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Accident Characteristics at Construction and Maintenance Zones in Urban Areas

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Abstract

Work zone safety is currently a major concern to transportation and highway engineers because of the relatively higher rates of accidents in these areas. There is a strong indication that during the next decade, emphasis will be placed on maintenance and rehabilitation of the nation's highways rather than on the construction of new highways. This will result in many more work zones. Unless effective measures are taken to increase safety in these work zones, a significant increase in accident rates will occur. This national phenomenon is also currently being observed in Virginia, where data have indicated that total and fatal accidents are over-represented in urban work zones. A clear understanding of work zone accident characteristics and traffic control devices is however needed to facilitate the development of effective guidelines that will significantly improve safety at urban work zones. Therefore, the Virginia Transportation Research Council undertook a study to determine accident characteristics at urban work zones and to evaluate the effectiveness of traffic control devices in reducing accident rates. All of the sites considered were within urban areas and have no access control; average speeds were between 25 and 48 mph. The traffic control devices evaluated do not include warning signs placed some distance ahead to inform motorists of the approaching work zones.

The results indicate that the major influencing factor on accident rates during the construction period on urban multilane highways is the accident rate just prior to the construction period. Also, the use of appropriate traffic control devices has a positive effect on safety in urban work zones, but the effectiveness depends on the type of traffic control used. The results also show that the most effective combination on multilane highways consists of flashing arrows, a flagger, and cones. On two-lane highways, flagmen and either cones, barricades, or static signs are most effective. Any combination not including flagmen, is less effective on two-lane highways than one including flagmen.

FINAL REPORT

ACCIDENT CHARACTERISTICS AT CONSTRUCTION AND MAINTENANCE ZONES IN URBAN AREAS

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and

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

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ABSTRACT

Work zone safety is currently a major concern to transportation and highway engineers because of the relatively higher rates of accidents in these areas. There is a strong indication that during the next decade, emphasis will be placed on maintenance and rehabilitation of the nation's highways rather than on the construction of new highways. This will result in many more work zones. Unless effective measures are taken to increase safety in these work zones, a significant increase in accident rates will occur. This national phenomenon is also currently being observed in Virginia, where data have indicated that total and fatal accidents are over-represented in urban work zones. A clear understanding of work zone accident characteristics and traffic control devices is however needed to facilitate the development of effective guidelines that will significantly improve safety at urban work zones. Therefore, the Virginia Transportation Research Council undertook a study to determine accident characteristics at urban work zones and to evaluate the effectiveness of traffic control devices in reducing accident rates. All of the sites considered were within urban areas and have no access control; average speeds were between 25 and 48 mph. The traffic control devices evaluated do not include warning signs placed some distance ahead to inform motorists of the approaching work zones.

The results indicate that the major influencing factor on accident rates during the construction period on urban multilane highways is the accident rate just prior to the construction period. Also, the use of appropriate traffic control devices has a positive effect on safety in urban work zones, but the effectiveness depends on the type of traffic control used. The results also show that the most effective combination on multilane highways consists of flashing arrows, a flagger, and cones. On two-lane highways, flaggers and either cones, barricades, or static signs are most effective. Any combination not including flaggers, is less effective on two-lane highways than one including flaggers.

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INTRODUCTION

One of the major concerns of professionals in the area of highway safety is the safety of urban highway users and workers in work zones. This is because the combination of heavy traffic volumes in urban work zones and the disruptive nature of work zone activities, usually results in a significant increase in accident rates. This issue is getting more important because of the proliferation of work zones on the nation's highways as greater emphasis is placed on maintenance and rehabilitation work rather than on new construction. The problem is further compounded by increasing traffic volumes, especially in urban areas. An analysis of reported work zone accidents in Virginia for example, indicated that total accidents and fatal accidents are over-represented in urban work zones (1). The proliferation of work zones will therefore result in a significant increase in accident rates unless some measures are taken to increase safety in these areas. However, a clear understanding of work zone accident characteristics and the effect of diffferent control device is needed before appropriate measures can be developed. The Research Council therefore undertook a study to determine accident characteristics at urban work zones and to evaluate the effectiveness of traffic control devices in reducing accident rates.

PURPOSE AND SCOPE

The purpose of the study was to identify the accident and traffic characteristics that are prevalent in urban work zones in Virginia and to evaluate urban work zone traffic control devices commonly used in the Commonwealth. Emphasis was placed on determining to what extent accident rates increase during periods of work zone activities and to what extent the types of traffic control devices used influence the occurrence and type of accidents. The specific objectives of the study were

- o to analyze recent accident data for construction and maintenance zones in urban areas of Virginia
- o to identify traffic characteristics that have significant impact on these accidents
- o to evaluate traffic control devices commonly used in urban work zones in Virginia
- o to develop guidelines for selecting devices for controlling traffic in urban work zones that will be effective in reducing accident rates.

METHODOLOGY AND RESEARCH APPROACH

The methodology for carrying out the project includes the following tasks:

- o literature review
- o compilation of historical accident data and types of traffic control devices used in urban work zones (study sites) where work has been completed
- o field collection of traffic and accident data in urban work zones (project sites) before and during project
- o analysis of accident data to determine significant characteristics
- o development of regression models relating accident rates before and during project with control devices used
- o development of guidelines for selecting suitable devices for controlling traffic in urban work zones.

Literature Review

A review of the literature was carried out to identify results and recommendations from recent studies similar to this project. The review was conducted through the facilities of The University of Virginia and the Virginia Transportation Research Council. Also, contacts were made and information was obtained from the Texas Transportation Institute and the Federal Highway Administration. Federal standards and guidelines (2) were reviewed so that adequate cognizance would be taken of them in developing the guidelines given in this report.

The literature review revealed that although a significant amount of research has been undertaken on the effects of work zone activities on the operation of rural highways, much less has been done for urban highways. Research findings related to this project may however be generally classified under the following categories:

- traffic control devices
- work zone accidents
- traffic characteristics
- traffic conflicts.

Traffic Control Devices

The main traffic control devices usually associated with maintenance and rehabilitation work in urban areas are signs and channelization devices--such as cones, vertical panels, drums, barricades, pavement markings, and other delineators. Signs are mainly used to warn and alert drivers of speed reductions and hazards created by the construction and maintenance activities, whereas channelization devices are used to guide and direct traffic safely pass the hazards. Flagging is also an important traffic control device, particularly for obtaining speed reductions in urban areas. A major part of the research effort so far has been to determine the effectiveness of these devices with respect to driver compliance and traffic operation. Much less emphasis has been placed on determining the effectiveness of these devices in reducing the number of accidents in work zones. For example, a study conducted by Pain and others concluded that cones were easily detected from a long distance away, mainly because of their orange mass and triangular shape (3). Drums were also noted to be highly visible from long distances both at night and during the day. Laboratory test results also indicated that there was no distinct difference between Type I and Type II barricades in terms of detectibility.

Raised pavement markers are more frequently used at construction zones to improve traffic performance. A study carried out to evaluate the adequacy of temporary raised pavement markers concluded that an adequate day/night construction zone marker should have the following features (4):

- a streamlined profile
- microscopic cube corners, sealed prismatic air cells, cube corner reflectors, or multiple-glass lens reflectors,
- a balance between the reflector and casing area exposed to driver.

A study on work zone speed control measures concluded that passive control measures such as signing are not very effective in slowing drivers under normal conditions, whereas active measures--such as flagging, law enforcement (a stationery patrol car), changeable message signs (CMSs), and effective lane reduction--tend to be relatively more effective (5). The level of effectiveness, however, depends on the specific active measure used and the prevailing conditions. In selecting one or a combination of active measures, consideration should be given to the following interrelated factors (5):

- duration of potential hazard requiring speed control
- type of facility
- observed speed reduction
- overall cost of treatment
- instutional constraints (e.g. availability of CMSs, police officers, police cars, trained flaggers).

Work Zone Accidents

Analysis of Texas data has shown that a high percentage of work zone accidents occur during daylight hours in good weather and during the summer months. This suggests that accidents occur most frequently at work zones when work zone activities are in progress (6). Nighttime accidents at work zones tend to occur more often at taper areas, which emphasizes the need for adequate lighting and suitable channelization in these areas.

An analysis of the data for 2,127 reported work zone accidents in Virginia during 1977 indicated that these accidents represent about 1.5

percent of all reported accidents, and about 48 percent of these accidents occurred at sites with one or more lanes closed (1). Over 80 percent of these accidents occurred when the pavement surface was dry, and about 70 percent occurred during daylight hours during clear weather. These results tend to confirm that the majority of work zone accidents occur during work zone activities. The most common type of accident was the rear-end collision (35 percent of the total). This factor contributed to the relatively low severity of the work zone accidents.

Graham and others carried out a time-trend analysis of data on accidents at 79 work zones in 7 states and concluded that work zones resulted in an average increase of 1 to 6 accidents per month (7). The relative number of lanes closed has also been found to have a significant impact on accident rates at work zones. For example, six or eight-lane interstate highways reduced to one lane in each direction had increases in accident rates of over 100 percent, whereas those reduced to two lanes in each direction had increases of about 5 percent (7). Also, four-lane divided interstate highways reduced to two-lane, two-way operation had relative increases in accident rates that were twice that of those in which the roadway was simply reduced to one lane in each direction. Five-lane undivided highways with two-way left-turn lanes reduced to two-lanes during construction experienced the highest accident rate increase of all road types (7).

Studies conducted by McGee and Borodavkin have also shown that increases in accident rates at work zones also depend on the duration and length of the construction zone. Higher increases were observed at short work zones with short durations than at long work zones with long durations (8, 9).

Traffic Characteristics

Average speed and speed variances are two main characteristics of traffic flow that significantly affect accident rates and/or severity. It has been shown that one of the major problems at work zones is the large speed differential among vehicles, especially at work zones where speed limits have been considerably reduced from the normal speed limit (10). The posting of a speed limit much less than the normal speed limit usually does not result in most drivers reducing their speeds to the posted speed limit because drivers tend to drive at a speed that in their opinion is suitable for the prevailing conditions regardless of the posted speed limit (11).

Traffic Conflicts

A traffic conflict is generally defined as an event that involves the interaction of two or more vehicles in which one or more drivers take an evasive action to avoid a collision. Although traffic conflicts do not necessarily result in the occurrance of an accident, they are, however, symptomatic of the same factors that cause or contribute to accidents. In other words, an accident is simply a conflict where the preventative action was too little or too late. A traffic conflict analysis is therefore used in lieu of or in addition to accident data as an inexpensive but reliable tool to diagnose safety and operational deficiencies and permit evaluation of improvements within a short period. A recent study has shown that traffic conflicts of certain types are good surrogates of accidents in that they produce estimates of average accident rates nearly as accurate and just as precise as those produced from historical accident data (12).

Compilation of Historical Data on Accident and Traffic Control Devices Used

A survey of city, traffic, and resident engineers in Virginia was carried out to identify sites in urban areas at which rehabilitation or maintenance work had been undertaken from 1982 through 1985. The survey was conducted through a questionnaire, and information was sought on the length of the work zone, the type of traffic control devices used, the duration of the work activities, and the type of highway. Figure 1 shows the survey questionnaire used. Additional information was also obtained from traffic control plans when these were available.

The information obtained was then used to identify suitable sites for the study. Sites at which the duration of the work was fewer than 30 days were excluded, since it was felt that this duration was too short for any meaningful accident analysis of the periods before and during the work. Sites with low volumes (ADT< 3000) were also excluded since it was observed that the impact of work zone activities on the accident rate at these sites was minimal. Twenty six sites were selected. The locations and relevant characteristics of the study sites are shown in Table 1. At each of these sites, it was necessary to shift lanes and/or close a lane during the maintenance or rehabilitation work. In addition, twelve sites without work zones were selected to serve as control sites. These control sites were selected to represent the different traffic and geometric characteristics of the study sites. Their locations and relevant traffic characteristics are shown in Table 2.

The accident records were then examined to identify the accidents that occurred at the selected sites just prior to and during the period of the work. Accident data were then extracted for a period just prior to and approximately equal to the duration of the project. These were treated as the "before" data. Accident data for the duration of the

SURVEY QUESTIONNAIRE

(1) Name of City ______________________

(2) Location of Work Zone

(a) Street Name or Route No. ______________

(b) Name of Closest Intersection ____________

(c) Distance from Closest Intersection (Ramp) to start of Work Zone ______________________

(3) Length of Work Zone ____________________

(4) Work was done at night _____ / Day _____

(5) Work started on ____________ (Date) and was completed on ____________ (Date)

(6) Type of Highway (Please check one)

____ Multilane Divided Highway

____ Highway with four or more lanes without a raised median

____ Three-lane highway

____ Two-lane highway

(7) Briefly describe type of traffic control used.

