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CRASH CHARACTERISTICS AT WORK ZONES

Final Report

by

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16. Abstract

Work zones tend to cause hazardous conditions for vehicle drivers and construction workers since they generate conflicts between construction activities and the traffic, and therefore aggravate the existing traffic conditions. Every effort should therefore be made to minimize the negative impacts of work zones. A clear understanding of the characteristics of work zone crashes will enhance the selection of the appropriate measures that can minimize the negative impacts of work zones.

This study investigated the characteristics of work zone crashes in Virginia that occurred between 1996 and 1999. The information on each crash was obtained from the police crash records. Each crash was located in one of five areas of the work zone: (i) Advance Warning Area, (ii) Transition Area, (iii) Longitudinal Buffer Area, (iv) Activity Area, and (v) Termination Area. An analysis of the percentage distributions was then carried out, with respect to the locations of the crashes, the severity, collision types and different types of highways. The proportionality test was used to determine significant differences at the 5% significance level. Also certain crash characteristics such as the proportions of single and multi-vehicle crashes were compared for work-zone and non-work-zone crashes. The results indicate that the Activity Area (Area 4) is the predominant location for work zone crashes regardless of the highway type, and that rear-end crashes are the predominant type of crashes. The results also indicated that the proportion of the sideswipe in same direction (SS) crashes in the Transition Area (area 2) is significantly higher than that in the Advance Warning Area (Area 1). The proportionality tests also showed that work-zone crashes involve higher proportion of multi-vehicle crashes than non-work-zone crashes and that work-zone crashes involve a higher proportion of fatal crashes than do non-work-zone crashes.

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ABSTRACT

Work zones tend to cause hazardous conditions for vehicle drivers and construction workers since they generate conflicts between construction activities and the traffic, and therefore aggravate the existing traffic conditions. Every effort should therefore be made to minimize the negative impacts of work zones. A clear understanding of the characteristics of work zone crashes will enhance the selection of the appropriate measures that can minimize the negative impacts of work zones.

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work-zone crashes and that work-zone crashes involve a higher proportion of fatal crashes than do non-work-zone crashes.

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CHAPTER 1: INTRODUCTION

With the completion of the interstate highway system in the United States, roadwork has shifted from new construction to maintenance and rehabilitation. The Transportation Equity Act for the 21st Century (TEA 21) provided a significant increase in funding for highway construction and maintenance. Thus, it is expected that rehabilitation work will increase significantly during the next few years. In addition, it is expected that traffic volumes on the nation's highways will continue to increase. Since it is not feasible to close long stretches of highways while rehabilitation work is being undertaken, it will be necessary to provide for the flow of increasing volumes of traffic while rehabilitation work is in progress. This in turn will result in a significant increase in the number of work zones, which will require an increased effort in improving safety at these locations. A clear understanding of the distributions and characteristics of work zone crashes at particular locations will enhance the selection of effective countermeasures that can be used to minimize the negative effects of work zones. These locations are generally referred to as the advance warning area, transition area (taper), longitudinal buffer area, activity area and terminations area (See Figure 1).

1.1 Problem Statement

Many research projects (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12) have been conducted to study the crash character tics and distributions at work zones. However, the results are inconsistent with respect to several characteristics. Nemeth and Rathi *(10)* concluded that high variation exists not only in accident experiences of different sites but also in accident reporting from different agencies. Therefore, some of the study results from different states may not be transferable. In addition, most existing studies were conducted in the 1970s and 1980s. No recent study has been done concerning the distributions and characteristics of work zone crashes. The crash experience may have been different due to the changes in the traffic characteristics and the continuous safety improvement over the years.

Most of the studies have considered the complete length of the work zone, without any consideration of the specific location of the crashes within the work zone. Among the few studies addressing the specific location of work zone crashes, discrepancies exist. Additionally, nearly none of them have further analysis on the crash characteristics and distribution at different areas. Therefore, an identification of the locations at which crashes are prevalent, coupled with an analysis of the characteristics and distribution of the crashes at different locations, will provide valuable information that can facilitate the identification of more appropriate and potentially effective countermeasures.

1.2 Purpose and Scope

The purpose of this study is to determine the characteristics of and distribution of crashes at specific location within work zones, study these distributions with respect to different time periods, different road types, single and multiple vehicle involvement, heavy vehicle involvement, and compare the differences of the distributions of work-zone crashes and non-work-zone crashes. The specific objectives are:

1. to identify the predominate location within work zones where crashes occur
2. to determine the predominant types of crashes and the distribution of severity at each location
3. to study the collision type and severity distribution with respect to different road types, different time periods, nighttime and daytime, single and multiple vehicle involvement and heavy vehicle involvement
4. to compare the differences of the distributions of work-zone crashes and non-work-zone crashes
5. to generate ideas for possible effective countermeasures as a result of the aforementioned analysis

This study will be limited to work zone crashes occurring from 1996 through 1999 in Virginia. Only crashes that are reported to the police will be included in the study. These crashes will therefore be at or exceed the threshold of a Property Damage Only (PDO) crash with a cost of at least $ 1,000.

