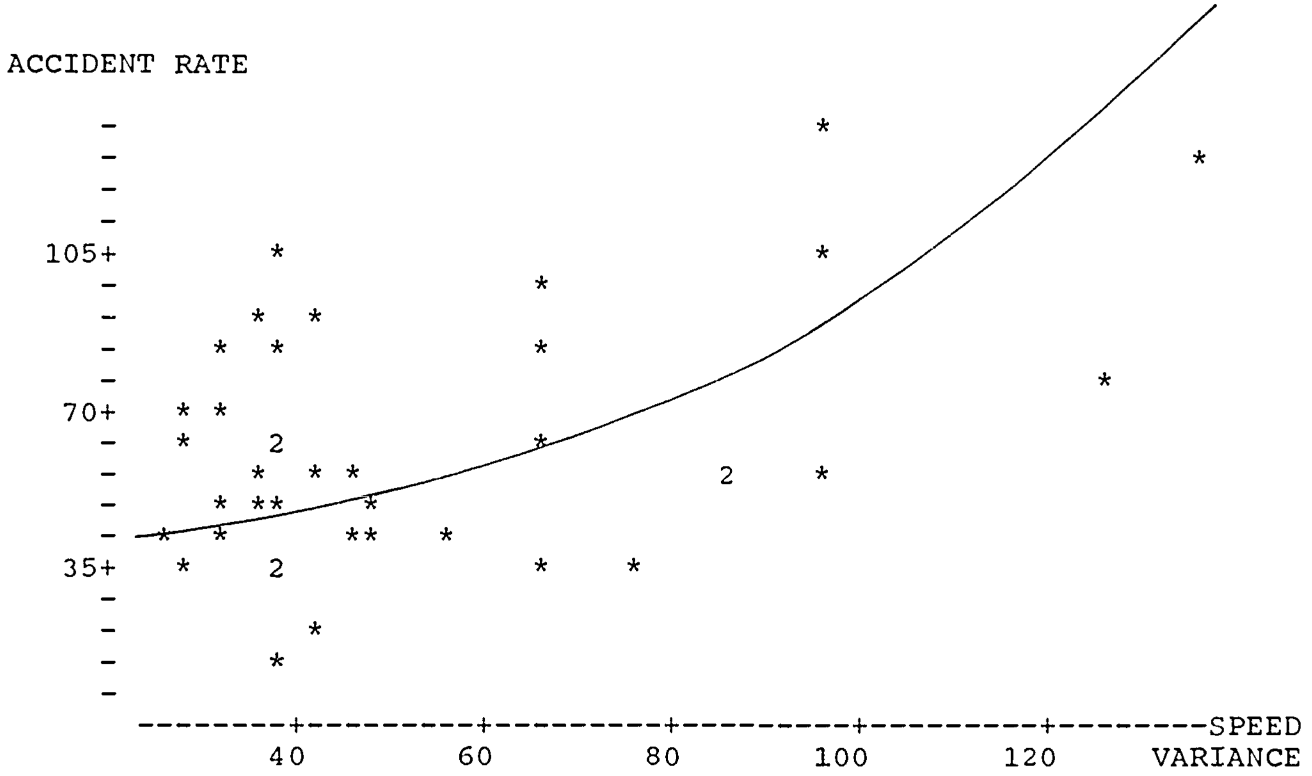
ACCRT = Accident rate in number of accidents per 100 million vehicle miles of travel.

SPVA = Speed Variance

The corresponding plots for arterial highways are shown in Figure 7. These plots also indicate that as speed variance increases accident rates also increase. The model explains about 82% of the variation and is given as:

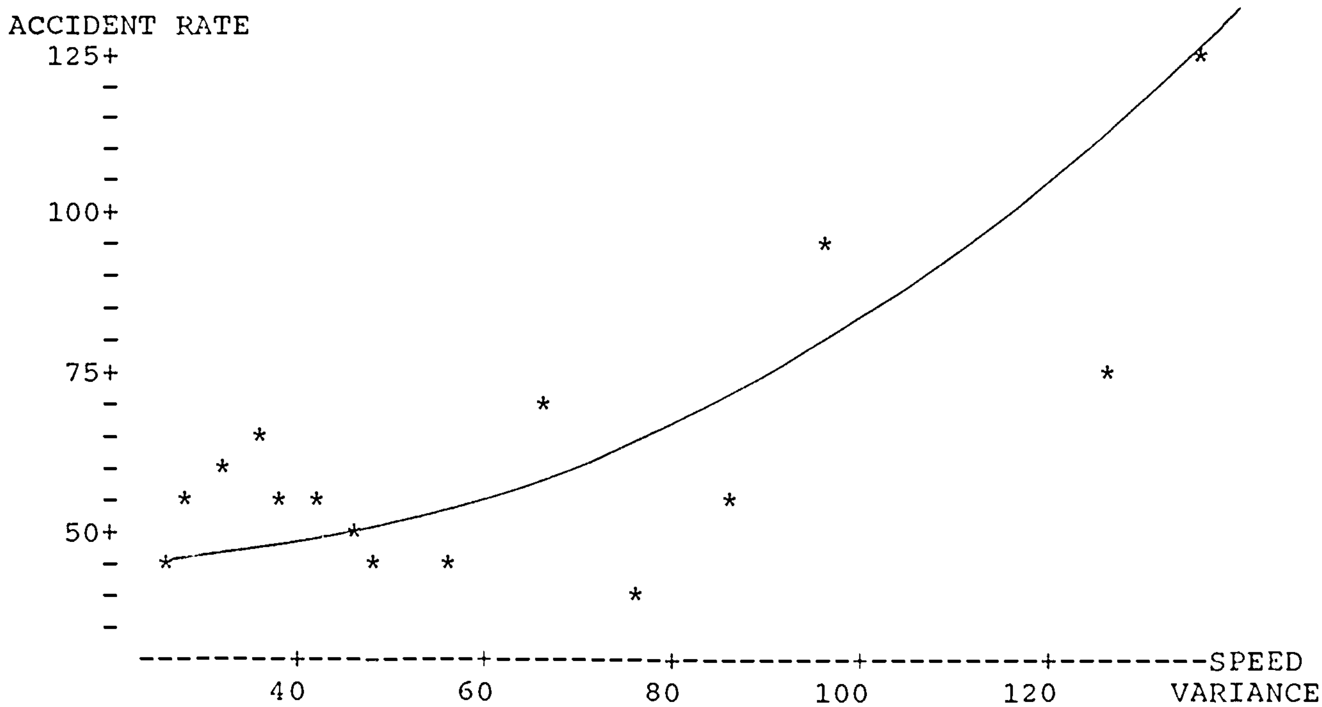
$$ACCRT = 168 + 0.00273\ (SPVA)^2 \quad ....(5)$$