Figure 1. Construction and maintenance zones in urban areas survey questionnaire.

Table 1

SITES AT WHICH HISTORICAL
DATA WERE OBTAINED (STUDY SITES)

CITY	SITE NUMBER	HIGHWAY TYPE*	ADT (DAYS) Before	ADT (DAYS) During	Project Duration (DAYS)	LENGTH (MILES)
ROANOKE	R1	2	21,620	21,620	352	0.58
	R2	2	18,700	21,620	678	0.51
	R3	2	29,760	30,710	51	3.10
	R4	2	47,040	49,860	105	6.35
RICHMOND	C1	1	10,780	10,780	1096	0.70
	C2	2	13,240	13,240	900	1.83
LYNCHBURG	L1	2	16,380	16,380	106	0.10
	L2	4	4,240	4,240	594	0.87
	L3	2	20,540	20,540	42	0.07
	L4	2	17,960	17,960	217	0.04
	L5	3	10,280	10,280	280	1.57
	L6	4	10,650	10,650	197	0.06
	L7	4	7,000	7,000	153	0.80
HAMPTON	H1	4	8,130	8,130	792	0.50
	H2	4	13,700	13,700	747	0.50
	H3	1	49,890	52,670	596	1.40
	H4	1	49,490	52,190	565	0.60
	H5	1	55,100	62,250	109	0.40
	H6	1	48,560	49,305	270	0.62
	H7	1	50,950	53,510	213	1.00
SOUTH BOSTON	B1	1	4,100	6,275	462	0.24
STAUNTON	S1	4	3,000	3,760	247	0.21
LEESBURG	E1	4	15,470	17,790	593	0.68
PORTSMOUTH	P1	1	25,070	22,610	365	0.31
NEWPORT NEWS	N1	1	28,240	29,940	443	1.00
NORFOLK	K1	1	58,290	58,290	201	1.20

*Highway Type
1 Multilane Divided Highway
2 Highway with Four or More Lanes without a Raised Median
3 Three-lane Highway
4 Two-lane Highway

Table 2

CONTROL SITES

CITY	SITE NUMBER	HIGHWAY TYPE*	AADT BEFORE	AADT DURING	LENGTH MILES
ROANOKE	R3C	2	49,090	51,060	3.10
HAMPTON	H3C	1	51,315	54,700	1.50
	H5C	1	52,020	58,770	2.00
	H6C	1	48,560	49,305	1.00
	H7C	1	48,950	60,730	1.30
SOUTH BOSTON	B1C	1	5,220	5,800	1.60
STANELY	S1C	4	4,040	4,520	1.10
	S1C2	4	3,000	3,760	1.40
LEESBURG	E1C	4	17,160	18,670	1.75
	E1C2	4	28,070	30,100	1.60
NEWPORT NEWS	N1C	1	28,240	29,940	1.50
NORFOLK	K1C	1	54,150	54,150	1.50

*Highway Type
1 Multilane Divided Highway
2 Highway with Four or More Lanes without a Raised Median
3 Three-lane Highway
4 Two-lane Highway

project were taken as the "during" data. Since work at these selected sites had been completed before the start of this project, it was not possible to obtain traffic data during the rehabilitation or maintenance work.

Collection of Traffic and Accident Data at Urban Work Zones Before and During the Project

The survey of city, traffic, and resident engineers also included a questionnaire that sought information on planned projects in urban areas.

The criteria used previously for selecting sites were again used to select sites at which traffic and accident data would be collected before and during the project. A total of seven sites were selected. These are called project sites in this report. The locations and relevant characteristics for these sites are shown in Table 3. Figures A1 through A10 of the Appendix show the layout of some of these sites.

Data on traffic characteristics such as traffic volumes, conflicts, speeds, and headways were then collected prior to the installation of the work zone ("before data") and during the progress of the work ("during data"). The Leupold Steven's Traffic Data Recorder (TDR) was used to collect data on traffic volumes, speeds, and headways for 24 hour intervals while traffic conflicts were manually recorded for 8 hour periods. In order to facilitate meaningful comparison, traffic data were collected during the same weekdays and time of the day for both the "before" and "during" data. A summary of the traffic data is shown in Table 4.

Data on conflicts were also collected prior to the installation of the work zone and during the project. Again, "before" and "during" data for any given site were collected on the same weekday and time of day to facilitate meaningful comparison. A summary of the conflict data is shown in Table 5.

Table 3

PROJECT SITES AT WHICH FIELD DATA WERE COLLECTED

CITY	SITE NUMBER	HIGHWAY TYPE*	AADT BEFORE	AADT DURING	LENGTH MILES
DANVILLE	TC1	2	18,220	18,220	0.29
	TC2	2	18,220	18,220	0.29
HAMPTON	TC3	4	12,360	13,080	2.16
HARRISONBURG	TC4	2	5,780	5,930	0.50
LYNCHBURG	TC5	3	3,500	3,525	0.97
	TC6	3	3,500	3,525	0.97
ROCKY MOUNT	TC7	2	11,640	11,640	0.39

*Highway Type
1 Multilane Divided Highway
2 Highway with Four or More Lanes without a Raised Median
3 Three-lane Highway
4 Two-lane Highway

Table 4

SUMMARY OF TRAFFIC DATA

SITE	BEFORE AVERAGE SPEED (mph)	BEFORE SPEED VARIANCE $(mph)^2$	BEFORE AVERAGE HEADWAY (ft)	DURING AVERAGE SPEED (mph)	DURING SPEED VARIANCE $(mph)^2$	DURING AVERAGE HEADWAY (ft)
TC1	41.93	30.47	597.5	30.11	48.72	291.3
TC2	46.60	27.77	574.5	41.47	30.03	471.9
TC3	36.90	35.40	423.7	39.40	45.16	429.6
TC4	30.35	41.35	517.9	25.12	36.68	430.5
TC5	30.83	27.04	290.4	25.55	27.29	297.1
TC6	29.91	44.89	296.5	20.09	36.85	360.90
TC7	26.40	28.11	384.0	26.40	39.31	381.1

Table 5

SUMMARY OF CONFLICT DATA AT PROJECT SITES

SITE	AVERAGE CONFLICTS/HOUR BEFORE	AVERAGE CONFLICTS/HOUR DURING
TC1	4.85	114.50
TC2	69.56	107.89
TC3	20.22	78.89
TC4	53.54	86.15
TC5	20.67	320.67
TC6	22.00	360.00
TC7	45.41	62.82

ANALYSIS AND RESULTS

The following subsections summarize the procedures and the results of the analysis conducted on the data compiled and collected.

Accident Characteristics

The data collected on accident characteristics were summarized to identify the effect (if any) of environmental factors on changes in accident rates and to determine to what extent work zone activities affected accident type. An analysis of the data was also carried out to determine whether significant changes occurred in the accident rate and the overall accident severity during the construction period when compared with similar characteristics for the period prior to the construction activities.

Environmental Factors

The distributions of "before" and "during" accidents with respect to surface condition, weather, and light conditions are shown in Figures 2, 3, and 4 respectively. These indicate that adverse environmental conditions had little or no effect on the occurrence of these accidents, since a significant majority occurred during daylight hours, or on dry pavement, or on clear days. In addition, the respective distributions for the "before" and "during" accidents are very similar. In general, about 65 percent of the accidents occurred on dry pavement, about 55 percent during the day, and about 50 percent during clear weather. These results suggest that most of the "during" accidents occurred during periods of work zone activities.

Accident Rates

The accident rates were computed for both the control sites and study sites using vehicle miles of travel (VMT) as the exposure data. The VMT at each site was estimated using the ADT at the site, the length of the work zone and the duration of the project. Tables 6 and 7 show the "before" and "during" accident rates at the study and control sites respectively. In order to determine whether there was a significant difference in accident rates between the study and control sites, it was necessary to use a nonparametric method that does not require the assumption of normally distributed random variables with equal variances as the distribution of accident rates at the sites may not be normal. The Wilcoxon Rank - Sum test was therefore selected for this analysis.