CHAPTER 2: LITERATURE REVIEW

A review of the literature on the characteristics of work zone crashes, traffic control devices and possible countermeasures for work zone crashes was carried out through the Transportation Research Information System (TRIS), the University of Virginia libraries and the Virginia Transportation Research Council library. The studies reviewed are summarized under the following sub-headings:

- Crash rates
- Crash severity
- Crash location
- Other crash characteristics
- Traffic characteristics
- Traffic control devices

2.1 Crash Rates

Hall and Lorenz *(1)* indicated that crash experience during construction increased by 26% compared with the same period in the previous year when there was no construction. Rouphail and others *(2)* showed that the crash rates during construction increased by 88% compared to the before period at long-term work zones, while the crash rates at short-term work zones were not affected by the roadwork. Garber and Woo *(3)* concluded that on average, the accident rates at work zones on multilane highways in Virginia increased about 57 percent and the accidents at work zones on two-lane urban highways in Virginia increased about 168 percent when compared with accident rates prior to the installation of the work zones. However, the literature also indicates the accident rates depend on the type of traffic control device used at the work zones. A study by Pigman and Agent *(4)* also shows that accident rates during construction exceeded those in the before period at 14 of the 19 sites where accident rates were calculated. Nemeth and Migletz *(5)* also showed that accident rates during construction increased significantly compared to the before period. Two studies *(3, 6)* revealed that crash rates at work zones were higher than at non-work-zone locations.

2.2 Crash Severity

Two studies *(4, 7)* showed work zone crashes were more severe than other crashes, while two other studies *(1, 3)* concluded the severity of work zone crashes was not significantly different from all crashes. Four studies *(2, 5, 8, 10)* stated that work zone crashes were (slightly) less severe than all crashes. Hargroves *(9)* studied the work zone crashes that occurred in Virginia for the year of 1977 and concluded that the average work zone crash was slightly less severe than the average crash compared by the percentage of property damage only (PDO) crashes and the numbers of persons killed or injured per crash. He also stated that the average work zone crash was slightly more severe than the average crash in terms of the number of vehicles involved per crash and average property damage.

2.3 Crash Location

Five studies *(4, 5, 9, 10, 11)* addressed the specific locations of crashes in work zones. Two studies *(4, 9)* found that most crashes (44.7%, 54.1%) occurred at the work area (combining the longitudinal buffer area and the activity area, See Figure 1). Nemeth *(5)* concluded that 39.1% and 16.6% accidents occurred in longitudinal buffer area and activity area respectively. In another study *(10)*, Nemeth used another set of location categories and showed that most crashes occurred at single lane zones, crossover and bi-directional zones (Two Lane Two Way Operation). Goddin *(11)* indicated that 69% of the crashes occurred in the activity area.

2.4 Other Crash Characteristics

The results of several studies *(1, 2, 3, 4, 5, 8, 9, 10, 11)* indicated that rear end crashes were the predominant collision type at work zones. Four studies *(1, 2, 3, 7)* indicated that multi-vehicle crashes were over-represented at work zones while three studies *(1, 4, 9*) indicated that heavy vehicles were over-represented in work zone crashes. Pigman and Agent *(4)* concluded that work zone crashes involving heavy vehicles were more severe than those in which heavy vehicles were not involved.

Pigman and Agent *(4)* also concluded that crashes during darkness were more severe, while Nemeth and Migletz *(5)* during the daylight hours were more severe than those occurring at night or at dawn and dusk. Two studies *(5, 12)* concluded that nighttime crashes were especially concentrated at transition areas. Ha and Nemeth *(8)* also concluded that night crashes were fixed object crashes and single vehicle crashes were dominant at night.

2.5 Traffic Characteristics

Paulsen and others *(13)* showed 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. Garber and Gadiraju *(14)* determined that accidents on both freeways and arterials increased as speed variance increased. Garber and Woo *(3)* found that there were generally increases in speed variances during the periods when work zones were installed and the change in speed variance is related to the change in accident rates. Garber and Gadiraju *(14)* also showed that drivers tend to drive at a speed that, in their opinion, is suitable for the prevailing conditions regardless of the posted speed limit. Therefore, a speed limit much less than the normal speed limit does not result in most drivers reducing their speeds to the posted speed limit.

The simulation study conducted by Nemeth and Rathi *(10)* showed that the negative impact of higher speeds and the introduction of trucks was eliminated when merging drivers were assumed to respond to the lane closure signs immediately. His simulation results also show that the introduction of a speed zone did not improve conditions, but early merging behavior minimized both speed variance and probability of disturbance at the transition area (area 2). However, Nemeth and Rathi *(10)* stated that the result of a driver survey indicated that some drivers prefer to pass a few open-lane vehicles before merging into the open-lane traffic.