36



(a)

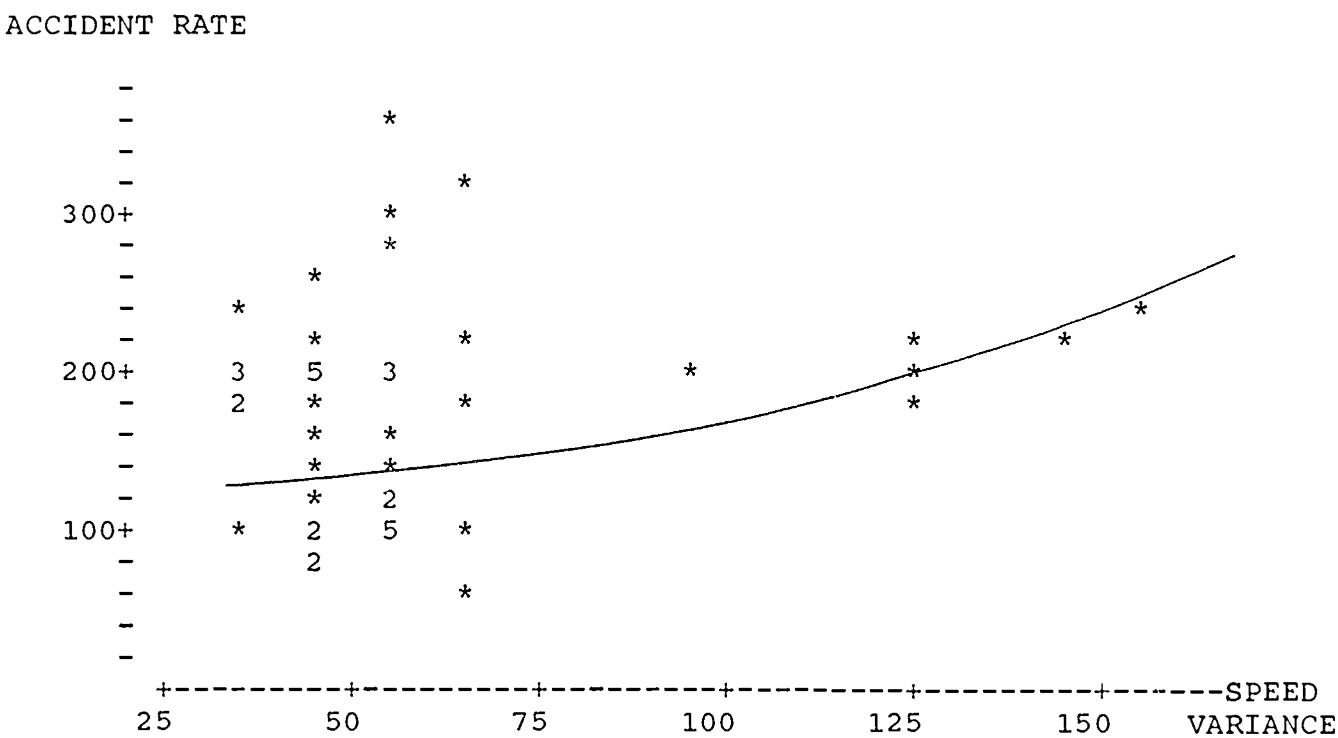
DATA FROM ALL FOUR YEARS



(b)

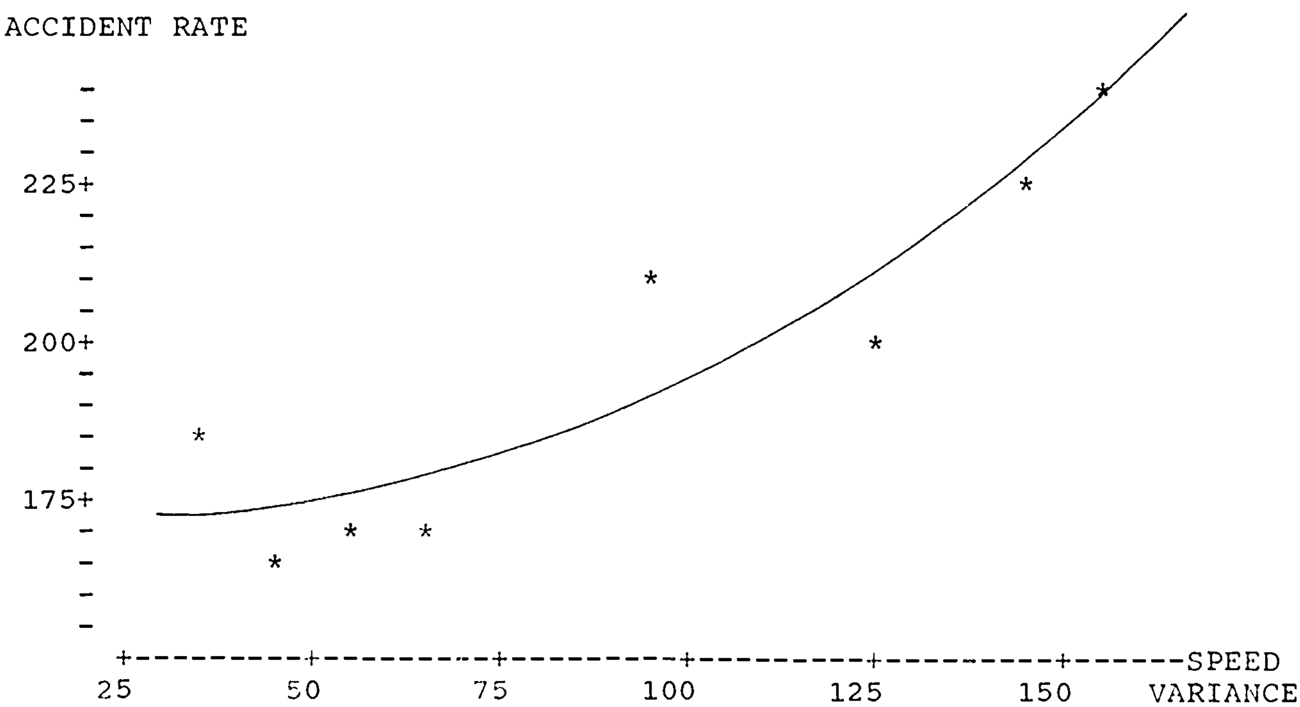
MEANS OF DATA POINTS IN (a) FOR A GIVEN SPEED VARIANCE

FIGURE 6 : ACCIDENT RATE VS. SPEED VARIANCE FOR INTERSTATE HIGHWAYS



(a)

DATA FROM ALL FOUR YEARS



(b)