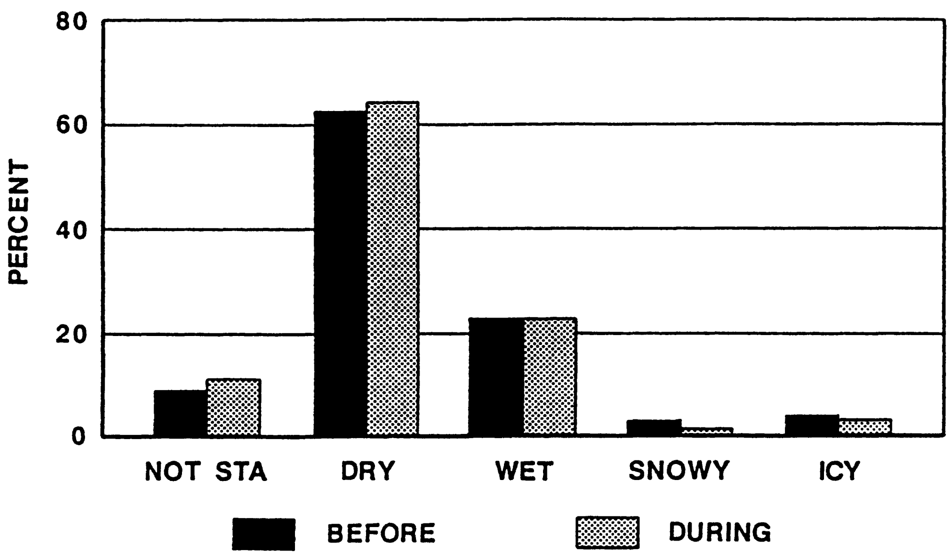

Fig. 2 Accident Frequency (Percent) by Surface Conditions

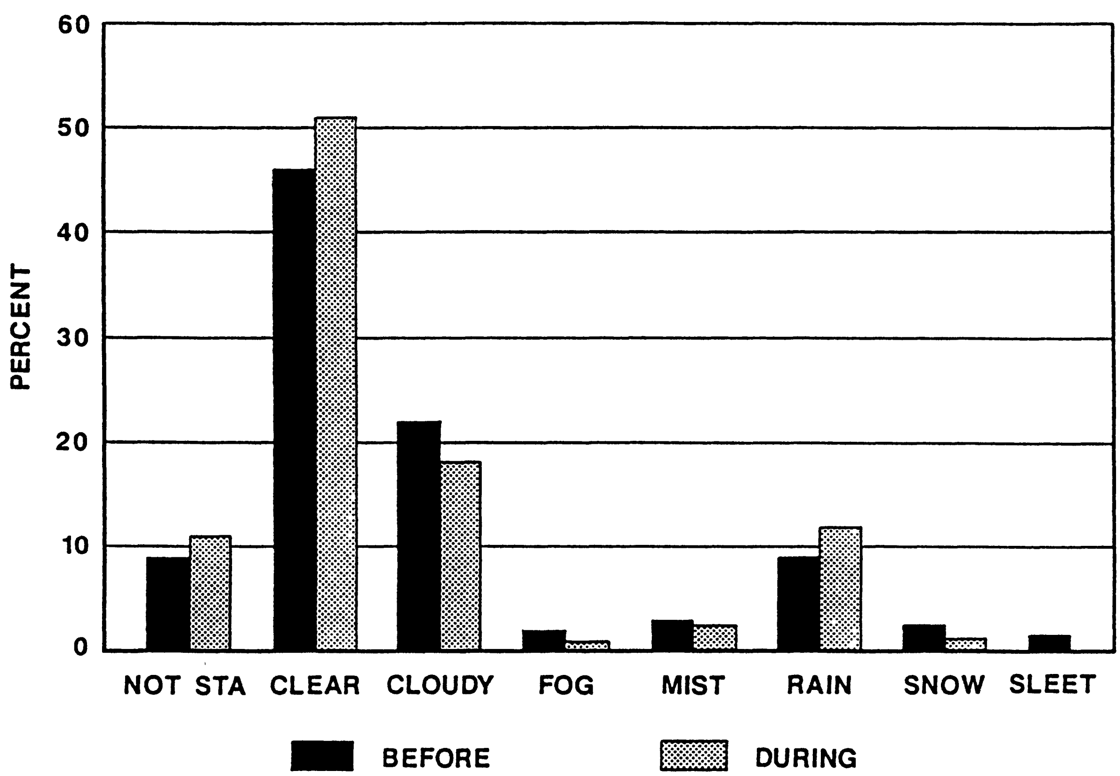

Fig. 3 Accident Frequency (Percent) by Weather Conditions

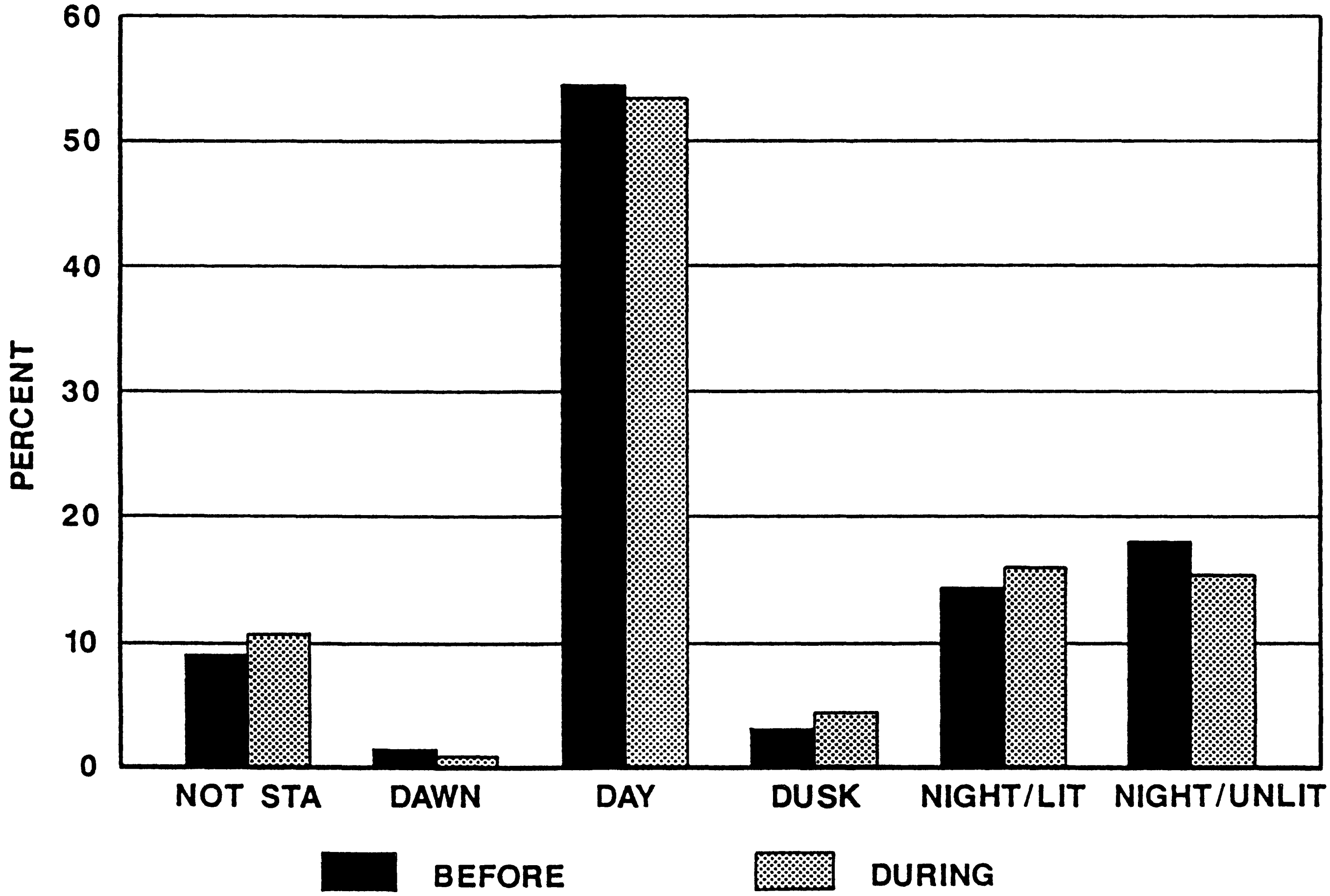

Fig. 4 Accident Frequency (Percent) by Light Conditions

Table 6

ACCIDENT RATES AT STUDY SITES

SITE	ACCIDENT RATE* BEFORE	DURING
R1	2.5246	4.0780
R2	2.5415	1.1583
R3	1.1768	1.4417
R4	0.7160	1.9252
C1	0.7983	0.3627
C2	3.4578	5.4113
L1	6.6153	11.5189
L2	1.7478	1.8255
L3	24.4993	33.1194
L4	29.0429	57.7320
L5	0.9835	1.1064
L6	6.7688	23.8317
L7	2.1099	5.8357
H1	0.0000	3.2430
H2	0.6134	0.1954
H3	1.4719	2.8215
H4	1.9493	2.6559
H5	2.4975	2.2107
H6	2.1761	2.1944
H7	2.8565	2.2919
B1	0.8491	2.8745
S1	2.6433	5.1482
E1	2.3765	3.4913
P1	2.8131	3.9097
N1	0.8607	0.7236
K1	0.4124	0.7824
Mean	4.0190	6.9957

*Number of accidents per million vehicle miles of travel

1540

Table 7

ACCIDENT RATES AT CONTROL SITES

SITE	ACCIDENT RATE* BEFORE	DURING
R3C	0.7415	1.1903
H3C	1.8037	2.0963
H5C	0.4409	0.4684
H6C	2.2013	2.6640
H7C	1.3280	1.3742
B1C	0.6678	1.4007
S1C	2.2504	2.4555
S1C2	2.2102	2.3167
E1C	0.8325	0.9446
E1C2	1.3519	1.4031
N1C	1.2295	1.1256
K1C	0.7103	0.6738
Mean	1.3140	1.5094

*Number of accidents per million vehicle miles of travel

In this test, a comparison was made between two populations in terms of their medians. The hypotheses used were:

$$H_o: M_x = M_y$$
$$H_1: M_x < M_y$$

where

M_x = the median of accident rates at the control sites

M_y = the median of accident rates at the study sites

The test statistic for this test is

$$W_W = \frac{W_m - E(W_m)}{\sqrt{Var\ W_m}}$$

where

W_m = the sum of ranks associated with the small sample

$E(W_m)$ = [m(m+n+1)/2]

$Var\ W_m = \sqrt{mn(m+n+1)/12}$

m,n = sample sizes

The test was carried out separately for the "before" and "during" data. Appendix B shows the analysis and results. The results indicate that although the null hypothesis cannot be rejected for the "before" accident rates at a 5 percent significance level, it can be rejected for the "during" accident rates. This means that at the 95 percent confidence level, it can be concluded that there is a significant difference in accident rates between the study and control sites for the "during" period, but this conclusion cannot be made for the "before" period. This suggests that the difference in accident rates between the study and control sites increased during the construction period, which implies a relatively greater increase in accident rates at the study sites during the construction period.

Accident Severity

The effect of work zone activities on accident severity was also tested using the Wilcoxon Rank-Sum test. The accident severity rate for a given period at a site was determined by multiplying the number of accidents in each severity category by a severity weighting factor for that category and dividing the sum by the vehicle miles of travel for the period being considered. The severity weighting factors used were 12 for fatal, 3 for injury, and 1 for property-damage-only accidents. Tables 8 and 9 show the accident severity rates obtained for the study and control sites respectively. The tests were then carried out for the study and control sites, and the results are shown in Appendix C. The results indicate that at the 5 percent significance level, there was no difference between the severity rates for the "before" and "during" periods at the study or the control sites. It can therefore be concluded that accident severity is not significantly affected by work zone activities.

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Table 8

ACCIDENT SEVERITY RATES AT STUDY SITES

SITE	SEVERITY RATE BEFORE	SEVERITY RATE DURING
R1	0.2822	0.5437
R2	0.3344	0.1390
R3	0.2105	0.1854
R4	0.1427	0.3369
C1	0.2395	0.0362
C2	0.5150	0.7887
L1	0.9450	2.3030
L2	0.1737	0.2738
L3	3.2660	3.3119
L4	3.7340	9.6220
L5	0.1437	0.1548
L6	0.6768	5.5607
L7	0.2493	0.8169
H1	0.0000	0.4169
H2	0.0613	0.0586
H3	0.2606	0.5565
H4	0.4224	0.6018
H5	0.5828	0.2948
H6	0.3321	0.2908
H7	0.4699	0.4055
B1	0.3399	0.8624
S1	0.5287	1.5445
E1	0.3056	0.7680
P1	0.6329	0.8599
N1	0.1352	0.1688
K1	0.0412	0.1351
Mean	0.3471	1.1937

Table 9

ACCIDENT SEVERITY RATES AT CONTROL SITES

SITE	SEVERITY RATE BEFORE	SEVERITY RATE DURING
R3C	0.1401	0.2478
H3C	0.3315	0.3998
H5C	0.0970	0.1093
H6C	0.4474	0.5108
H7C	0.2951	0.3585
B1C	0.2937	0.2332
S1C	0.4497	0.4088
S1C2	0.3767	0.2317
E1C	0.0833	0.1396
E1C2	0.2465	0.2666
N1C	0.3607	0.1608
K1C	0.1184	0.1531
Mean	0.2700	0.208

Collision Type

In order to test whether the existence of a work zone significantly affects the distribution of the accidents by collision type, a test statistic for comparing two proportions was used. The hypothesis is

$$H_o: P_1 = P_2$$

$$H_1: P_1 = P_2$$

The test statistic is given as:

$$P_\alpha = \frac{P_1 - P_2}{\sqrt{P(1-P)\ (1/_{n_1} + 1/_{n_2})}}$$

where

P_1 = the proportion of a specific type of accident during the period the work zone was installed

P_2 = the proportion of the same type of accident (as for P_1) before the work zone was installed

P = pooled estimates

$$= \frac{n_1 P_1 + n_2 P_2}{n_1 + n_2}$$

n_1 = number of accidents during the period the work zone was installed

n_2 = number of accidents before the work zone was installed

The test was performed on the data for each study site separately at a 5 percent significance level. The predominant types of collisions identified for both the "before" and "during" periods were rear end, angle, and side-swipe same direction. The results of the analysis indicate that there was no significant difference in the proportional distribution of the collision types at any of the sites. This suggests that the type of collision is not significantly affected by the installation of the work zone. (Details of the analysis are given in Appendix D).

Number of Vehicles Involved

Table 10 shows the percentage distribution of accidents by number of vehicles involved for both the "before" and "during" data. It can be seen that there is an increase in the two-vehicle accidents for the "during" period, which results in a higher proportion of multivehicle crashes. This suggests that one effect of installing work zones in urban areas is an increased interaction among vehicles in the traffic stream, which results in relatively higher multivehicle crashes. The implementation of measures to reduce this interaction among vehicles will therefore aid in reducing accident rates at work zones.

Alcohol Effect

The percentage distribution of alcohol-related accidents is shown in Table 11 for the "before" and "during" data. Hardly any difference exists between the two distributions. Approximately 12 percent of both the "before" and "during" accidents involved drivers who had been

Table 10

PERCENTAGE DISTRIBUTION OF ACCIDENTS BY NUMBER OF VEHICLES INVOLVED

Number of Vehicles Involved in Crash	Percentage Before Data	Percentage During** Data
1	17.30	11.63
2	69.10	77.21
3	12.20	10.70
>3	1.40	0.46

*Based on 215 accidents
**Based on 309 accidents

Table 11

PERCENTAGE DISTRIBUTION OF ACCIDENTS BY DRIVER ALCOHOL INTAKE

Alcohol Condition	Percentage Before Data*	Percentage During Data**
No drinking	88.54	87.25
Drunk	5.73	5.34
Impaired	2.87	1.47
Not impaired	2.86	5.39

*Based on 204 accidents
**Based on 338 accidents

drinking. This suggests that work zone installations in urban areas do not necessarily result in a relative increase in alcohol-related accidents. Countermeasures to reduce drinking and driving will therefore not necessarily significantly reduce the relative increase in accident rates at work zones since the effect of these countermeasures will most likely be the same for both periods.