2.6 Traffic Control Devices

The traffic control devices used in work zones mainly include signs, arrow boards, and channelization devices -- such as cones, barrels, jersey barriers, etc. Signs are mainly used to warn and alert drivers of speed reductions and hazards created by the construction and rehabilitation activities, whereas arrow boards and channelization devices are used to guide and direct traffic safety through work zones. A Flagger is also an important traffic control measure.

A major part of research efforts has been to determine the effectiveness of traffic control devices with respect to driver compliance and traffic operation. NCHRP Report 236 *(15)* concluded that cones were easily detected far away and barrels were also noted to be highly visible from long distances both at night and during the day. A study *(16)* 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 and changeable message signs (CMSs), tend to be relatively effective. That study found that flagging and law enforcement are both suitable for all types of highway facilities, and have similar advantages in that they are relatively inexpensive in the short term and relatively quick and easy to implement and remove, with little or no disruption to traffic flow. CMS has similar advantages, but is also suitable for long-term applications, and is effective at night and in inclement whether. Other advantages of CMS included direct control by the contractor over its use, and no manpower requirement, averting high labor costs and management responsibilities. Two studies *(17, 18)* showed that a changeable message sign (CMS) with a radar unit is an effective speed control device for controlling speeds and speed variances both in short-term (one week or less) and long-term (up to seven weeks) work zones. Nemeth and Rathi *(10)* recommended changeable message signs (CMSs) should be considered to inform drivers of possible stop-and-go conditions to reduce the potential for multiple vehicle crashes. They also showed that Ohio Turnpike use flashing amber lights on four signs in the advance warning area on both sides of the roadway and by the rubber cones along the taper (transition area) beside the arrow board used in the taper area. Garber and Woo *(3)* showed that flagging is very effective at work zones on urban two-lane highways.

2.7 Summary

The literature review revealed inconsistent results for many of the studies with respect to several crash characteristics. A summary table of the results from the literature and this study is shown in Table 1. Nemeth and Rathi *(10)* also concluded that high variation exists not only in accident experiences of different sites but also in accident reporting from different agencies. Table 2 shows the difference in study scopes of several major studies concerning crash characteristics. The discrepancies among the results of these studies may be due to several factors, including the number of crashes considered, the time period during which the crashes occurred and the types of highways considered and whether the crashes considered were all work zone related. This study has therefore taken these factors into consideration in building up the data used for the analysis.

Subject	Results	Remarks
Crash rates	1,2,3,4,5: crash rates Increase than the before period	These results are consistent and show crash rate increases in work zones
	3,6: show crash rates at work zones are higher than at at non-work-zone locations	
Crash location	4, 9, 11: most crashes occurred at area 4 or the combined area of area 3 & 4	10 is inconsistent with the other studies
	10: most crashes occurred in area 3	
RE crashes	1,2,3,4,5,8,9,10,11: RE are the predominant collision type	These results are consistent
Multiple-vehicle crashes	1,2,3,7: mutiple-vehicle crashes over-represented at work zones	These results are consistent
Crash severity	4,7: work zone crashes were more severe	These results are inconsistent
	1,3: the severity is not signicantly different from all crashes	
	2,5,8.9,10: work zone crashes were slightly less severe	
Crash Severity for nighttime	4: work zone crashes during nighttime were more severe	These results are inconsistent
	5: work zone crashes during daytime were more severe	
Location distribution during nighttime	5,12: nighttime crashes were especially concentrated at area 2	These two results are consistent
Severity of crashes involving heavy vehicles	4: work zone crashes involving heavy vehicle were more severe	Only one study is identified
Collision type distribution during nighttime	8: nighttime crashes were fixed object crashes	Only one study is identified
Multiple vehicle involvement during nighttime	8: single vehicle crashes were dominant at night	Only one study is identified

Table 1 Major Study Results Concerning Crash Characteristics

Reference	Year	Duration	Length or Number of Sites	Number of Crashes	States	Road Type
1	1982-85	Average 255 days	168 projects, 172 sections, 1045 miles	631	NM	Rural section of Interstate and Federal-Aid Primary
2	1980-85	N/A	4 long-term, 25 intermittent or weekend projects	N/A	IL	Chicago Area Expressway System
3	1982-85	Generally larger than 30 days	26 sites	N/A	VA	Urban two-lane, three-lane highway, highway with 4 or more lanes without a raised median
4	1983-86	4 years	N/A	2013	KY	All
5	1973	mostly within 1 year	21 sites, 384 miles	151	OH	Rural Interstates
7	1984-85	2 years	N/A	N/A	30 states	All
8	1982-86	N/A	All, then 60 projects, then 9 projects	N/A	OH	All
9	1977	1 year	N/A	1847 selected out of 2127	VA	All
10	Around 1978	28 months	240 miles	185	OH	Ohio Turpike

Table 2 Study Scopes of Major Studies Concerning Crash Characteristics

CHAPTER 3: METHODOLOGY

Information on each work zone crash that occurred from 1996 through 1999 in Virginia was obtained from police accident reports. A review of each report was first undertaken to ascertain that each crash selected for the study was work zone related. A total of 1484 crashes out of the 1939 obtained from the database were then selected for the study. The data were summarized in Table 3.