MEANS OF DATA POINTS IN (a) FOR A GIVEN SPEED VARIANCE

FIGURE 7 : ACCIDENT RATE VS. SPEED VARIANCE FOR ARTERIAL HIGHWAYS

TEST OF MODELS

In order to test the validity of the models developed relating accident rates with speed variance and speed variance with design speed and posted speed limit, 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. This entailed the use of equation 6, which is commonly employed in determining critical accident rates for a given section of a highway.

$$C = A + K\sqrt{A/M} + 1/2M \qquad \ldots\ldots\ldots\ldots(6)$$

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% confidence (1.96)

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

Traffic and accident data files from the four study years were sorted by highway category, and mean accident values computed for each category. The critical accident rate for each location was then computed. Sites at which accident rates were higher than the corresponding critical accident rates were then identified and a total of 31 sites were randomly selected for testing the models developed. This resulted in 124 observations for the four-year study period. The difference between the design speed and the posted speed limit for each site was then compared with the range of 5 - 10 mph, which the model suggests for minimum accident rates, using the following hypothesis:

The relationship between speed variance and the difference between the design speed and posted speed limit, is that the speed variance would be higher on either side of a desirable zone of 5-10 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 stated 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 speed limit is either less than 5 or greater than 10. This can be mathematically stated as:

$$\text{ACCR} > \text{CRIT},\ x < 5,\ x > 10 \Longrightarrow \text{TRUE}$$

$$\text{ACCR} < \text{CRIT},\ x < 5,\ x < 10 \Longrightarrow \text{TRUE}$$

$$\text{OTHERWISE} \Longrightarrow \text{FALSE}$$

The test was applied to 124 observations. The results, validated the hypothesis in that about 80% of the observations satisfied the conditions of the hypothesis.

The next hypothesis tested was that 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 then computed using equation 3, and the expected accident rates computed for the respective sites using either equation 4 or 5. The results indicate that the accident rates were reduced at 73% of the sites considered, which supports the hypothesis.

The results indicate that at a relatively small percentage of the sites, the hypothesis wasn't confirmed. The most likely reason for this is that most of the accidents that have occurred at those sites might have been due to non-speed related factors. The hypothesis was however 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.

1. Accident rates increase with increasing speed variance for all classes of roads.

2. Speed variance on a highway segment tends to be a minimum when the difference between the design speed and the posted speed limit is between 5 and 10 mph.

3. For average speeds between 25 mph and 70 mph, speed variance decreases with increasing average speed.

4. The difference between the design speed and the posted speed limit has a significant effect on the speed variance.

5. The increasing trend of average speed with respect to the design speed, suggests that as the roadway geometric characteristics improve, drivers tend to go at increasing speeds irrespective of the posted speed limit.

6. The accident rate on a highway does not necessarily increase with 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	Posted Speed Limit
70	60 or 65
60	50 or 55
50	40 or 45

REFERENCES

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APPENDICES

APPENDIX - A

A sample output obtained from Leupold & Stevens Traffic Analysis System, is displayed.

The first page gives the information programmed into it and the distribution of vehicle speeds. The second page shows the summary of above information and other statistics.

LISTING OF COLLECTED DATA

STA.	I.D.	PROG.	INTERVAL	SETUP DATE	SETUP TIME	RETRIEVAL DATE	RETRIEVAL TIME
1315	3123	2904	60	609	0	610	1524

REPORT FOR --- 6/ 9 TUESDAY

SPEEDS	1-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-99	
TIME 1: 0	8	1	0	1	4	15	52	119	113	56	21	10	400
TIME 2: 0	11	1	2	1	1	19	43	11	76	32	12	3	318
TIME 3: 0	13	1	1	0	5	9	31	86	82	26	19	9	282
TIME 4: 0	22	1	4	2	2	4	20	68	72	28	6	7	238
TIME 5: 0	29	9	0	0	1	14	31	95	91	46	19	4	339
TIME 6: 0	68	17	23	0	7	13	151	171	223	76	25	3	777
TIME 7: 0	42	14	12	0	7	65	384	755	639	160	38	7	2123
TIME 8: 0	28	8	5	2	14	57	381	886	668	151	23	7	2230
TIME 9: 0	10	2	2	2	9	44	310	616	529	155	29	5	1713
TIME 10: 0	15	4	3	4	11	48	288	537	483	171	39	5	1608
TIME 11: 0	18	5	9	3	9	34	298	511	501	190	41	5	1624
TIME 12: 0	19	3	6	5	19	76	329	579	461	178	33	6	1714
TIME 13: 0	18	4	3	4	18	65	313	524	453	181	40	5	1628
TIME 14: 0	23	7	7	9	13	78	334	466	446	146	40	10	1579
TIME 15: 0	25	2	8	6	17	69	299	499	557	163	42	11	1698
TIME 16: 0	30	4	4	3	17	60	379	595	569	221	45	4	1931
TIME 17: 0	21	5	6	14	42	253	470	705	482	124	27	4	2153
TIME 18: 0	30	4	8	3	10	70	321	519	496	103	40	9	1613
TIME 19: 0	23	8	9	2	9	20	220	334	363	128	46	11	1173
TIME 20: 0	31	13	3	4	2	25	168	196	239	104	19	5	809
TIME 21: 0	32	3	5	2	4	18	53	138	132	45	20	9	461
TIME 22: 0	27	7	7	0	5	14	52	151	158	62	22	10	515
TIME 23: 0	36	7	7	0	1	16	24	97	141	59	16	7	411
TIME 24: 0	7	1	2	0	4	17	56	150	157	44	18	5	462
--TOTALS--	586	131	136	67	231	1103	5007	8914	8131	2649	682	162	27799

ANALYSIS AND SUMMARY

STA.	I.D.	PROG.	INTERVAL	SETUP DATE	SETUP TIME	RETRIEVAL DATE	RETRIEVAL TIME
1315	3123	2004	60	609	0	610	1524

REPORT FOR --- 6/ 9 TUESDAY

SPEEDS	1-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-99	
--TOTALS--	586	131	136	67	231	1103	5007	8914	8131	2649	682	162	27799
-PERCENT-	2.11	0.47	0.49	0.24	0.83	3.97	18.01	32.07	29.25	9.53	2.45	0.58	100.00
ACC. PER.	2.11	2.58	3.07	3.31	4.14	8.11	26.12	58.19	87.43	96.96	99.42	100.00	100.00

NO. VEHICLES 27799

NO. VEH. OVER 55 MPH 20538 73.88 PERCENT
NO. VEH. OVER 60 MPH 11624 41.81 PERCENT
NO. VEH. OVER 65 MPH 3493 12.57 PERCENT

85TH PERCENTILE SPEED 65 MPH
50TH PERCENTILE SPEED 59 MPH

MEAN(AVERAGE) SPEED 58.42 STD. DEVIATION 8.28
NO. OF VEHICLES REQUIRED FOR .95 CONFIDENCE LEVEL 274

APPENDIX - B

This contains a sample data file with 21 columns, for the year 1985. The other three files are also of same format. The data fields as coded in programs are shown above each column. The description of each is given below.