Effects of Work Zone Length and Project Duration

The percentages of change in accident rates between the "before" and "during" periods are shown in Table 12 together with the corresponding project durations and work zone lengths. Logarithmic models relating the percentages of change in accident rate and the project durations and work zone lengths were then developed as follows:

- For all highways combined:

$$Dip = -10.346 + 4.05193\, Ln(DD) - 0.4249\, Ln(1/L) - 0.3748\, [Ln(DD)]^2 + 0.0423\, [Ln(1/L)]\, [Ln(DD)] + 0.1964\, [Ln(1/L)]^2 \qquad [1]$$

- For multilane divided highways:

$$Dip = -2.5140 + 1.09295\, Ln(DD) - 4.94988\, Ln(1/L) - 0.1086\, [Ln(DD)]^2 + 0.5384\, [Ln(1/L)]\, [Ln(DD)] + 2.1365\, [Ln\ 1/L]^2 \qquad [2]$$

- For highways with four or more lanes without raised medians

$$Dip = -15.4252 + 6.0880\, Ln(DD) + 1.0070\, Ln(1/L) - 0.5660\, (LnDD)^2 - 0.2873\, [Ln(1/L)]\, [Ln(DD)] + 0.1639\, [Ln(1/L)]^2 \qquad [3]$$

where

Dip = Percentage change in accident rates

$$= \frac{\text{"During" Accident Rate - "Before" Accident Rate} \times 100\%}{\text{"Before" Accident Rate}}$$

L = Length of Work Zone (miles)

DD = Project Duration (days)

Ln indicates log to base e

The R-square values obtained are 0.3753, 0.8167, and 0.9538 for equations [1], [2], and [3] respectively. These R-square values indicate a better fit when the relationships are developed separately for the different types of highways. No equation could be developed for the

Table 12

PROJECT DURATION, WORK ZONE LENGTH, AND PERCENTAGE INCREASE IN ACCIDENTS

Site	Highway Type	Project Duration (Day)	Work Zone Length	Percentage Change in Accident Rate
R1	2	352	0.58	61.53
R2	2	678	0.51	-51.43
R3	2	51	3.10	22.51
R4	2	105	6.35	168.88
C1	1	1096	0.70	-54.57
C2	2	900	1.83	56.50
L1	2	106	0.10	74.16
L2	4	594	0.87	4.45
L3	2	42	0.07	35.14
L4	2	217	0.04	98.78
L5	3	280	1.57	12.50
L6	4	197	0.06	252.08
L7	4	153	0.80	176.59
H1	4	792	0.50	
H2	4	747	0.50	-68.15
H3	1	596	1.40	91.69
H4	1	565	0.60	36.25
H5	1	109	0.40	-11.48
H6	1	270	0.62	0.84
H7	1	213	1.00	-19.77
B1	1	462	0.24	238.53
S1	4	247	0.21	94.76
E1	4	593	0.68	46.91
P1	1	365	1.31	38.98
N1	1	443	1.00	-15.93
K1	1	201	1.20	89.72

three-lane highway since there was only one three-lane study site. Also, the R-square value obtained for the equation for two-lane highways was very low and therefore not included.

Figure 5 shows representative plots for the different relationships developed. These generally indicate that in general for a given work zone length, the percentage difference in accident rates increases with increase in the duration of the project up to a maximum duration of 150 to 200 days. This suggests that in order to minimize the increase in accident rates at work zones, projects should be completed in the shortest possible time. Table 13 shows representative computed values for the percentage change in accident rates for different work zone lengths and project durations using equation [1]. These values show that for a given duration, percentage change in accident rate decreases with increase in work zone length for short zone lengths of up to about 0.6 mile. For work zone lengths greater than about 0.6 mile, however, percentage change in accident rate increases with an increase in length. This suggests that in order to minimize accident rates, urban work zones should be kept to a maximum of 0.6 miles.

Traffic Characteristics

The data collected on traffic volume, speeds, and headways at the project sites were analyzed to determine whether any of the characteristics of these variables were significantly affected by the installation of the work zones. The characteristics tested were, hourly volumes, average speed, speed variance, speed distribution, mean headway and headway distribution.

Hourly Volumes

A comparison of the hourly volumes before and during the installation of the work zone was carried out using ANOVA for each site at which traffic data were collected. The results obtained are shown in Table E1 of Appendix E. These results indicate that at a 5 percent significance level, there was no significant difference in traffic volumes before and during work zone activities. This suggests that any differences that may be identified in other variables, such as accident rates and speeds, were not due to the impact of traffic volumes.

Average Speed, Speed Variance, and Speed Distributions

Analysis of variance was also used to test for differences in "before" and "during" values of average speeds and speed variances at a 5

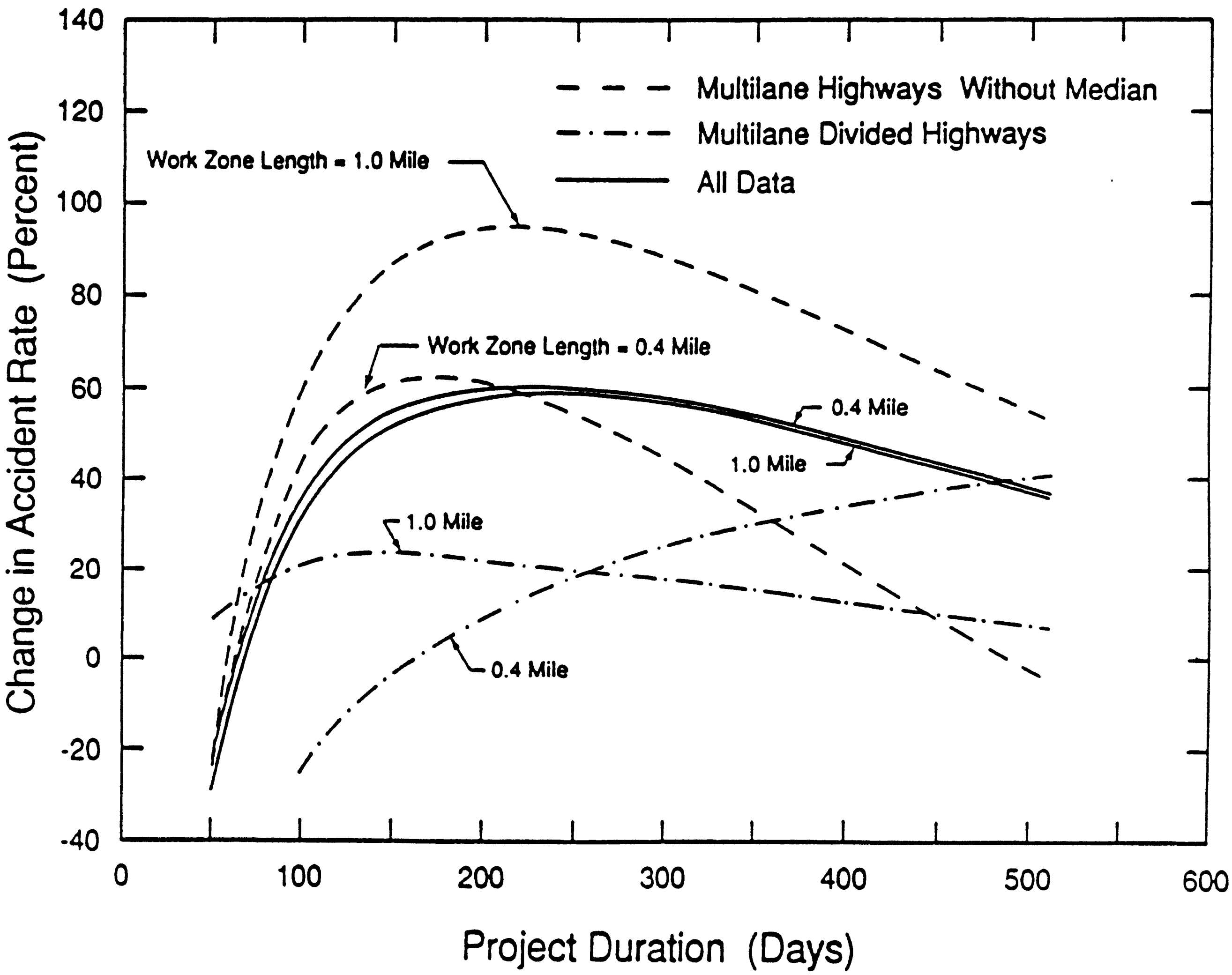


Figure 5. Changes in accident rate v. project duration and work zone length.

percent significance level. The results shown in Table 14 indicate that at nearly all sites, there was a significant difference in both average speeds and speed variances. The results shown in Table 14 also indicate

Table 13

PERCENTAGE DIFFERENCE IN ACCIDENT RATES

Work Zone Lengths (miles)	Duration (Days)								
	100	150	200	250	300	350	400	450	500
0.2	50.96	71.89	79.26	80.70	79.11	75.82	71.53	66.64	61.39
0.4	32.54	52.28	58.81	59.60	54.47	53.73	49.05	43.82	38.25
0.6	30.52	49.56	55.59	56.00	53.56	49.56	44.65	39.21	33.47
0.8	32.99	51.54	57.23	57.36	54.71	50.51	45.44	39.86	33.99
1.0	37.15	55.32	60.73	60.66	57.83	53.49	48.29	42.60	36.63
1.2	42.01	59.86	65.05	64.81	61.84	57.38	52.08	46.30	44.31
1.4	47.13	64.71	69.72	69.33	66.24	61.68	56.29	50.44	44.31
1.6	52.31	69.68	74.52	74.00	70.81	66.17	60.70	54.78	48.60
1.8	57.48	74.63	79.33	78.71	75.42	70.70	65.18	59.19	52.95
2.0	62.56	79.53	84.10	83.38	80.01	75.22	69.64	63.60	57.31

Table 14

RESULTS OF ANOVAS ON "BEFORE" AND "DURING" MEAN SPEED AND SPEED VARIANCE DATA AT THE PROJECT SITES

Site Location	Variable	Computed F	Remark
Danville	Mean Speed	707.20	Significant
	Speed Variance	17.92	Significant
Harrisonburg	Mean Speed	546.54	Significant
	Speed Variance	22.37	Significant
Lynchburg NB	Mean Speed	839.18	Significant
	Speed Variance	0.12	Not Significant
Lynchburg SB	Mean Speed	10.72	Significant
	Speed Variance	4.64	Significant
Rocky Mount	Mean Speed	0.00	Not Significant
	Speed Variance	0.40	Not Significant

that although there were in general decreases in mean speeds, there were mainly increases in speed variances during the periods the work zones were installed.

The ANOVA test was also used to determine whether significant differences occurred in the speed distributions between the "before" and "during" periods. No significant difference was observed for the sites at which speed data were collected. The speed distribution in each case could be described by the normal distribution.

Mean Headways and Headway Distributions

A comparison of the mean headways for the "before" and "during" data was also carried out using ANOVA. The results are shown in Table E2 of Appendix E. The results indicate that there was no significant difference in mean headways.

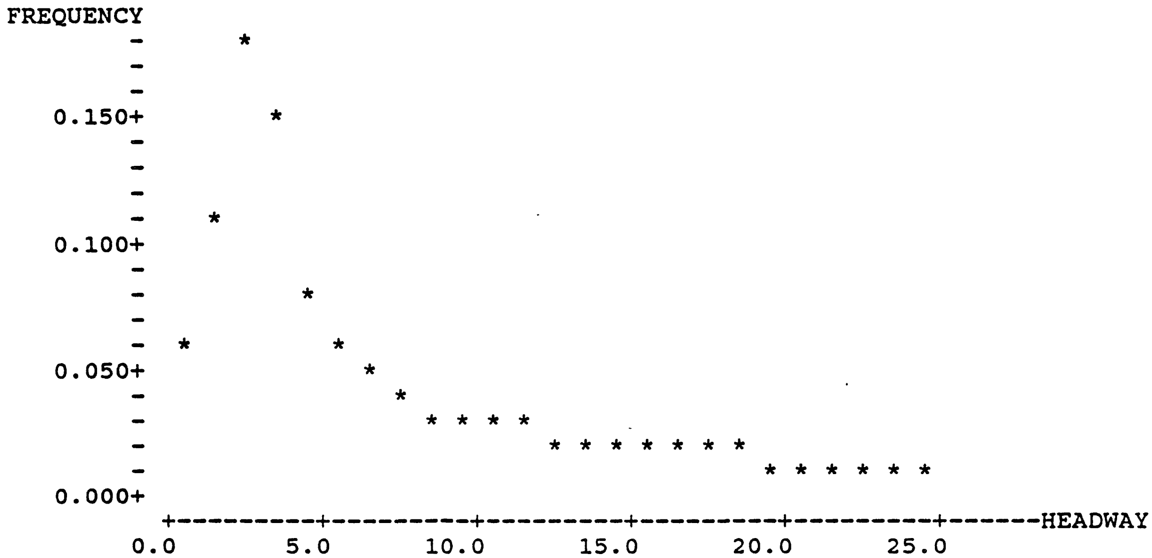
The headway distribution in the traffic stream was also examined to determine whether the installation of the work zones had any influence. Figures 6 and 7 show two typical cases of this analysis. It was found that both the "before" and "during" headway data fitted the Erlang distribution. Although there were slight differences in the "before" and "during" distribution parameters at each site, these were not significant.