	1996	1997	1998	1999	Total
Fatal	3	5	6	3	17
Injury	158	146	175	87	566
PDO	232	221	293	155	901
Total	393	372	474	245	1484

Table 3 Data Summary by Severity and Year

The location of each crash was then identified and noted as one of the five areas of a work zone. These areas are:

(1) Advance Warning Area

(2) Transition Area

(3) Longitudinal Buffer Area

(4) Activity Area

(5) Termination Area.

The basis for exclusion include:

(1) The crash was not coded as work zone crash or there is no clue on the police accident report that the crash happened in work zones

(2) The crash happened in work zones, but it is obvious that it was caused by factors other than work zones, for example, drivers falling asleep, using cell phones or picking up some objects from the floor of the vehicle.

(3) The crash happened in work zones, but there is no way that the location of the crash can be decided with respect the five areas mentioned above.

These five areas are shown in figure 1. In addition, information was obtained on the severity (Fatal, Injury, or Property Damage Only), the collision type (rear end, angle, sideswipe, fixed object), road type and time of day. Percentage distributions were then determined for the location of the crashes, the severity and the collision type. Each of these distributions was then determined for each road type, and time of day. Modeling efforts has been explored although no promising results have been obtained due to the unavailability to obtain the speed and volume data for each of the work zone crash. Therefore, proportionality tests were then conducted to determine the significance of the distributions of these characteristics. Several previous studies *(2, 3, 5)* also used proportionality test to conduct analysis on work zone crashes. Two types of proportionality tests were conducted in this study. The first type (proportionality test on two proportions, referred in this study as Test 1) is used when the two proportions are from two independent populations. The second type (proportionality test on one proportion, referred as Test 2) is used when the two proportions are from the same population.

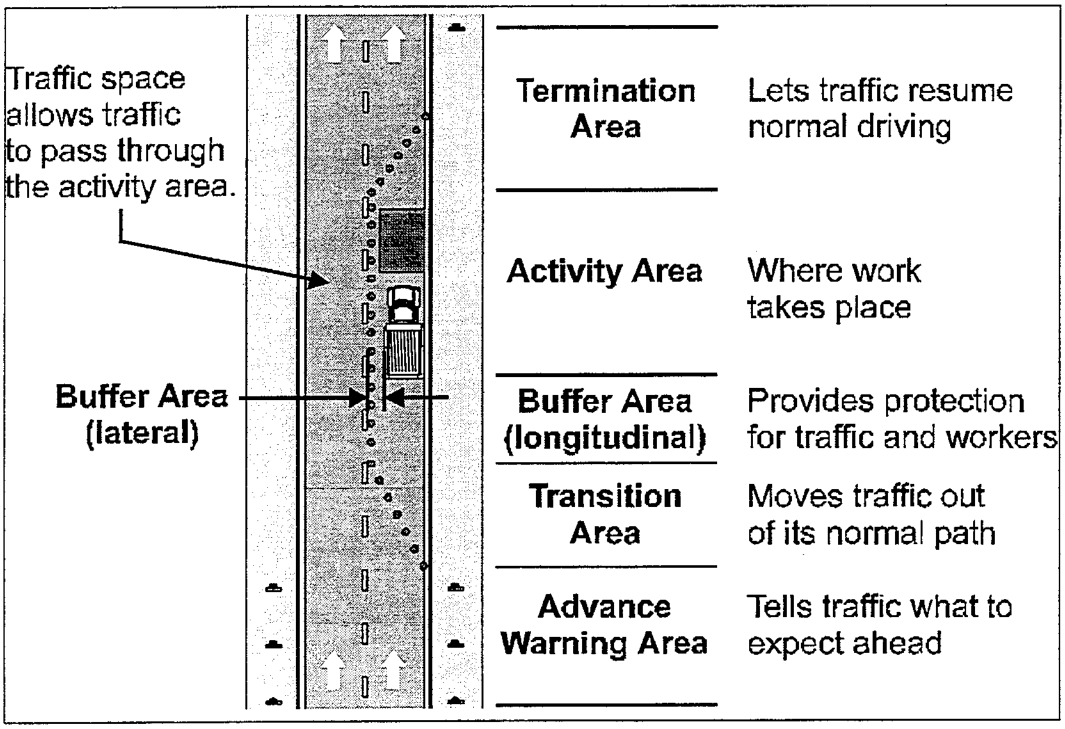


Figure 1 The Five Defined Areas of the Common Work Zone

Test 1, the proportionality test on two proportions, is a test of the quality of two independent means, namely p_1 and p_2, which are the probabilities of success resulting from two different processes. The test statistic is the Z value, which is given as:

$$Z = \frac{p_1 - p_2}{\sqrt{p(1-p)[(\frac{1}{n_1}) + (\frac{1}{n_2})]}} \qquad (1)$$

where p_1 and p_2 are the two proportions to be compared, p is the pooled estimate, and n_1 and n_2 are the population sample sizes:

$$p_1 = \frac{Y_1}{n_1}$$

$$p_2 = \frac{Y_2}{n_2}$$

$$p = \frac{Y_1 + Y_2}{n_1 + n_2}$$

where Y_1 and Y_2 are the number of successes for populations 1 and 2. This test was used to test the null hypothesis $H_0 : p_1 = p_2$ against that of $H_1 : p_1 > p_2$. If the calculated Z-statistic is greater than Z_α, which is the Z statistic corresponding to a significance level of α, then the null hypothesis is rejected and H_1 is accepted.

Test 2, the proportionality tests on one proportion is used when comparing proportions drawn from the same population. The test statistic is also the Z value, which is given as:

$$Z = \frac{Y + 0.5 - np_0}{\sqrt{np_0(1 - p_0)}} \text{ if } Y < np_0 \qquad (2)$$

or

$$Z = \frac{Y - 0.5 - np_0}{\sqrt{np_0(1 - p_0)}} \text{ if } Y > np_0 \qquad (3)$$

where n is the population sample size, Y is the number of success out of population n, p_0 is the proportion used to compare with the proportion of Y / n. This test was used to test the null hypothesis $H_0 : p_1 = p_2$ against that of $H_1 : p_1 > p_2$. If the calculated Z-statistic is greater than Z_α, which is the Z statistic corresponding to a significance level of α, then the null hypothesis is rejected and H_1 is accepted. The information about proportionality test can be obtained from most statistics software or books. NCSS 2000 is used for the proportionality tests conducted in this study.

A 5% significance level was used for all the hypotheses tested. The following null hypotheses were tested:

(1) The proportion of crashes at each location is not significantly different from the proportion at the other locations

(2) For all crashes, the proportion of each severity level is not different from the others

(3) The proportion of crashes by severity is the same for all locations

(4) The proportion of each collision type is not different from the other collision types.

The above null hypotheses were then repeated for each road type and by time of day.

In addition, the following null hypotheses were tested:

(1) The proportion of each severity type for single-vehicle involved crashes is not significantly different from that for multi-vehicle involved crashes

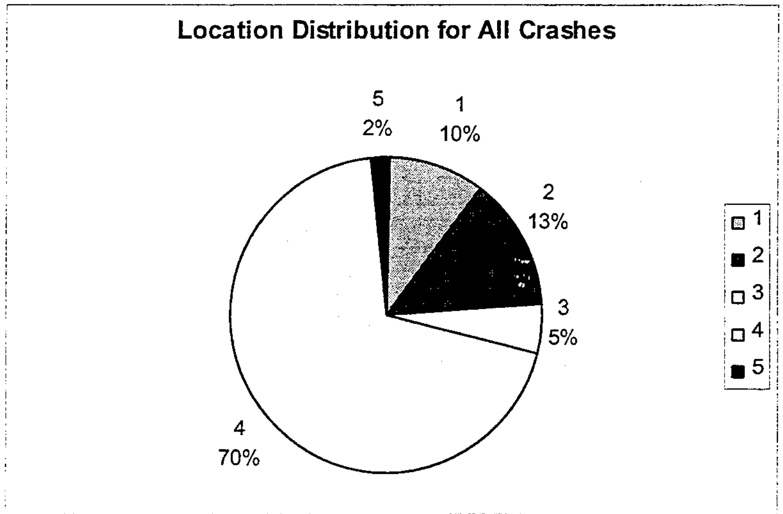
(2) The proportion of each severity type for work-zone crashes is not significantly different from that for non-work-zone crashes

(3) The proportion of each collision type for work-zone crashes is not significantly different from that for non-work-zone crashes

CHAPTER 4: RESULTS

4.1 Location Distribution

The location distribution for the 1484 work zone crashes examined is shown in Figure 2. This figure shows that the activity area (area 4) is the predominant crash location in a work zone, followed by the transition area (area 2), the advance warning area (area 1), the longitudinal buffer area (area 3) and the termination area (area 5) respectively. The results of the proportionality tests (Test 2. See Table 4) show that the proportion of crashes occurring at the Activity Area (Area 4) is significantly higher than that at each of the other locations. Although the importance of applying some exposures in the comparison of the number of crashes occurring within work zones, unfortunately, existing data do not include either the durations of the construction activities or the lengths of the work zones. Therefore, it was possible to computer crash rates based on travel exposures. The results, however, indicate that the predominant number of crashes occur within area 4. The unavailability of the data on the length of the work zone does not change this basic fact. Therefore, although incorporating exposures in the analysis may give additional information. This additional information would not affect the results that many more crashes occur in area 4. It is therefore the opinion of the authors that with regard to safety in work zones, the identification of the location where the majority of the crashes occur is of significant importance. The results of the proportionality tests (Test 2) also indicate that the proportions of crashes in the five areas are significantly different from each other.