1.	CAT	:The highway codes (1: interstate, 2: freeways & expressways, 3: urban arterials, 4: rural interstate, 5: rural arterials, 6: rural major collectors)
2.	STAT	:The station number of the location
3.	DES	:The design speed of roadway
4.	DIV	:Code for divided or undivided (1: divided, 2: undivided, 3: others or not known
5.	TER	:Terrain codes (1: level/flat, 2: rolling, 3: mountainous, 4: others or unknown)
6.	CSS:	Highway class codes (1: class I, 2: class II, 3: class III, 4: class IV, 5: interstate)
7.	LIM	:The posted speed limit
8	AVSPD	:The average speed observed in the location
9.	SPVAR	:The speed variance
10.	SKEW	.Skewness of speed distribution
11.	KURT	.Kurtosis of speed distribution
12.	ACCR	:Accident rate for the year
13.	PROP	.Damaged property in the year
14.	FAT	:Number of fatal accidents
15.	INJ	.Number of injury accidents

16. DAM :Damage only accidents

17. TACC :Total number of accidents

18. AUTO :Average daily passenger cars

19. SUT :Average daily single-unit trucks

20. TRKS :Average daily large trucks

21. ADT :Average daily traffic

CAT	STAT	DES	CIV	TER	CSS	LIM	AVSPC	SPVAR	SKEW	KURT	ACCR	PROP	FAT	INJ	DAM	TACC	AUTO	SUT	TRKS	ACT
1	2235	70	1	2	5	55	55.62	37.07	-0.114E+08	0.602E+09	94.0	87385	1	24	27	52	41550	8690	3150	53390
1	1315	65	1	2	5	55	57.54	65.37	-0.208E+08	0.136E+10	96.0	160500	0	10	23	33	14800	2765	3850	21415
1	1375	70	1	1	5	55	49.93	96.29	-0.381E+08	0.181E+10	130.0	146216	0	38	32	70	51200	8930	1050	61180
1	2393	70	1	1	5	55	56.93	32.22	-0.126E+08	0.602E+09	127.0	1165999	0	18	18	36	40400	13430	3200	57030
1	2461	70	1	2	5	55	60.32	46.85	-0.137E+08	0.172E+10	42.0	162600	1	23	30	54	83200	21190	7000	111390
2	1191	50	1	3	1	55	54.03	69.67	-0.810E+06	0.110E+09	76.0	49075	1	17	4	22	5650	2255	350	8255
2	1283	65	1	2	1	55	53.96	39.04	-0.519E+07	0.322E+09	141.0	1076349	0	22	22	44	42240	8360	1000	51600
3	1303	70	1	2	1	55	52.42	43.82	-0.209E+07	0.109E+09	31.0	1100	0	0	1	1	14170	3700	260	18130
3	1487	60	1	2	2	55	53.49	38.78	-0.358E+07	0.276E+09	234.0	721575	1	101	220	322	36600	7560	430	44590
4	2225	60	1	3	5	55	56.85	40.40	-0.118E+06	0.107E+09	91.0	32250	1	4	3	8	7750	2435	1600	11585
4	1363	70	1	2	5	55	61.69	76.58	-0.225E+07	0.103E+10	48.0	9400	0	2	6	8	22350	5445	2100	29895
4	2455	70	3	2	5	55	56.78	30.70	-0.566E+07	0.365E+09	48.0	68790	0	5	21	26	45000	9840	6100	60940
4	2497	70	1	2	5	55	59.42	37.18	-0.370E+06	0.129E+09	13.0	2800	0	0	2	2	10100	2665	1500	14265
4	1167	70	1	2	5	55	57.26	36.31	-0.526E+06	0.665E+08	33.0	17450	0	4	5	9	9600	1290	1050	11940
4	2571	70	3	4	5	55	61.68	45.65	-0.146E+07	0.294E+09	44.0	88820	0	5	8	13	9700	2530	5200	17430
4	2597	70	1	2	5	55	58.53	38.24	0.136E+06	0.131E+08	62.0	26050	0	4	4	8	3180	925	660	4765
5	1185	50	3	3	4	55	44.09	57.15	-0.259E+06	0.172E+08	338.0	33570	0	10	6	16	1480	970	10	2460

5	2293	70	1	2	1	55	57.69	99.30	-0.222E+07	0.130E+09	210.0	16470	0	2	8	10	4270	1155	1200	6625
5	2381	70	3	1	1	55	52.39	48.27	-0.269E+0.	0.158E+09	51.0	2200	0	0	1	1	9500	2565	830	12895
5	1115	60	1	2	1	55	55.44	59.83	-0.104E+07	0.737E+08	96.0	35700	1	7	7	15	5640	975	330	6855
5	1515	65	2	2	1	55	50.63	41.04	-0.175E+06	0.907E+07	96.0	8360	0	1	6	7	2660	1120	180	3960
5	2585	60	3	2	1	55	45.77	54.52	-0.248E+05	0.951E+07	136.0	10300	0	4	2	6	1190	385	40	1615
5	2043	60	1	2	1	55	43.79	59.54	-0.107E+07	0.125E+09	83.0	14300	0	3	4	7	8910	1900	1100	11910
5	2025	65	3	4	6	55	54.99	37.74	-0.166E+05	0.598E+07	206.0	58900	0	7	16	23	2115	755	55	2925
5	2067	60	2	2	3	55	60.83	57.85	-0.247E+06	0.382E+08	108.0	6600	0	2	4	6	2300	1005	65	3370
5	1031	60	1	2	[illegible]	55	41.24	147.94	-0.200E+08	0.783E+09	132.0	119005	0	19	32	51	11720	3790	1300	16810
6	2173	55	3	1	6	55	40.37	44.14	-0.945E+05	0.519E+07	109.0	9040	1	2	4	7	1105	585	20	1710
6	1273	40	3	3	2	55	47.83	85.39	-0.817E+05	0.451E+07	126.0	3375	0	2	3	5	655	340	20	1015
6	2131	60	3	1	4	55	32.38	61.11	-0.156E+06	0.506E+07	103.0	15200	0	2	9	11	860	333	2	1195
6	2355	60	1	2	1	55	50.17	49.10	-0.160E+06	0.101E+08	267.0	19150	0	4	9	13	1970	1130	195	3295
6	2507	50	3	2	6	55	47.92	88.35	-0.469E+06	0.237E+08	66.0	6650	0	0	4	4	8350	2635	1300	12285
6	1565	50	3	2	3	55	45.92	95.50	-0.439E+06	0.194E+08	565.0	7380	0	4	5	9	290	148	2	440