Conflicts

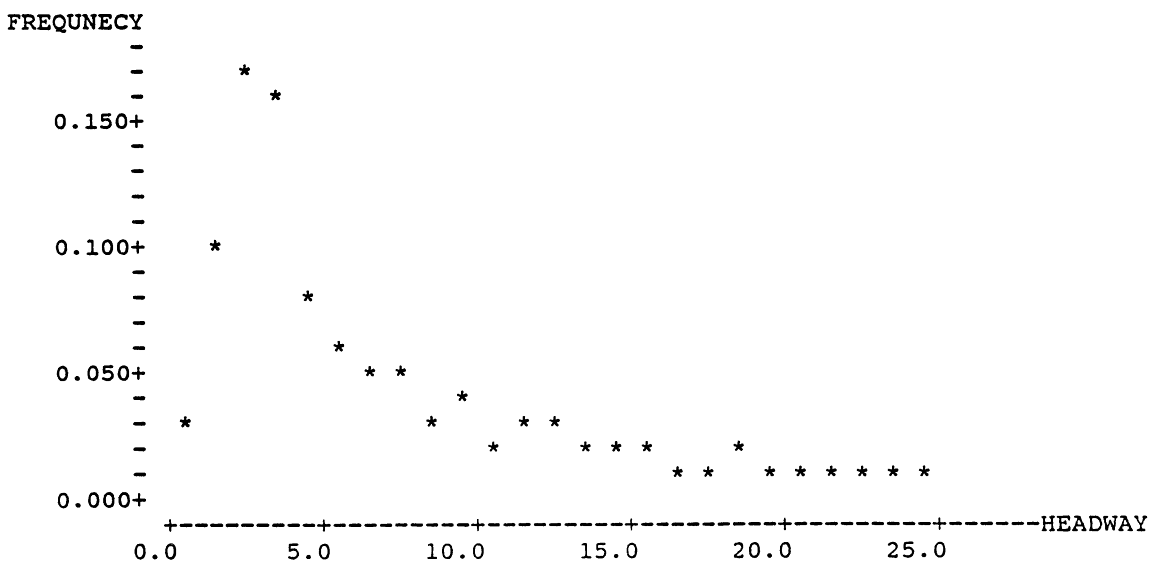
The conflict rates in terms of number of conflicts per hour at the project sites shown in Table 5 were also tested using ANOVA to determine the effect of the work zone on the occurrence of conflicts. The results are shown in Table E3 of Appendix E. A significant difference at the 5 per cent significance level was observed between the conflict rate for the "before" and "during" periods. The conflict rates for the "during" period were significantly higher than those for the "before" period (see Table 5). This result was expected because analysis of the accident data has shown that accident rates increased during the period of work zone activities, and it has been shown by Migletz et al. that the expected accident rate is directly proportional to the average conflict rate at the same location (12).

A comparison of the types of conflicts for the "before" and "during" periods was also carried out to determine the effect of the work zones. The test for comparing two proportions described earlier was used. The predominant types of conflicts and their proportions are shown in Table 15. The results of the test are also shown in Table 15. These results do not show the same trend at all sites. Significant differences at the

HEADWAY DISTRIBTUIONS AT ROCKYMOUNT



(A) "BEFORE" PERIOD



(B) "DURING" PERIOD

Figure 6. Headway distributions at Rockymount.

Figure 7: HEADWAY DISTRIBUTIONS AT LYNCHBURG SB

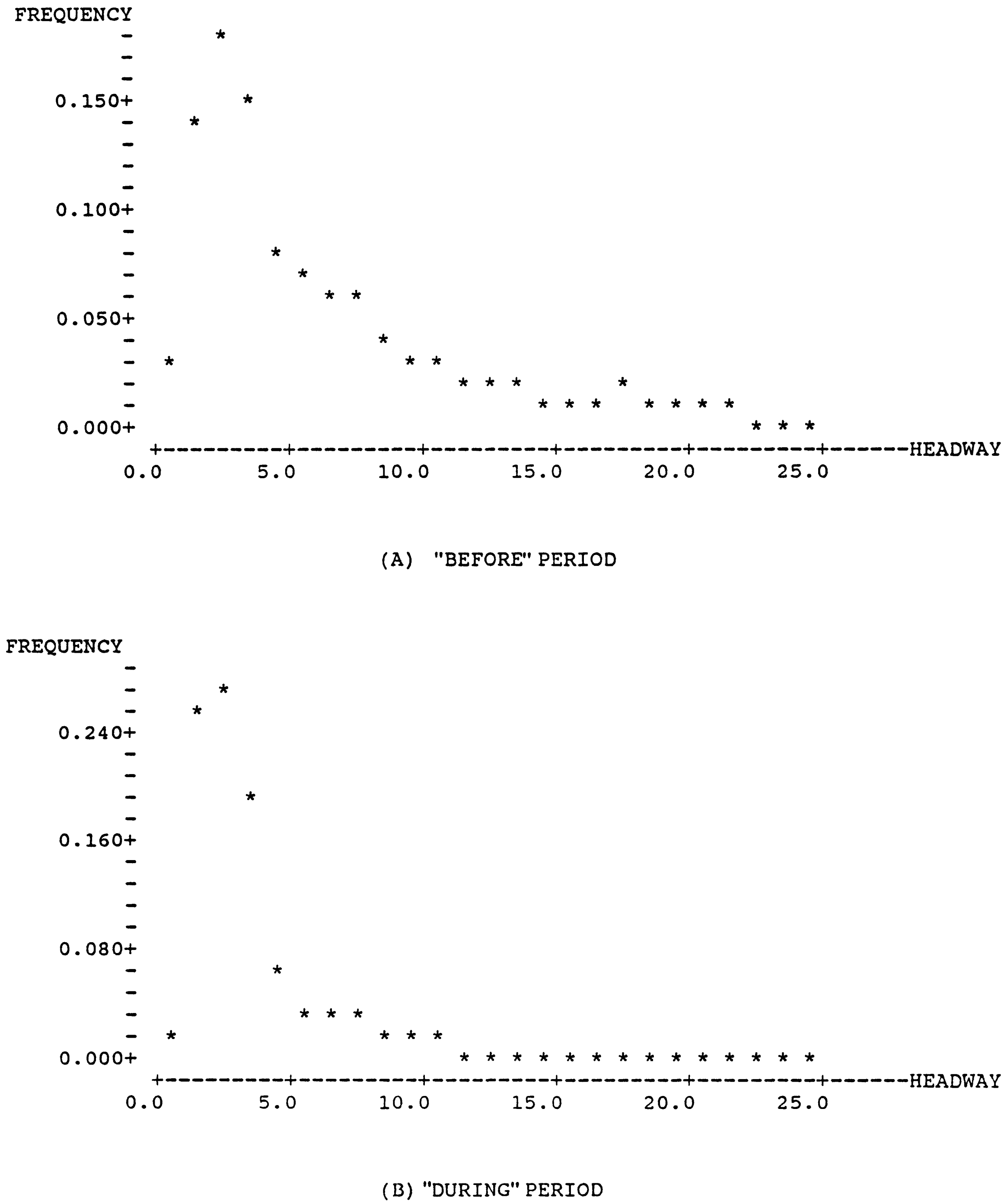


Figure 7. Headway distributions at Lynchburg SB.

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Table 15

COMPARISON OF CONFLICT PROPORTIONS

Site	Conflict Type*	Before Proportion	During Proportion	Computed Proportion	Remarks
Danville (EB)	1	0	0.010	0.518	Not Significant
	2	0.566	0.146	1.65	Not Significant
				5.52	Significant
	3	0.434	0.844		
Danville (WB)	1	0	0.046	4.74	Significant
	2	0.027	0.023	0.413	Not Significant
	3	0.931	0.931	0	Not Significant
	4	0.033	0	4.23	Significant
	5	.009	0	2.16	Significant
Hampton (NB)	1	0.016	0.014	0.18	Not Significant
	3	0.984	0.986	0.124	Not Significant
Lynchburg (SB)	1	0.363	0	11.57	Significant
	2	0.091	0.005	3.64	Significant
	3	0.500	0.995	12.46	Significant
	5	0.046	0.000	4.02	Significant
Lynchburg (NB)	1	0.677	0.025	11.4	Significant
	2	0.323	0.975	11.4	Significant
Harrisonburg (WB)	1	0.250	0.321	2.27	Significant
	2	0.074	0.103	0.416	Not Significant
	3	0.596	0.496	2.92	Significant
	5	0.080	0.080	0	Not Significant
Rocky Mount	1	0.065	0.042	0.89	Not Significant
	2	0.027	0.036	0.42	Not Significant
	3	0.908	0.922	0.39	Not Significant

*Conflict Types

1 Left turn same direction

2 Right turn same direction

3 Slow Vehicle

4 Lane change

5 Opposing left turn

5 per cent significance level of the proportional distribution of conflict types were observed at some sites but not at others. Changes in the conflict types may therefore be the result of the particular characteristics of the site at which the work was being done.

MODEL DEVELOPMENT

Two sets of models were developed. The first set relates changes in hourly conflict rates with changes in traffic characteristics, and the second set relates "during" accident rates with "before" accident rates and the types of traffic control devices used at the work zone.

The first set of models was developed using data collected during the study at the project sites, whereas the historic data obtained from the 26 study sites were used for the second set of models. The objective in developing the first set of models was to identify those traffic characteristics that could serve as surrogates for accidents and could be used to evaluate the effectiveness of different types of traffic control devices. The second set of models provides a means of estimating the accident rate during the time a work zone is installed if the "before" accident rate and the type of traffic control devices to be used are known. This set of models will also identify the combinations of traffic control devices that will most likely result in minimum accident rates when used at urban work zones.

Traffic Characteristics versus Differences in Hourly Conflict Rates

The traffic characteristics for which significant differences occurred were average speed and speed variance. Two models were therefore developed relating (1) the change in average speed with the change in hourly conflict rates and (2) the change in speed variance with the change in hourly conflict rates.

Change in Hourly Conflict Rate Versus Change in Average Speed

Regression analysis was used in this relationship, and the best fit is given in equation [4].

$$\Delta CRT = 33.2 + 16.6\ \Delta AVSPD \qquad (4)$$

where

ΔCRT = difference in conflict rates between the "before" and "during" periods

ΔAVSPD = difference in average speed between the "before" and "during" periods

This relationship, however, explains only 25 per cent of the variation as shown in Table F1 of Appendix F. The change in average speed cannot therefore serve as a good surrogate for the expected change in conflicts at a work zone. Since it is generally accepted that traffic conflicts are good surrogates of accidents, change in average speed cannot therefore serve as a good surrogate for the change in accident rates.