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Figure 2 Location Distribution for All Work Zone Crashes

a	# of Crashes at Area a Y	# of Total Crashes n	Y/n	b	# of Crashes at Area b Y0	# of Total Crashes n	p0 Y0/n	Z-Value	Conclusion
4	1030	1484	69.41%	2	200	1484	13.48%	63.06	P1>P2
2	200	1484	13.48%	1	149	1484	10.04%	4.36	P1>P2
1	149	1484	10.04%	3	81	1484	5.46%	7.71	P1>P2
3	81	1484	5.46%	5	24	1484	1.62%	11.63	P1>P2

Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Table 4 Proportionality Tests Results between Crashes Occurring in Different Areas (Test 2)

In order to study the effect of highway type on these distributions, the highways were first classified as interstate, primary and secondary, and then each road was further classified as urban or rural. In classifying the urban and rural roads, the Northern Virginia urban secondary roads were separated from the rest of the urban secondary roads as some urban secondary roads in Northern Virginia carry volumes that are as high as those on primary roads. Figure 3 shows the distribution of work zone crashes by road type. It should be noted, however, that although the highest percentage of work-zone crashes occurred at urban interstate highways, it cannot be concluded that the urban interstate highways are more susceptible to work zone crashes. This is because these crashes were not normalized for traffic volumes or the number of work zones on each type of road. Unfortunately, the data required for this analysis are not available. The location distributions for interstate, primary and secondary roads are shown in Figures 4-6 respectively.

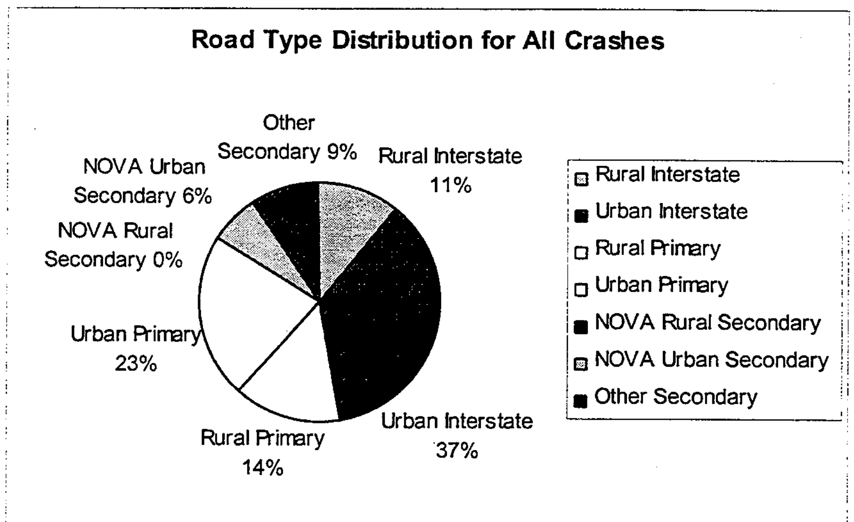
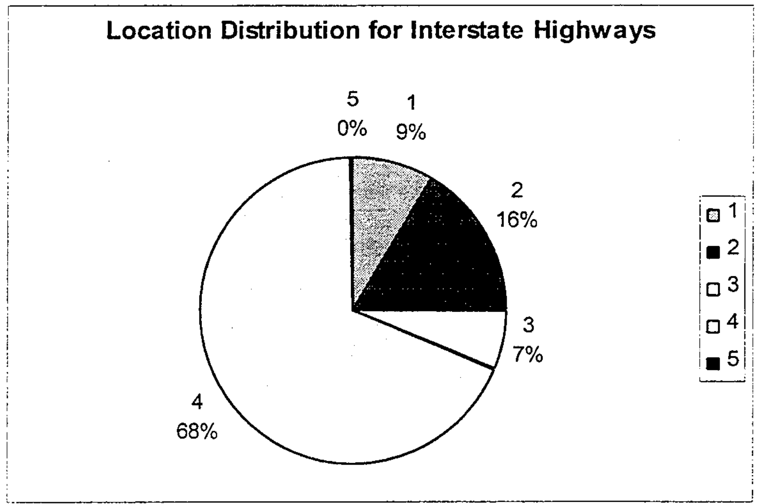