APPENDIX - C

The results of Oneway ANOVAs on traffic characteristics and accident characteristics are shown here. These pages are the computer printouts obtained during the analysis.

```
C12 : TOTAL ACCIDNENT RATE
C1  : HIGHWAY CATEGORY

MTB > oneway in c12 vs c1

ANALYSIS OF VARIANCE ON C12
SOURCE     DF        SS        MS        F
C1          5    496162     99232     8.22
ERROR     119   1436369     12070
TOTAL     124   1932532
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV   ---------+---------+---------+-------
    1      21      68.3      33.6     (-----*-----)
    2       8      96.7      30.4     (---------*---------)
    3       8     204.5      87.0                  (---------*---------)
    4      24      52.0      24.7   (-----*-----)
    5      40     140.9      60.3               (----*---)
    6      24     224.1     228.3                      (-----*-----)
                                    ---------+---------+---------+-------
POOLED STDEV =    109.9                   75       150       225
--------------------------------------------------------------------------

C9 : SPEED VARIANCE
C3 : DESIGN SPEED

MTB > onway in c9 vs c3

ANALYSIS OF VARIANCE ON C9
SOURCE     DF        SS        MS        F
C3          5      9436      1887     2.42
ERROR     119     92787       780
TOTAL     124    102223
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV   -------+---------+---------+---------
   40       4     86.57      3.28               (--------*--------)
   50      15     72.83     18.39               (---*----)
   55       2     48.32      5.92   (------------*------------)
   60      38     65.64     31.23              (--*--)
   65      18     50.29     16.30          (----*----)
   70      48     55.36     31.75             (-*--)
                                    -------+---------+---------+---------
POOLED STDEV =    27.92                 30        60        90
--------------------------------------------------------------------------

C9 : SPEED VARIANCE
C1 : HIGHWAY CODES

MTB > oneway in c9 vs c1

ANALYSIS OF VARIANCE ON C9
SOURCE     DF        SS        MS        F
C1          5     19535      3907     5.62
ERROR     119     82688       695
TOTAL     124    102223
```

```
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL       N      MEAN      STDEV     --+---------+---------+---------+----
    1      21     73.68      38.79                           (------*------)
    2       8     50.02      11.07       (----------*----------)
    3       8     48.37      11.48      (----------*----------)
    4      24     41.01      16.17      (-----*-----)
    5      40     62.23      30.72                     (----*----)
    6      24     74.35      18.63                           (-----*------)
                                       --+---------+---------+---------+----
POOLED STDEV =    26.36                 32        48        64        80
-----------------------------------------------------------------------------

C12 : TOTAL ACCIDENT RATE
C3  : DESIGN SPEED

MTB > oneway in c12 vs c3

ANALYSIS OF VARIANCE ON C12
SOURCE      DF        SS        MS          F
C3           5    342498     68500       5.13
ERROR      119   1590033     13362
TOTAL      124   1932532
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
LEVEL       N      MEAN      STDEV     ---+---------+---------+---------+---
   40       4     115.5       25.4       (----------*----------)
   50      15     241.1      276.3                        (-----*-----)
   55       2     134.0       35.4     (---------------*---------------)
   60      38     152.3       95.5                   (--*---)
   65      18     128.0       53.3              (-----*-----)
   70      48      76.4       52.9          (---*--)
                                       ---+---------+---------+---------+---
POOLED STDEV =    115.6                    0       100       200       300
-----------------------------------------------------------------------------

C9 : AVERAGE SPEED
C1 : YEAR

MTB > oneway in c9  vs c1

ANALYSIS OF VARIANCE ON C9
SOURCE      DF        SS        MS          F
C1           3      24.6       8.2       0.22
ERROR      121    4524.7      37.4
TOTAL      124    4549.4
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
LEVEL       N      MEAN      STDEV     ---------+---------+---------+------
   83      30    51.970      5.827      (-------------*-------------)
   84      33    52.152      5.918        (------------*-------------)
   85      32    52.559      6.912          (------------*-------------)
   86      30    53.143      5.689             (-------------*-------------)
                                       ---------+---------+---------+------
POOLED STDEV =    6.115                        51.2      52.8      54.4
-----------------------------------------------------------------------------
C10 : SPEED VARIANCE
C1  : YEAR
```

```
MTB > oneway in c10 vs c1

ANALYSIS OF VARIANCE ON C10
SOURCE      DF         SS          MS          F
C1           3       1611         537       0.65
ERROR      121     100611         831
TOTAL      124     102223
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL        N       MEAN       STDEV     --+---------+---------+---------+----
   83       30      60.76       33.19          (-------------*-------------)
   84       33      66.36       30.70                  (-----------*-----------)
   85       32      58.15       25.79       (------------*------------)
   86       30      57.30       24.83      (------------*------------)
                                          --+---------+---------+---------+----
POOLED STDEV =      28.84                  48.0      56.0      64.0      72.0
---------------------------------------------------------------------------
C13 : TOTAL ACCIDENT RATE
C1  : YEAR

MTB > oneway in c13 vs c1

ANALYSIS OF VARIANCE ON C13
SOURCE      DF         SS          MS          F
C1           3      49291       16430       1.06
ERROR      121    1883241       15564
TOTAL      124    1932532
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL        N       MEAN       STDEV     ----+---------+---------+---------+--
   83       30      109.3        68.9     (-----------*-----------)
   84       33      119.5        96.1        (-----------*-----------)
   85       32      125.1       108.2         (-----------*-----------)
   86       30      162.8       193.6                  (------------*-----------)
                                          ----+---------+---------+---------+--
POOLED STDEV =      124.8                     80       120       160       200
----------------------------------------------------------------------------

C8 : TOTAL ACCIDENT RATE
C4 : AVERAGE SPEED

MTB > oneway aov in c8 vs c4

ANALYSIS OF VARIANCE ON C8
SOURCE      DF         SS          MS          F
C4           8     181103       22638       4.46
ERROR      110     557785        5071
TOTAL      118     738888
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL        N       MEAN       STDEV     --+---------+---------+---------+----
   41        5     227.80      130.62                                (----*----)
   44        7     138.43      102.01                         (----*----)
   47       12     114.33       70.25                        (---*---)
   50       19     127.89       83.83                          (--*--)
   53       28     138.57       77.20                           (--*--)
   56       28     100.00       54.05                        (-*--)
```

```
    57          1        0.00        0.00    (------------*-----------)
    59         17       52.71       20.16                    (-*--)
    62          2       46.00        2.83             (-------*-------)
                                             --+---------+---------+---------+----
POOLED STDEV =      71.21             -120          0       120       240
-----------------------------------------------------------------------------

C12 : TOTAL ACCIDENT RATE
C9  : SPEED VARIANCE

MTB > oneway aov in c12 vs c9

ANALYSIS OF VARIANCE ON C12
SOURCE      DF         SS         MS         F
C9          12     431657      35971      2.35
ERROR      112    1714355      15307
TOTAL      124    1932532
                                          INDIVIDUAL 95 PCT CI'S FOR MEAN
                                          BASED ON POOLED STDEV
LEVEL        N       MEAN      STDEV    --+---------+---------+---------+----
   25        5       42.8       27.2             (----*-----)
   35       25      103.0       64.1                   (-*--)
   45       28      122.9       80.0                    (-*-)
   55       22      153.5       86.3                     (--*-)
   65       14      124.5       83.4                   (--*---)
   75        2       43.0        7.1         (--------*--------)
   85       11      231.5      309.9                        (---*--)
   95       10      135.3      160.6                   (---*---)
  125        4       98.5       15.6               (-----*-----)
  135        1      125.0        0.0          (------------*------------)
  145        1      132.0        0.0          (------------*------------)
  155        1      110.0        0.0         (------------*------------)
  175        1        8.0        0.0    (------------*------------)
                                        --+---------+---------+---------+----
POOLED STDEV =      123.7              -200          0        200       400
-----------------------------------------------------------------------------

C5 : SPEED VARIANCE
C4 : AVERAGE SPEED

MTB > oneway aov in c5 vs c4

ANALYSIS OF VARIANCE ON C5
SOURCE      DF         SS         MS         F
C4           8      34029       4254      7.04
ERROR      110      66459        604
TOTAL      118     100488
                                          INDIVIDUAL 95 PCT CI'S FOR MEAN
                                          BASED ON POOLED STDEV
LEVEL        N       MEAN      STDEV    -----+---------+---------+---------+-
   41        5      73.53      44.53                      (----*-----)
   44        7      65.17      16.17                     (---*----)
   47       12      88.33      34.85                            (--*---)
   50       19      85.12      37.90                           (--*--)
   53       28      49.43      13.47                   (-*--)
   56       28      49.65      17.69                   (-*--)
   57        1      29.38       0.00    (------------*------------)
   59       17      44.20      15.65                 (--*--)
```

```
   62         2      61.11      21.87                    (-------*--------)
                                              -----+---------+---------+---------+-
POOLED STDEV =     24.58                          0        40        80       120
-----------------------------------------------------------------------------------

C8  : AVERAGE SPEED
C3  : DESIGN SPEED

MTB > oneway in c8 vs c3

ANALYSIS OF VARIANCE ON C8
SOURCE      DF          SS         MS         F
C3           5      1655.3      331.1     13.61
ERROR      119      2894.1       24.3
TOTAL      124      4549.4
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL        N        MEAN      STDEV      ------+---------+---------+---------+
   40        4      47.410      2.482                   (-----*------)
   50       15      49.223      2.882                        (---*--)
   55        2      40.505      0.191       (--------*--------)
   60       38      49.310      7.499                          (-*-)
   65       18      54.136      2.755                               (--*--)
   70       48      56.231      3.419                                   (-*-)
                                           ------+---------+---------+---------+
POOLED STDEV =     4.932                       37.5      45.0      52.5      60.0
-----------------------------------------------------------------------------------

C8  : AVERAGE SPEED
C1  : HIGHWAY CATEGORY

MTB > onewaY IN C8 VS C1

ANALYSIS OF VARIANCE ON C8
SOURCE      DF          SS         MS         F
C1           5      2131.5      426.3     20.98
ERROR      119      2417.8       20.3
TOTAL      124      4549.4
                                           INDIVIDUAL 95 PCT CI'S FOR MEAN
                                           BASED ON POOLED STDEV
LEVEL        N        MEAN      STDEV      ----+---------+---------+---------+--
    1       21      55.723      3.833                            (--*---)
    2        8      52.797      1.940                   (-----*-----)
    3        8      53.739      1.246                     (-----*------)
    4       24      57.411      2.857                                (---*--)
    5       40      51.820      4.725                     (--*-)
    6       24      45.131      6.687       (--*---)
                                           ----+---------+---------+---------+--
POOLED STDEV =     4.508                      45.0      50.0      55.0      60.0

MTB > stop
*** Minitab Release 5.1 *** Minitab, Inc. ***
Storage available 260144  Storage used 30767
```