Change in Hourly Conflict Versus Change in Speed Variance

Two regression models were developed for this relationship. The first model uses all seven sets of data collected (see Table F2 of appendix F for regression results) and is given as:

$$\Delta CR = 173 - 3.7\Delta SPDV - 0.006(\Delta SPDV)^2 \qquad (5)$$

where

ΔCR = difference in conflict rates between "before" and "during" periods

SPDV = difference in speed variance between "before" and "during" periods

The coefficient of determination (R^2) for this model was however only 15.3 percent, indicating that only a small percentage of the variation in speed variance is explained by the model. A closer examination of the data, however, showed that the Lynchburg data consist of extremely large changes in conflict rate for a very small change in speed variance, whereas the rest of the data generally indicate an increasing trend in conflict rate as the speed variance increases. The reason for this difference is that the Lynchburg site is a two-lane road, which was converted to a single lane road serving traffic in both directions. This required traffic in one direction to be completely stopped while traffic was allowed to move in the opposite direction. Since this situation was completely different from those at the other sites, the data at Lynchburg were disregarded for the purpose of developing the second model. The result of the regression analysis excluding the Lynchburg data are given in Table F3 of Appendix F. The model obtained is given as:

$$\Delta CR = 4.3 + 9.3\Delta SPDV - 0.23(\Delta SPDV)^2 \qquad [6]$$

where

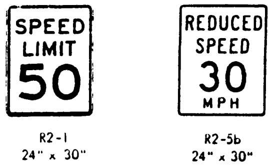
ΔCR = difference in hourly conflict rates between the "before" and "during" periods

$\Delta SPDV$ = difference in speed variance between the "before" and "during" periods, $(mph)^2$

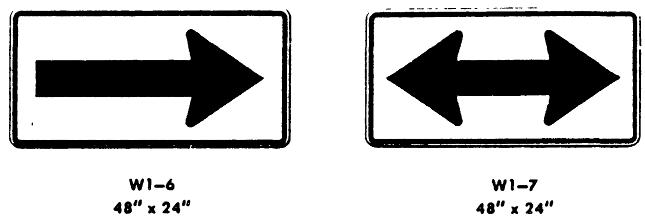
The coefficient of determination (R^2) for this model is 0.87 percent. This suggests that 87 percent of the change in hourly conflict rate is explained by the model. This model therefore suggests that change in speed variance can serve as a good surrogate for change in conflict rates and can therefore serve as a good surrogate for change in accident rates.

Accident Rate and Type of Control Devices Used

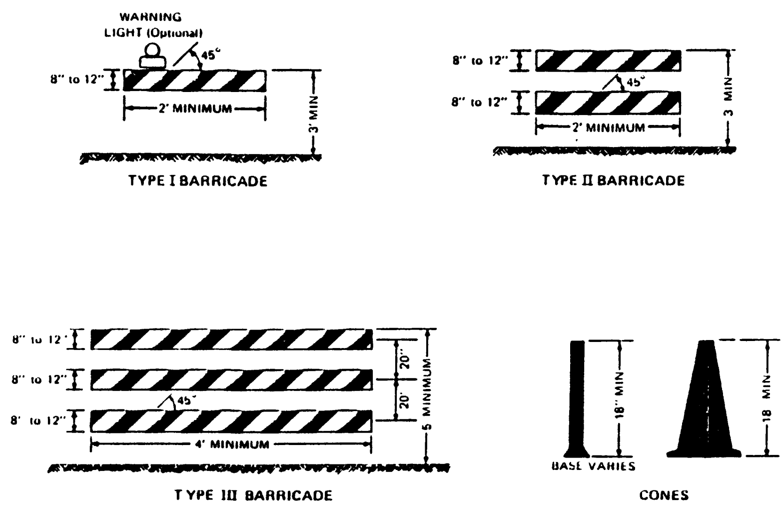
The types of control devices commonly used in urban work zones are, barricades, cones, flashing arrows, signs, and flaggers as shown in Figure 8. Each of these control devices was used at 11 or more of the 26 sites selected for the study. Temporary marking is however not commonly used and was used at only 4 sites. Also, it is common practice to use more than one type of control device at any given site (as can be seen from Table 16). The traffic control devices considered in this analysis did not include warning signs such as, "ROAD CONSTRUCTION 1000 FT," "ONE LANE ROAD 1000 FT," etc. placed some distance ahead of the work zone to inform motorists of the existence of work zones ahead. It was assumed that these signs would always be used at work zones as required by the Manual on Uniform Traffic Control Devices (MUTCD). The devices considered are those used in actually controlling the flow of traffic in the section of the highway affected by the work zone activities. These control devices were mainly used to indicate lower speed limits and/or to direct traffic to shifted lanes or from closed lanes. Since the researchers did not have any control over the type of traffic control device used, and only one set of control devices was used at any one site, it was first necessary to determine whether there was a correlation between the type of highway and the type of traffic control devices used (see Table G1 of Appendix G). Although the results obtained indicated no correlation at the 5 percent significance level, there was a strong indication that flaggers are nearly always used on two-lane highways. It was therefore necessary to develop the models relating accident rates



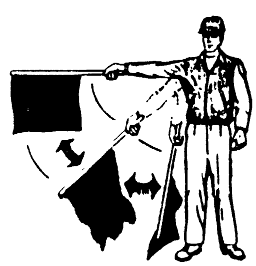
(a) Static Signs



(b) Large Arrows Usually With Flashing Burning Lights



(c) Channelization Devices



(d) Flagman

Figure 8. Types of control devices commonly used in urban areas.

Source: Manual On Uniform Traffic Control Devices
U.S. Department of Transportation,
Federal Highway Administration 1978.

Table 16

TYPES OF CONTROL DEVICES USED AT STUDY SITES

Site	Highway** Type	Traffic Control Devices Used** D1	D2	D3	D4	D5	D6
R1	2	X					
R2	2	X					
R3	2		X	X			
R4	2	X	X		X		
C1	1	X	X	X	X		X
C2	2	X	X	X	X		
L1	2		X	X	X		
L2	4		X		X	X	
L3	2		X	X	X	X	
L4	2		X	X	X		
L5	3		X		X	X	
L6	4	X			X		
L7	4		X		X	X	
H1	4	X	X	X	X	X	X
H2	4	X	X		X	X	
H3	1	X	X	X	X	X	X
H4	1	X	X	X	X	X	X
H5	1			X		X	
H6	1		X		X		
H7	1	X	X				
B1					X		
S1	4	X	X			X	
E1	4	X				X	
P1	1	X		X			
N1	1	X					
K1	1		X		X		

* Obtained from survey questionnaire and traffic control plans (when available).

**HIGHWAY TYPE
1 Multilane Divided Highway
2 Highway with four or More Lanes without a Raised Median
3 Three-lane Highway
4 Two-lane Highway

***TRAFFIC CONTROL DEVICES
D1 Barricades
D2 Cones
D3 Flashing Arrows
D4 Static Signs
D5 Flagmen
D6 Temporary Pavement Marking

with control devices by highway type. It should be emphasized however that these models relate only to urban work zones with no restriction on access. In developing the regression models, the different combinations of control devices used were first identified, starting with a combination of two devices at a site to a maximum of six devices at a site. A stepwise regression analysis was then carried out by representing the different combinations of the control devices as dummy variables, i.e., the value of a given combination is 1 when it is used and 0 when it is not used. The general form of the equations obtained is:

$$DACR = C + \gamma_1 (BACR) + \gamma_2 (CONDEV) \qquad (7)$$

where:

DACR = accident rate during the period the work zone is installed

BACR = accident rate before the work zone is installed

CONDEV = combination of control devices used at work zone

= 1 when used

= 0 when not used

C = intercept

γ_1, γ_2 = constants

The coefficient of determination obtained was higher than 90 percent for all the equations. The results obtained are shown in Tables 17 and 18.

The models obtained for the multilane highways indicate that the most significant independent variable is the "before" accident rate, and regardless of the combination of control devices used, the coefficient of the "before" accidents is between 1.75 and 1.85 with an average of 1.79 (see Table 17). Also, the intercepts for the multilane equations are very low and approximately equal zero. These results suggest that on the average, the accident rate at a work zone on an urban multilane highway will increase by about 79 percent above the rate before the installation of the work zone if no traffic control devices are used. This increase was however reduced to 57 percent with the traffic control devices actually used at the study sites (see Table 16). The amount of decrease, however, depends on the combination of traffic control devices used. The use of barricades as part of any combination on urban multilane highways, however, seems to reduce the effectiveness of the traffic control devices and may even result in a slight increase in accident rate above that for the same combination but excluding the barricades. This may be the

Table 17

REGRESSION MODELS RELATING "DURING" ACCIDENT RATES WITH "BEFORE" ACCIDENT RATES AND TYPES OF CONTROL DEVICES USED

	(Urban Multilane Highways)			
Control devices used	Intercept	γ_1	γ_2	R^2
Cones and flashing arrows	0.739	1.791	-1.686	0.92
Cones and flagmen	0.936	1.765	-2.013	0.92
Flashing arrows, and flagmen	0.820	1.781	-2.321	0.92
Cones, flashing arrows, and flagmen	1.081	1.783	-2.634	0.92
Flashing arrows, flagmen, and temporary pavement marking	0.906	1.849	-1.084	0.93
Barricades, cones, and flagmen	0.319	1.781	-1.084	0.92
Barricades, flashing arrows, and flagmen	0.195	1.804	-1.398	0.92

result of drivers perceiving a reduction in lane widths when barricades are used.

The equations for two-lane highways consisted of intercepts much higher than those for multilane highways. These equations also indicate that the effect of not using any traffic control device at a two-lane urban work zone will be more serious than it is for multilane highways. The use of an appropriate combination of traffic control devices would however reduce the "during" accident rate. The equations also indicate that any combination of control devices consisting of flagger and either cones, static signs, or barricades would be effective in reducing

Table 18

REGRESSION MODELS RELATING "DURING" ACCIDENT RATES WITH "BEFORE" ACCIDENT RATES AND TYPES OF CONTROL DEVICES USED

Two-Lane Urban Highways

Control devices used	Intercept	γ_1	γ_2	R^2
Static signs and flagmen	15.772	1.177	- 14.31	0.962
Barricades and flagmen	16.505	1.116	- 15.06	0.962
Cones and flagmen	15.115	1.288	- 13.697	0.964
Cones, static signs, and flagmen	16.958	1.114	- 15.429	0.965
Barricades, cones, and flagmen	14.765	1.318	- 13.330	0.964
Barricades, flashing arrows, and flagmen	7.902	2.466	- 4.665	0.986

accident rates at urban two-lane work zones. Any combination not including a flagger was found to be less effective than those including a flagger. Unlike the results for multilane highways, the results for two-lane highways do not indicate a negative effect when barricades are used. In fact, the combination of barricades and flaggers seems to be as effective as either static signs and flaggers or cones and flaggers. These results also indicate that the use of flaggers is a very effective means of traffic control at work zones on two-lane highways in urban areas. It must be noted, however, that flaggers must be properly trained and should have breaks at regular intervals for them to be efficient and effective.

The most effective combinations of traffic control devices identified in this study were (1) cones, flashing arrows, and flaggers on multilane highways and (2) cones and flaggers or static signs and flaggers on two-lane highways.

It should be noted however that the layout of these control devices must be in accordance with MUTCD. Also, although the results indicate that barricades and flaggers is also an effective combination for two-lane highways, this combination is not included above, because barricades are not now commonly used in Virginia.

Test of Models

In order to test the effectiveness of the models developed, it was assumed that one of the effective combinations of traffic control devices determined by the regression models was used at each study site and the expected "during" accident rate was then computed for each site using the appropriate model. Cones and flaggers were used at sites on two-lane highways, and cones, flashing arrows, and flaggers on multilane highways. The results obtained for the sites on multilane highways are shown in Table 19, and those for two-lane highways are shown in Table 20. These results suggest that if the combination of traffic control devices suggested by the models had been used at the study sites, the mean of the resulting "during" accident rates would have been about 35 percent lower than the observed multilane site rates at the two-lane sites and about 7 percent lower at the multilane sites. This suggests that the combinations of traffic control devices suggested by the models are more effective in reducing accident rates than the actual combinations used at the study sites.

It should be noted however that the model for cones, flashing arrows, and flagmen on multilane highways may not be suitable for predicting "during" accident rates when the "before" accident rates are very low (less than 1.00). When this model is used, the predicted "during" accident rates tend to be less than zero (see Table 19). In determining the mean of the "during" accident rates, however, the neggative accident rates were each treated as zero. This however did not significantly affect the final result since each of the negative values was very small.

Discussion of Results

Although the results of the analysis clearly indicate that certain combinations of control devices are more effective than others in reducing accident rates at work zones, it should be noted that these results are based on data obtained at a number of selected sites at which specific types of work were being done. The conclusions presented in the next section are therefore solely based on these data. The authors realize that the selections of a set of traffic control devices for a given job will depend on the type of work and the specific location at which the work is being carried out. The results, however, give a good

Table 19

OBSERVED AND EXPECTED ACCIDENT RATES AT MULTILANE HIGHWAYS

Site	Accident Rates* Observed Before	Observed During	Expected During**
R1	2.5246	4.0780	2.9686
R2	2.5415	1.1583	2.9785
R3	1.1768	1.4417	0.5452
R4	0.7160	1.9252	-0.2764
C1	0.7983	0.3627	-0.1296
C2	3.4578	5.4113	4.6123
L1	6.6153	11.5189	10.2421
L3	24.4993	33.1194	42.1292
L4	29.0429	57.7310	50.2305
L5	0.9835	1.1064	0.2006
H3	1.4719	2.8215	1.0714
H4	1.9493	2.6559	1.9226
H5	2.4975	2.2107	2.9000
H6	2.1961	2.1944	2.3626
H7	2.8565	2.2919	3.5401
B1	0.8491	2.8745	-0.0341
P1	2.8131	3.9097	3.4623
N1	0.8687	0.7236	-0.0041
K1	0.4124	0.7824	-0.8177
Mean	4.6458	7.2799	6.7972
Percentage Increase		57.0	46.0

*Number of accidents per million vehicle miles of travel
**Based on using model for the most efficient combination of traffic control devices, i.e., cones, flashing arrows, and flagmen.