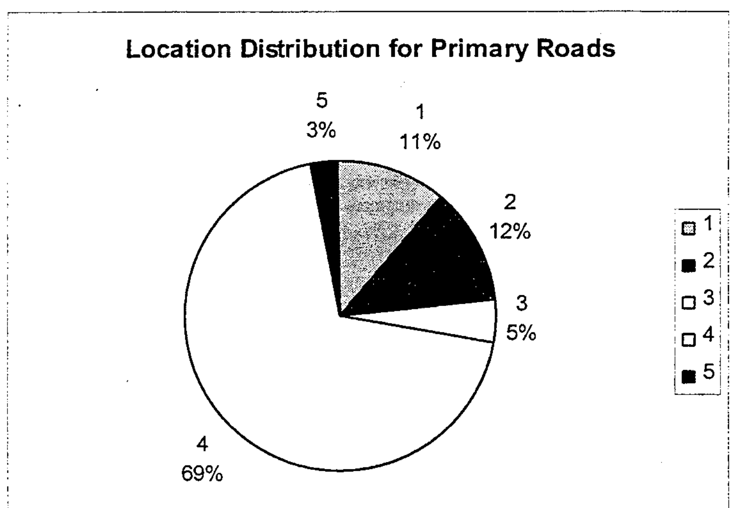
Figure 3 Road Type Distribution for All Work Zone Crashes



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

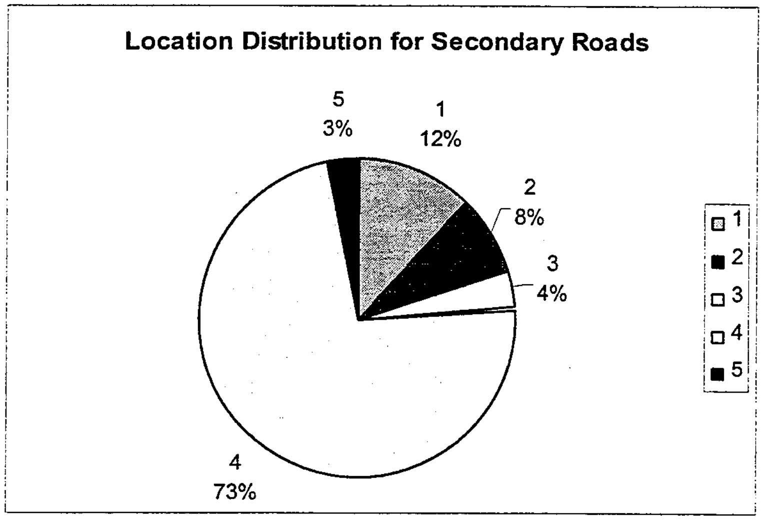
Figure 4 Location Distribution for Work Zone Crashes Occurring on Interstate Highways



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Figure 5 Location Distribution for Work Zone Crashes Occurring on Primary Roads



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Figure 6 Location Distribution for Work Zone Crashes Occurring on Secondary Roads

Table 5 shows the percentage distribution of crashes by road type (with each road further classified as urban and rural) and location at the work zones. When comparing the location distribution for interstate highways and the location distribution for all crashes, using Test 1, the proportion of crashes occurring in each area for interstate highways is compared to the proportion of crashes occurring in the same area for all crashes excluding those occurred on interstate highway. The reason for the exclusion is that that the population for crashes occurring on interstate highways is a part of the population for all crashes and thus it is not reasonable to assume these two proportions are independent. The results of the proportionality tests shown in Table 6, indicate that the respective proportion of the crashes occurring in area 4 for interstate, primary or secondary roads is not significantly different from the proportion of the crashes in area 4 for the other two road types. This indicates that area 4 is more susceptible to crashes regardless of the type of highways. It should be noted that only 24 crashes out of the 1484 occurred in the termination area (area 5). This indicates that the termination area is the safest area in a work zone with respect to numbers of crashes.

Road Type	Number of Crashes	Work Zone Location				
		Area 1	Area 2	Area 3	Area 4	Area 5
Urban Interstate	544	7.2%	16.9%	6.2%	69.3%	0.4%
Rural Interstate	159	13.8%	13.8%	7.6%	64.8%	0.0%
Urban Primary	339	6.8%	10.3%	4.4%	76.1%	2.4%
Rural Primary	206	18.0%	15.5%	5.3%	57.8%	3.4%
NOVA Urban Secondary	94	9.6%	5.3%	7.5%	72.3%	5.3%
NOVA Rural Secondary	2	0.0%	0.0%	50.0%	50.0%	0.0%
Other Secondary	140	13.6%	10.0%	0.7%	74.3%	1.4%

Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Table 5 Percentage Distribution of Crashes by Work Zone Location and Road Type

a	Interstate Highways: # of Crashes at Area a Y1	Interstate Highways: # of Total Crashes n1	p1 Y1/n1	Primary & Secondary Roads: # of Crashes at Area a Y2	Primary & Secondary Roads: # of Total Crashes n2	p2 Y2/n2	Z-Value	Conclusion
1	61	703	8.68%	88	781	11.27%	-1.6579	p1<p2
2	114	703	16.22%	86	781	11.01%	2.9317	p1>p2
3	46	703	6.54%	35	781	4.48%	1.7459	p1>p2
4	480	703	68.28%	550	781	70.42%	-0.8948	p1=p2
5	2	703	0.28%	22	781	2.82%	-3.8616	p1<p2