APPENDIX - D

This shows the results of regression analyses, performed during model development. The printouts are as obtained through the interactive execution on MINITAB. Each analysis shows the equation, R-square, and the t-ratios for the parameters.

REGRESSION STATISTICS FOR MODEL OF AVERAGE SPEED AND DESIGN SPEED

MTB > regress c2 1 c3

The regression equation is
C2 = 42.5 + 0.00259 C3

Predictor	Coef	Stdev	t-ratio
Constant	42.537	2.305	18.46
C3	0.0025915	0.0006461	4.01

s = 1.711 R-sq = 84.3% R-sq(adj) = 79.0%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	47.107	47.107
Error	3	8.784	2.928
Total	4	55.891	

REGRESSION STATISTICS FOR MODEL OF SPEED VARIANCE AND AVERAGE SPEED

C5 = - 16.7 + 204803 C22

Predictor	Coef	Stdev	t-ratio
Constant	-16.654	7.978	-2.09
C22	204803	23054	8.88

s = 3.565 R-sq = 94.0% R-sq(adj) = 92.9%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	1002.8	1002.8
Error	5	63.5	12.7
Total	6	1066.4	

REGRESSION STATISTICS FOR MODEL OF SPEED VARIANCE AND (DES - SP LIMIT)

```
MTB > let c11 = c10 -10  (subtract 10 from x , the
      difference between design speed and the speed limit)


MTB > let c12=c11**2   ........ square the (x-10)

MTB > regress c5 vs c12

The regression equation is
C5 = 57.0 + 0.0499 C12

Predictor        Coef          Stdev     t-ratio
Constant        57.017         3.674       15.52
C12            0.04994       0.01235        4.04

s = 6.540       R-sq = 84.5%     R-sq(adj) = 79.3%

Analysis of Variance

SOURCE       DF          SS            MS
Regression    1      699.49        699.49
Error         3      128.32         42.77
Total         4      827.81
```

REGRESSION STATISTICS FOR MODEL OF ACCIDENT RATES AND AVERAGE SPEED

```
MTB > regress c2 1 c1

The regression equation is
C2 = 433 - 6.13 C1

Predictor        Coef          Stdev     t-ratio
Constant       432.67          53.45        8.10
C1             -6.134          1.019       -6.02

s = 19.81       R-sq = 85.8%     R-sq(adj) = 83.4%

Analysis of Variance

SOURCE       DF          SS            MS
Regression    1       14224         14224
Error         6        2355           392
Total         7       16578
```