Table 20

OBSERVED AND EXPECTED ACCIDENT RATES AT TWO-LANE HIGHWAYS

Site	Accident Rates* Observed Before	Observed During	Expected During**
L2	1.7478	1.8255	3.3955
L6	6.7688	23.8317	8.9990
L7	2.1099	5.8357	3.7996
H1	0.000	3.2430	1.4450
H2	0.6134	0.1954	2.1296
S1	2.6433	5.1482	4.3444
E1	2.3765	3.4913	4.0972
Mean	2.3228	6.2244	4.0373
Percentage Increase		168.0	74.0

*Number of accidents per million vehicle miles of travel
**Based on using cones and flagmen.

indication of the types of traffic control devices that should be considered for use at work zones on urban highways.

Further research is however needed from which data on accidents can be obtained at the same location for the same job when different combinations of traffic control devices are used. This will facilitate the direct correlation between accident rates and the variation of traffic control devices used for specific types of work.

CONCLUSIONS

The following conclusions are based on the results of the analysis.

Accident Characteristics

- Adverse environmental conditions have little or no effect on accident occurrence at Virginia's urban work zones.
- Accident rates increase at a relatively higher rate at urban work zones than at non-work zone locations.
- The type and severity of accidents are not significantly affected by the installation of a work zone in an urban area.
- Predominant collision types at urban work zones are similar to those at non-work zones and are angle, rear-end, and sideswipe.
- Work zones tend to increase the interaction of vehicles, resulting in a proportional increase of multivehicle crashes at these locations.
- Alcohol is not responsible for the increase in accident rates at work zones.
- The accident rate during periods of maintenance and rehabilitation work for multilane highways is highly dependent on the accident rate just prior to the work period.
- Accident rates at work zones on multilane highways in Virginia increase on the average by about 57 percent when compared with accident rates just prior to the installation of the work zones. The amount of increase, however, depends on the type of traffic control devices used at a given site.

- Accident rates at work zones on two-lane urban highways in Virginia increase on the average by about 168 percent when compared with accident rates just prior to the installation of the work zones. The amount of increase also depends on the type of traffic control devices used.

Traffic and Geometric Characteristics

- Average speed and speed variance are significantly affected by work zone activities. Although there is a general lowering of average speeds, speed variance tends to increase during work zone activities.

- Mean headways and headway distributions are not significantly affected by the installation of work zones in urban areas. The headways generally fit the Erlang distribution.

- The change in average speed between the "before" and "during" periods is not related to the change in accident rates and cannot therefore be used as a surrogate for the change in accident rates.

- The change in speed variance is related to the change in accident rates and can therefore be used as an appropriate surrogate.

- Urban work zone lengths should be limited to 0.6 mile since longer work zones tend to increase the accident rates.

- Projects should be kept to a minimum duration to minimize the increase in accident rate during the project.

Traffic Control Effectiveness

- The most effective combination of traffic control devices for work zones on multilane highways is cones, flashing arrows, and flagmen. The use of this combination will result in an average increase of only about 46 percent in the accident rate during the period the work zone is installed.

- The use of barricades as part of any combination of control devices on urban multilane highways seems to reduce the effectiveness of the traffic control devices and may even result in a slight increase in the "during" accident rate above that for the same combination but excluding the barricades.

- The effective combinations of traffic control devices for work zones on urban two-lane highways are (1) cones and flagmen and (2) static signs and flaggers. There is no significant difference in the effectiveness of these combinations.

- The use of any of these combinations would result in an average increase of only about 74 percent in the accident rate during the period the work is installed, which is much less than the 168 percent observed from the data.

- The use of flaggers is a very effective means of traffic control at work zones on urban two-lane highways.

- For work zones on two-lane urban highways, any combination of traffic control devices not including flaggers was found to be far less effective than any one that included flaggers.

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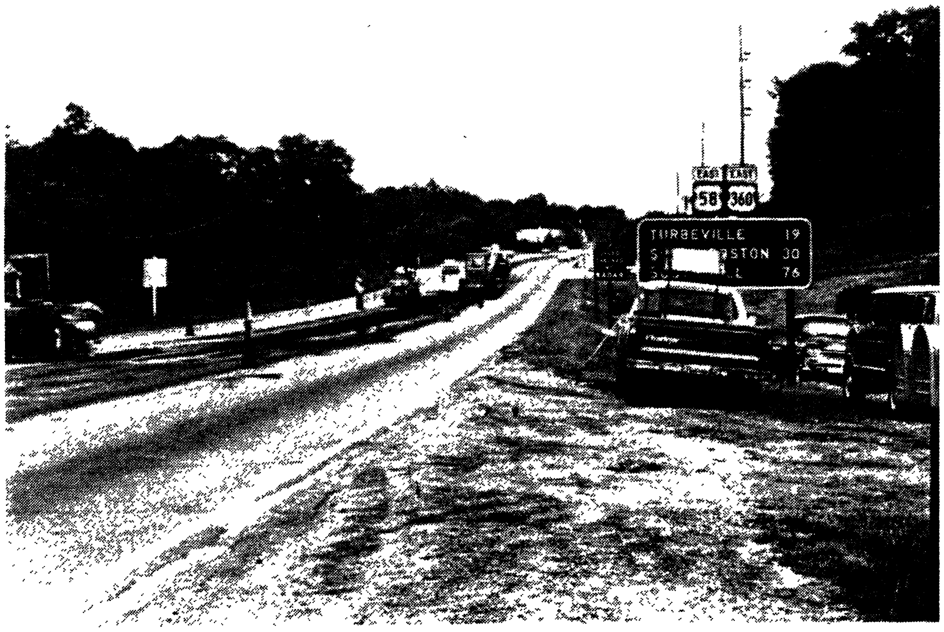
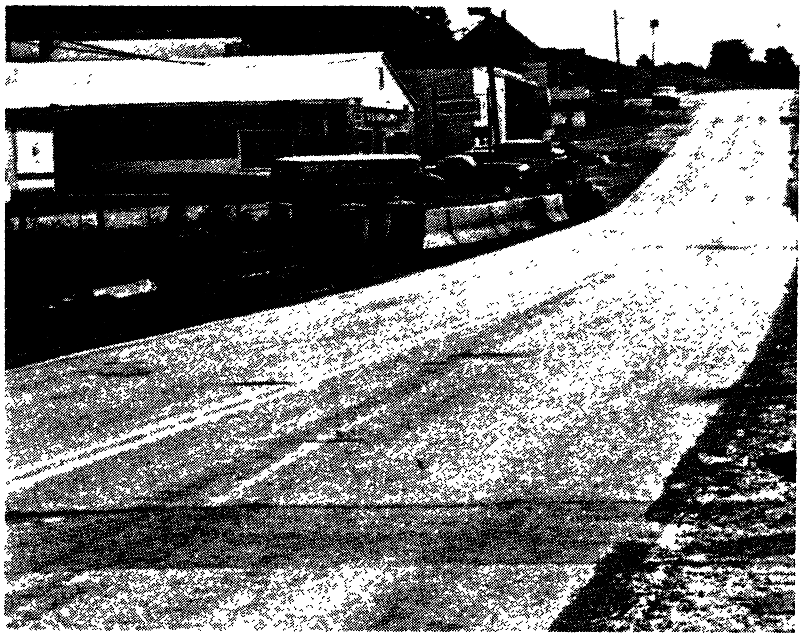
APPENDIX A

A1. Danville Site before construction.



A2. Danville Site during construction.

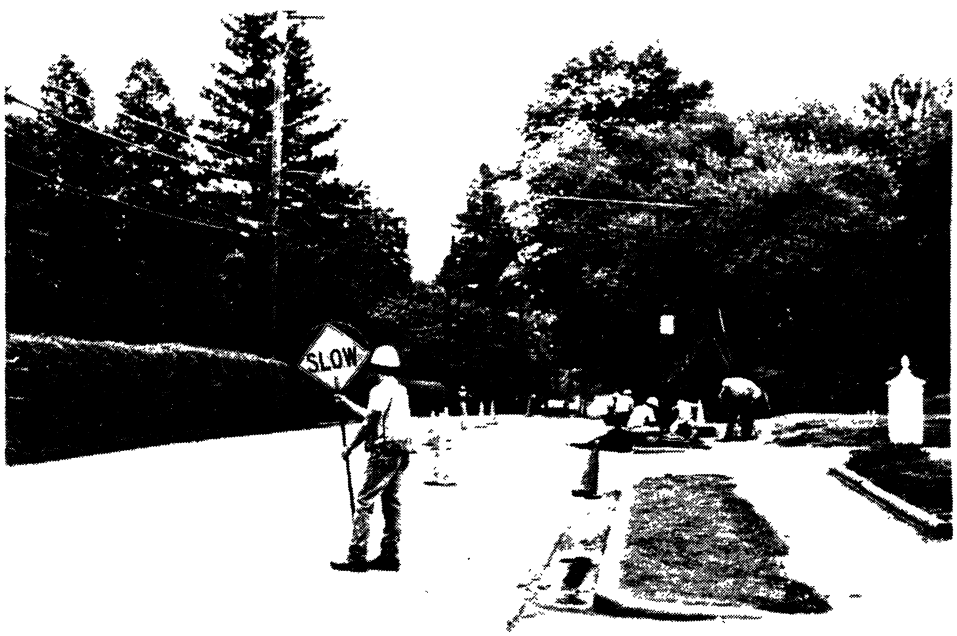
1572



A3. Rocky Mount Site before construction.

A4. Rocky Mount Site during construction.

A5. Lynchburg Site before construction.

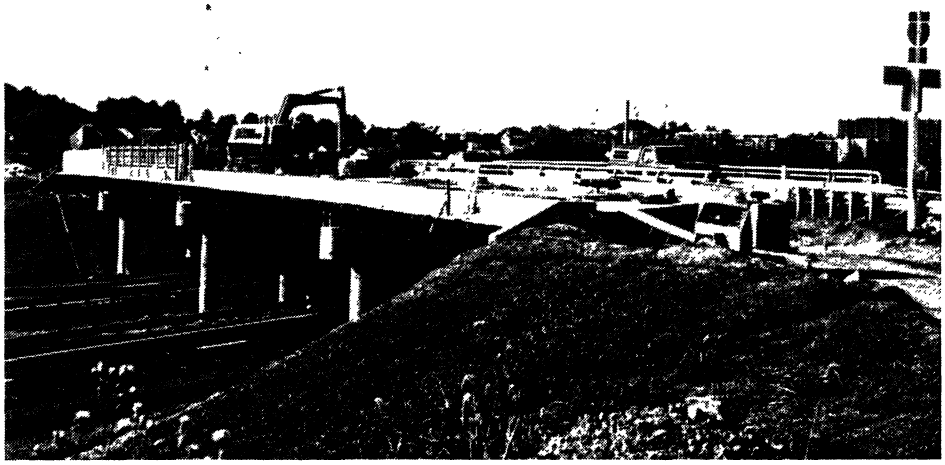


A6. Lynchburg Site during construction.

A7. Hampton Site before construction.

A8. Hampton Site during construction.

A9. Harrisonburg Site during construction.



A10. Harrisonburg Site during construction.