D - 3

REGRESSION STATISTICS FOR MODELS OF ACCIDENT RATES AND SPEED VARIANCE

INTERSTATE

```
MTB > let c30=C30**2
MTB > regress c35 1 c32

The regression equation is
C35 = 46.9 + 0.00316 C32

Predictor        Coef          Stdev     t-ratio
Constant       46.862          5.350        8.76
C32         0.0031631      0.0007390        4.28

s = 15.17        R-sq = 58.5%     R-sq(adj) = 55.3%

Analysis of Variance

SOURCE         DF          SS          MS
Regression      1      4217.2      4217.2
Error          13      2992.7       230.2
Total          14      7209.9
```

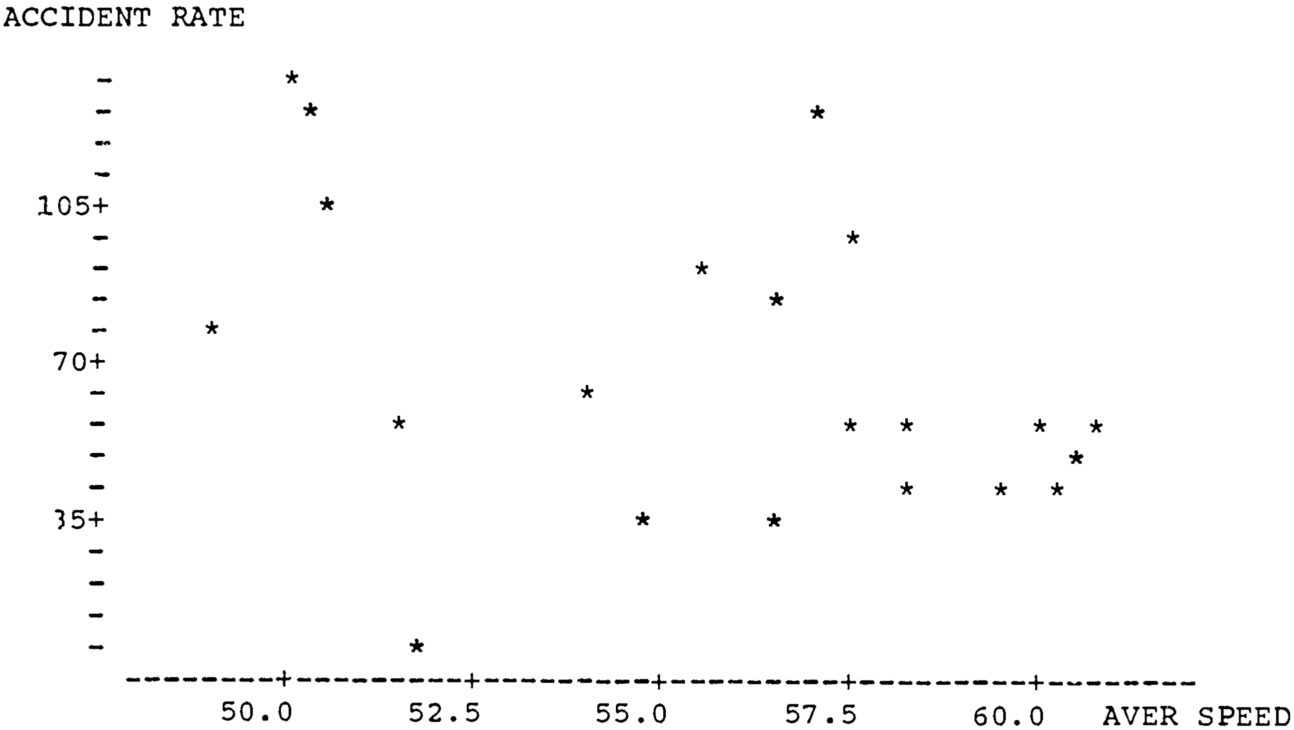
ARTERIALS

```
MTB > let c32=c30**2
MTB > regress c35 1 c32

The regression equation is
C35 = 168 + 0.00273 C32

Predictor        Coef          Stdev     t-ratio
Constant      168.123          6.883       24.43
C32         0.0027316      0.0005245        5.21

s = 12.56        R-sq = 81.9%     R-sq(adj) = 78.9%

Analysis of Variance

SOURCE         DF          SS          MS
Regression      1      4278.8      4278.8
Error           6       946.6       157.8
Total           7      5225.4
```

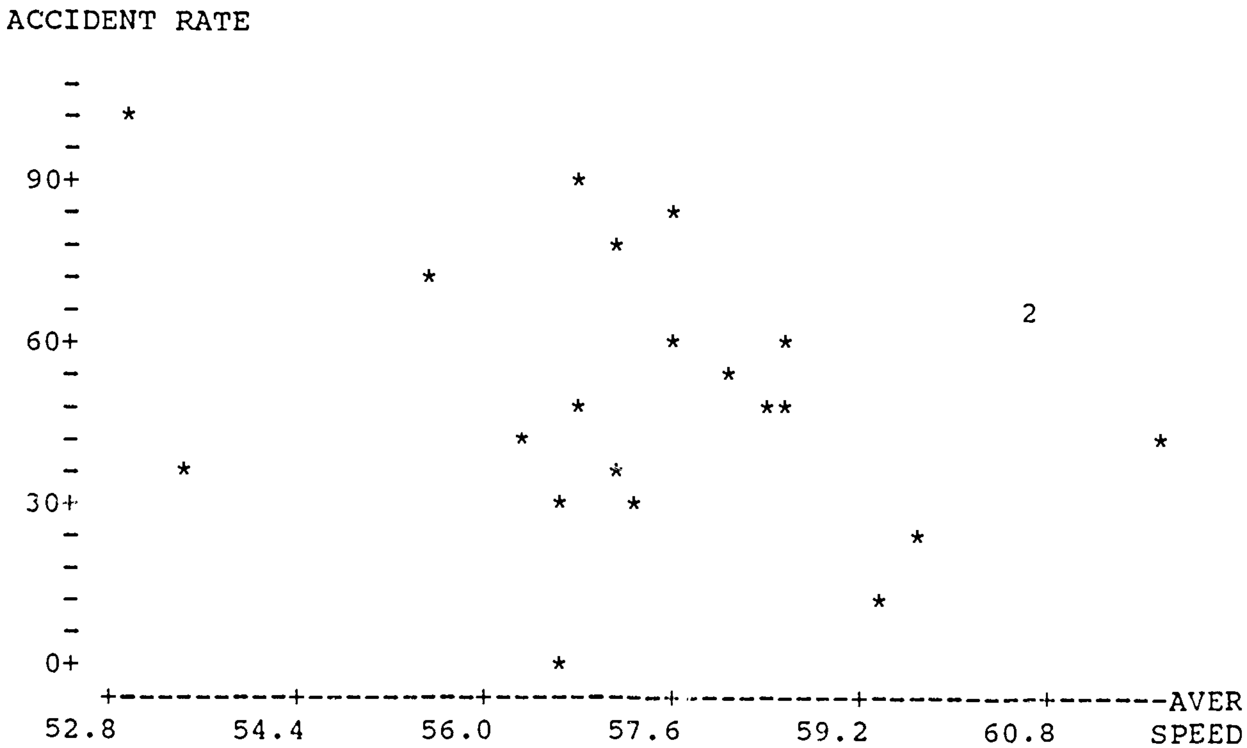
APPENDIX - E

The plots of accident rate vs. average speed for various kinds of highways are shown. No significant or obvious relationship could be found.

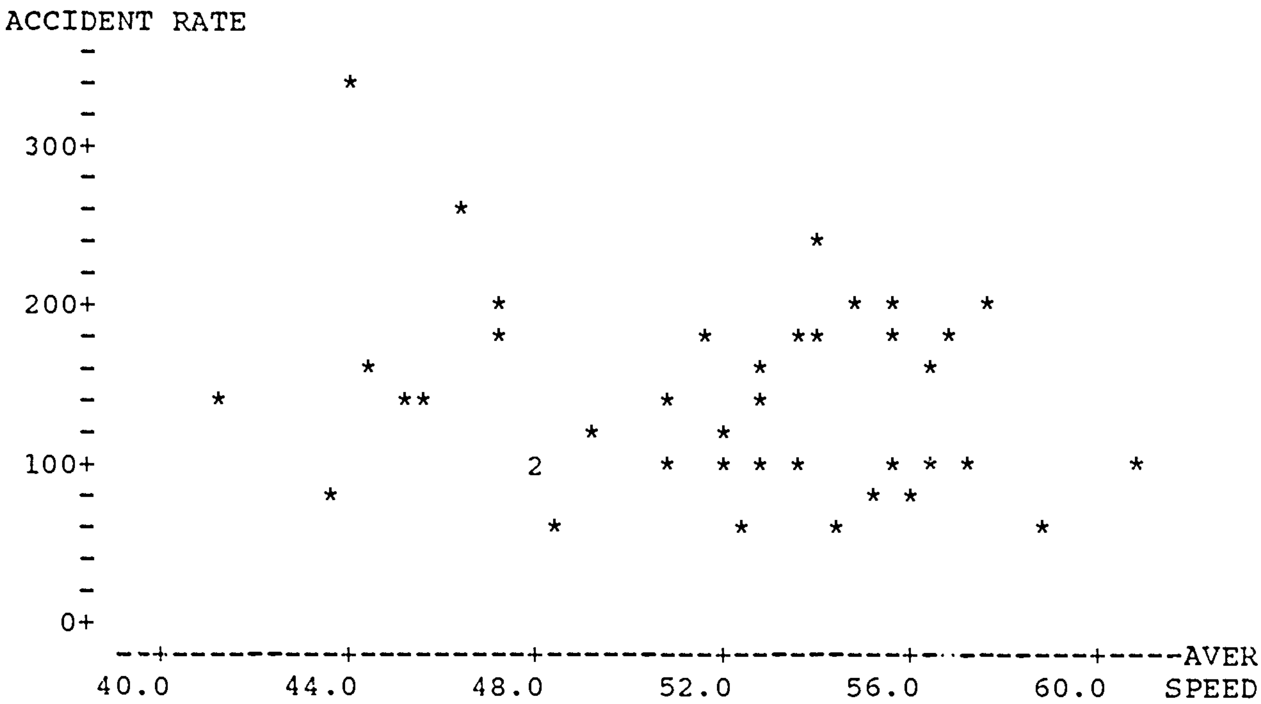
URBAN INTERSTATE



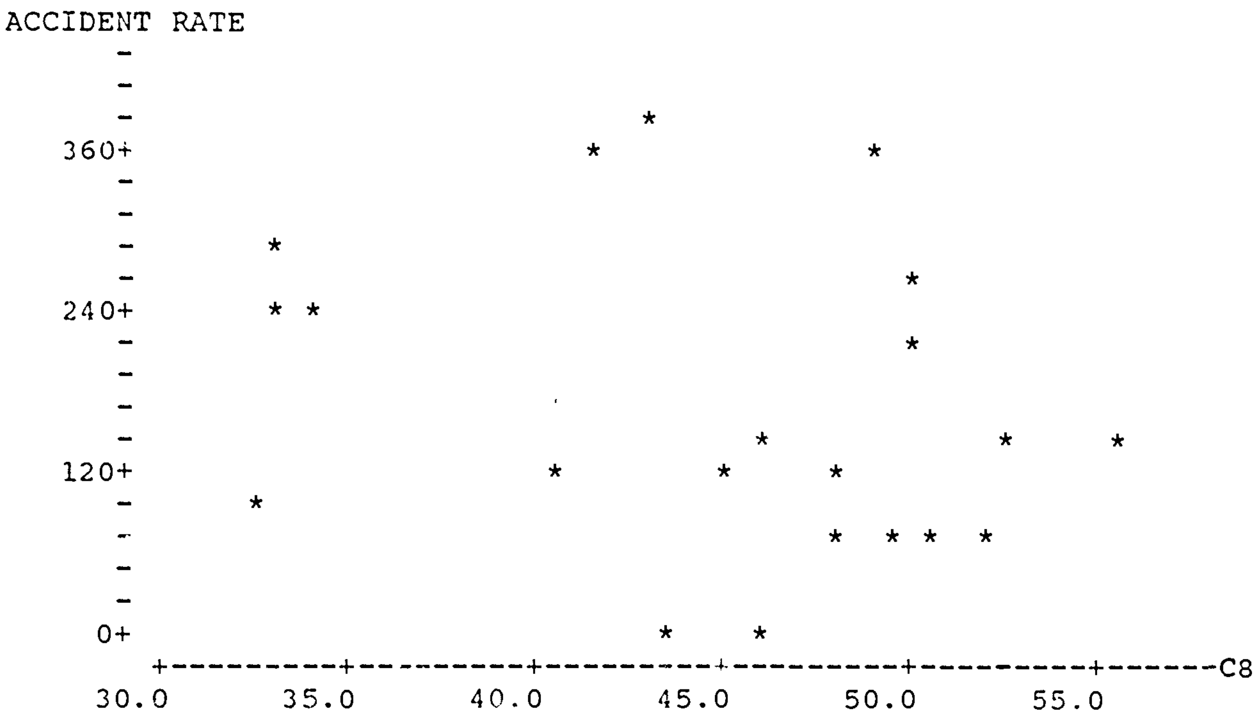
RURAL INTERSTATE



RURAL ARTERIALS



RURAL MAJOR COLLECTORS



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