APPENDIX B

TESTING THE VARIABILITY OF ACCIDENT RATES BEFORE CONTRUCTION AT STUDY AND CONTROL SITES

ANALYSIS FOR VARIABLE ACCR CLASSIFIED BY VARIABLE SITE

WILCOXON SCORES (RANK SUMS)

LEVEL	N	SUM OF SCORES	EXPECTED UNDER HO	STD DEV UNDER HO	MEAN SCORE
1	26	566.00	507.00	31.84	21.77
2	12	175.00	234.00	31.84	14.58

WILCOXON 2-SAMPLE TEST (NORMAL APPROXIMATION)
(WITH CONTINUITY CORRECTION OF .5)
S= 175.00 Z=-1.8371 PROB >|Z|=0.0662

T-TEST APPROX. SIGNIFICANCE=0.0742

KRUSKAL-WALLIS TEST (CHI-SQUARE APPROXIMATION)
CHISQ= 3.43 DF= 1 PROB > CHISQ=0.0639

TESTING THE VARIABILITY OF ACCIDENT RATES DURING CONTRUCTION AT STUDY AND CONTROL SITES

ANALYSIS FOR VARIABLE ACCR CLASSIFIED BY VARIABLE SITE

WILCOXON SCORES (RANK SUMS)

LEVEL	N	SUM OF SCORES	EXPECTED UNDER HO	STD DEV UNDER HO	MEAN SCORE
1	26	580.00	507.00	31.84	22.31
2	12	161.00	234.00	31.84	13.42

WILCOXON 2-SAMPLE TEST (NORMAL APPROXIMATION)
(WITH CONTINUITY CORRECTION OF .5)
S= 161.00 Z=-2.2768 PROB >|Z|=0.0228

T-TEST APPROX. SIGNIFICANCE=0.0287

KRUSKAL-WALLIS TEST (CHI-SQUARE APPROXIMATION)
CHISQ= 5.26 DF= 1 PROB > CHISQ=0.0219

APPENDIX C

ESTING THE VARIABILITY OF SEVERITY RATES BEFORE AND DURING CONSTRUCTION AT STUDY SITES

ANALYSIS FOR VARIABLE SEVER CLASSIFIED BY VARIABLE TIME

WILCOXON SCORES (RANK SUMS)

LEVEL	N	SUM OF SCORES	EXPECTED UNDER H0	STD DEV UNDER H0	MEAN SCORE
1	26	615.00	689.00	54.64	23.65
2	26	763.00	689.00	54.64	29.35

WILCOXON 2-SAMPLE TEST (NORMAL APPROXIMATION)
(WITH CONTINUITY CORRECTION OF .5)
S= 615.00 Z=-1.3451 PROB >|Z|=0.1786

T-TEST APPROX. SIGNIFICANCE=0.1845

KRUSKAL-WALLIS TEST (CHI-SQUARE APPROXIMATION)
CHISQ= 1.83 DF= 1 PROB > CHISQ=0.1756

TESTING THE VARIABILITY OF SEVERITY RATES AT CONTROL SITES

ANALYSIS FOR VARIABLE SEVER CLASSIFIED BY VARIABLE TIME

WILCOXON SCORES (RANK SUMS)

LEVEL	N	SUM OF SCORES	EXPECTED UNDER HO	STD DEV UNDER HO	MEAN SCORE
1	12	151.00	150.00	17.32	12.58
2	12	149.00	150.00	17.32	12.42

WILCOXON 2-SAMPLE TEST (NORMAL APPROXIMATION)
(WITH CONTINUITY CORRECTION OF .5)
S= 151.00 Z= 0.0289 PROB >|Z|=0.9770

T-TEST APPROX. SIGNIFICANCE=0.9772

KRUSKAL-WALLIS TEST (CHI-SQUARE APPROXIMATION)
CHISQ= 0.00 DF= 1 PROB > CHISQ=0.9540

APPENDIX D

Table D1

TABLE : COMPARISON OF COLLISION TYPE PROPRTIONS

SITE	COLL TYPE	PROP DURING	PROP BEFORE	COMPUTED P	EXPECTED P	REMARK *
R1	1	0.56	0.47	0.503	1.96	0
	2	0.28	0.41	-0.835	1.96	0
	9	0.11	0.12	-0.061	1.96	0
R2	1	0.67	0.74	-0.384	1.96	0
	2	0.33	0.16	1.057	1.96	0
R4	2	0.14	0.27	-0.722	1.96	0
	4	0.43	0.28	0.812	1.96	0
	11	0.29	0.07	1.940	1.96	0
	13	0.14	0.28	-0.767	1.96	0
R5	1	0.58	0.37	3.137	1.96	1
	2	0.05	0.04	0.198	1.96	0
	4	0.13	0.21	-1.505	1.96	0
	8	0.03	0.02	0.327	1.96	0
	11	0.03	0.04	-0.376	1.96	0
	13	0.19	0.29	-1.664	1.96	0
C1	2	0.67	1.00	-0.667	1.96	0
C2	1	0.28	0.43	-1.811	1.96	0
	2	0.50	0.38	1.360	1.96	0
	3	0.03	0.02	0.156	1.96	0
	4	0.08	0.04	0.942	1.96	0
	5	0.03	0.04	-0.268	1.96	0
	9	0.03	0.04	-0.268	1.96	0
P1	1	0.40	0.38	0.108	1.96	0
	11	0.10	0.13	-0.168	1.96	0

Table D1 (continued)

	13	0.30	0.25	0.235	1.96	0
LO	1	0.50	0.50	0.000	1.96	0
	2	0.50	0.14	1.210	1.96	0
L1	5	0.33	1.00	-1.247	1.96	0
L2	1	1.00	0.17	2.582	1.96	1
L4	2	0.56	0.64	-0.419	1.96	0
	4	0.11	0.07	0.330	1.96	0
	5	0.11	0.07	0.330	1.96	0
	9	0.11	0.21	-0.637	1.96	0
L5	2	0.60	0.23	1.488	1.96	0
	9	0.40	0.46	-0.235	1.96	0
L6	1	0.33	0.20	0.422	1.96	0
L7	1	0.40	0.09	1.468	1.96	0
	2	0.40	0.55	-0.539	1.96	0
	9	0.20	0.27	-0.311	1.96	0
H3	9	1.00	0.67	0.667	1.96	0
H4	1	0.59	0.49	1.193	1.96	0
	4	0.21	0.06	2.439	1.96	1
	5	0.03	0.02	0.456	1.96	0
	11	0.02	0.08	-2.058	1.96	1
	13	0.14	0.33	-2.982	1.96	1
H5	1	0.57	0.11	4.414	1.96	1
	4	0.09	0.08	0.151	1.96	0
	11	0.04	0.06	-0.418	1.96	0
	13	0.22	0.53	-2.988	1.96	1
H8	1	0.50	0.67	-0.586	1.96	0
H9	1	0.78	0.74	0.290	1.96	0

Table D1 (continued)

	4	0.06	0.16	-1.002	1.96	0
	13	0.17	0.11	0.546	1.96	0
H0	1	0.69	0.26	3.278	1.96	1
	11	0.08	0.06	0.183	1.96	0
	13	0.23	0.39	-1.265	1.96	0
B1	11	0.50	1.00	-0.866	1.96	0
E1	1	0.44	1.00	-2.640	1.96	1
K1	1	0.36	0.33	0.097	1.96	0
	4	0.27	0.33	-0.206	1.96	0
	13	0.27	0.33	-0.206	1.96	0
N3	1	0.50	0.14	1.391	1.96	0
	13	0.33	0.57	-0.858	1.96	0

0 - not significant
1 - significant

APPENDIX E

Table E1 ANALYSIS OF VARIANCE FOR HOURLY VOLUMES

```
MTB > AOVONEWAY C1 C2

ANALYSIS OF VARIANCE
SOURCE      DF         SS          MS          F
FACTOR       1     271245      271245       1.08
ERROR       12    3013622      251135
TOTAL       13    3284867
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
LEVEL        N       MEAN       STDEV  -------+---------+---------+---------
C1           7      807.5       244.4  (-------------*-------------)
C2           7     1085.9       665.2           (-------------*-------------)
                                       -------+---------+---------+---------
POOLED STDEV =      501.1                  600       900      1200
```

Table E2 **ANALYSIS OF VARIANCE FOR HEADWAY(FT)**

```
MTB > AOVONEWAY C3 C7

ANALYSIS OF VARIANCE
SOURCE      DF        SS         MS         F
FACTOR       1     13961      13961      1.34
ERROR       12    125018      10418
TOTAL       13    138979
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL        N      MEAN      STDEV  -+---------+---------+---------+-----
C3           7     440.6      126.1           (----------*----------)
C7           7     377.5       70.3  (----------*-----------)
                                     -+---------+---------+---------+-----
POOLED STDEV =     102.1            300       375       450       525
```

Table D3 **ANALYSIS OF VARIANCE FOR HOURLY CONFLICTS**

```
MTB > AOVONEWAY C4 C8

ANALYSIS OF VARIANCE
SOURCE      DF        SS         MS         F
FACTOR       1     57175      57175      7.21
ERROR       12     95197       7933
TOTAL       13    152372
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL        N      MEAN      STDEV  ------+---------+---------+---------+
C4           7     33.75      22.86   (--------*---------)
C8           7    161.56     123.87                  (---------*--------
                                     ------+---------+---------+---------+
POOLED STDEV =     89.07                   0        75       150       225

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

APPENDIX F

Table F1 MODEL FOR CHANGE IN HOURLY CONFLICTS VS. CHANGE IN AVERAGE SPEED

```
CHANGE IN
HOURLY CONFLICTS

         -
         -                                        *
         -
      300+                      *
         -
         -
         -
         -
      200+
         -
         -
         -
         -
      100+                                                *
         -
         -          *
         -                      2
         - *
        0+
          +---------+---------+---------+---------+---------+------CHANGE IN
         0.0       2.5       5.0       7.5      10.0      12.5    MEAN SPEED
```

```
MTB > REGRESS C24 1 C21

The regression equation is
C24 = 33.2 + 16.6 C21
```

Predictor	Coef	Stdev	t-ratio
Constant	33.24	87.57	0.38
C21	16.64	12.87	1.29

s = 127.4   R-sq = 25.1%   R-sq(adj) = 10.1%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	27105	27105
Error	5	81091	16218
Total	6	108195	

Table F2 MODEL FOR CHANGE IN HOURLY CONFLICTS VS .CHANGE IN SPEED VARIANCE

(USING ALL SETS OF DATA)

```
 CHANGE IN
 HOURLY CONFLICTS
            -
            -            *
            -
        300+ *
            -
            -
            -
            -
        200+
            -
            -
            -
            -
        100+                           *
            -                    *
            -     *   *
            -                                                     *
          0+
            +---------+---------+---------+---------+---------+------CHANGE I
           0.0       7.0      14.0      21.0      28.0      35.0   SPEED VARIA
```

```
MTB > LET C44 = C22**2
MTB > REGRESS C24 2 C44 C22
```

The regression equation is
C24 = 173 - 0.006 C44 - 3.7 C22

Predictor	Coef	Stdev	t-ratio
Constant	173.0	110.1	1.57
C44	-0.0060	0.4338	-0.01
C22	-3.71	17.87	-0.21

s = 151.3 R-sq = 15.3% R-sq(adj) = 0.0%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	2	16581	8290
Error	4	91615	22904
Total	6	108195	

SOURCE	DF	SEQ SS
C44	1	15594
C22	1	987

Table F3 MODEL FOR CHANGE IN HOURLY CONFLICTS VS. CHANGE IN SPEED VARIANCE

(EXCLUDING LYNCHBURG DATA)

```
CHANGE IN
HOURLY CONFLICTS
          -
          -                           *
          -
          -
       90+
          -
          -
          -
          -
       60+            *
          -
          -
          -
          -   *
       30+       *
          -
          -                                                  *
          -
          -
           +---------+---------+---------+---------+---------+------CHANGE IN
         0.0       7.0      14.0      21.0      28.0      35.0   SPEED VARIANC
```

```
MTB > LET C104=C102**2
MTB > REGRESS C101 2 C102 C104
```

The regression equation is
C101 = 4.3 + 9.30 C102 - 0.230 C104

Predictor	Coef	Stdev	t-ratio
Constant	4.33	18.87	0.23
C102	9.300	2.734	3.40
C104	-0.22989	0.06351	-3.62

s = 18.24   R-sq = 87.0%   R-sq(adj) = 74.0%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	2	4459.6	2229.8
Error	2	665.3	332.6
Total	4	5124.8	

SOURCE	DF	SEQ SS
C102	1	101.3
C104	1	4358.3

APPENDIX G

Table G1: Correlation Analysis for Control Device and Type of Highway

Type of Control Device	χ^2 Computed	$\chi^2_{0.05,3}$ Expected	Remarks
D1	1.94	7.81	Not Significant
D2	1.56	7.81	Not Significant
D3	5.19	7.81	Not Significant
D4	1.03	7.81	Not Significant
D5	8.24	7.81	Significant
D6	0.64	7.81	Not Significant