a	Primary Roads: # of Crashes at Area a Y1	Primary Roads: # of Total Crashes n1	p1 Y1/n1	Interstate Highways & Secondary Roads: # of Crashes at Area a Y2	Interstate Highways & Secondary Roads: # of Total Crashes n2	p2 Y2/n2	Z-Value	Conclusion
1	60	545	11.01%	89	939	9.48%	0.6436	p1=p2
2	67	545	12.29%	133	939	14.16%	-1.0172	p1=p2
3	26	545	4.77%	55	939	5.86%	-0.8883	p1=p2
4	377	545	69.17%	653	939	69.54%	-0.1482	p1=p2
5	15	545	2.75%	9	939	0.96%	2.6409	p1>p2

a	Secondary Roads: # of Crashes at Area a Y1	Secondary Roads: # of Total Crashes n1	p1 Y1/n1	Interstate Highways & Primary Roads: # of Crashes at Area a Y2	Interstate Highways & Primary Roads: # of Total Crashes n2	p2 Y2/n2	Z-Value	Conclusion
1	28	236	11.86%	121	1248	9.70%	1.0167	p1=p2
2	19	236	8.05%	181	1248	14.50%	-2.662	p1<p2
3	9	236	3.81%	72	1248	5.77%	-1.2128	p1=p2
4	173	236	73.31%	857	1248	68.67%	1.4171	p1=p2
5	7	236	2.97%	17	1248	1.36%	1.7914	p1>p2

Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Table 6 Proportionality Test Results between Crashes in Each Area for Each Road Type and Crashes in Each Area for The Other Two Road Types (Test 1)

4.2 Severity Distribution

Severity distributions were obtained for all crashes at different locations and for different road types. Table 7 shows the severity distribution by location and road type. Figure 7 shows the severity distribution for all crashes. The results of proportionality tests (Test 2) indicate that the most prevalent severity type is Property Damage Only (PDO) for all road types except for "rural primary" and "other secondary" roads, where the proportions for injury and PDO crashes are not significantly different from each other.

Road Type	Number of Crashes	Work Zone Location														
		Area 1			Area 2			Area 3			Area 4			Area		
		Fatal	Injury	PDO	Fatal	Injury	PDO	Fatal	Injury	PDO	Fatal	Injury	PDO	Fatal	Injury	PDO
Urban Interstate	544	0.2%	2.6%	4.4%	0.0%	5.7%	11.2%	0.0%	2.0%	4.2%	0.5%	26.3%	42.5%	0.0%	0.2%	0.2%
Rural Interstate	159	0.0%	5.0%	8.8%	0.0%	3.8%	10.1%	0.6%	2.5%	4.4%	2.5%	22.0%	40.3%	0.0%	0.0%	0.0%
Urban Primary	339	0.0%	3.3%	3.6%	0.0%	2.4%	8.0%	0.0%	1.8%	2.7%	0.6%	26.0%	49.6%	0.0%	1.2%	1.2%
Rural Primary	206	0.5%	8.3%	9.2%	0.0%	8.7%	6.8%	0.5%	2.4%	2.4%	1.0%	26.7%	30.1%	0.0%	1.0%	2.4%
NOVA Urban Secondary	94	0.0%	2.1%	7.4%	0.0%	1.1%	4.2%	0.0%	3.2%	4.3%	1.1%	27.7%	43.6%	0.0%	0.0%	5.3%
NOVA Rural Secondary	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%	50.0%	0.0%	0.0%	0.0%
Other Secondary	140	0.0%	4.3%	9.3%	0.0%	5.0%	5.0%	0.0%	0.7%	0.0%	0.7%	37.9%	35.7%	0.0%	0.0%	1.4%

Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Table 7 Percentage Distribution of Crashes by Severity, Location and Road Type

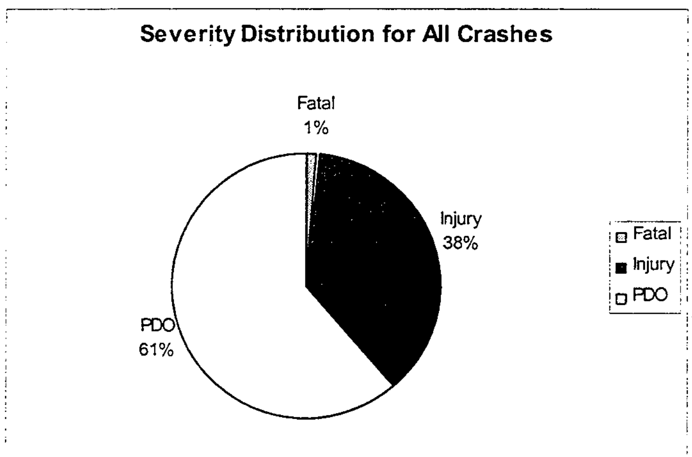


Figure 7 Severity Distribution for All Work Zone Crashes

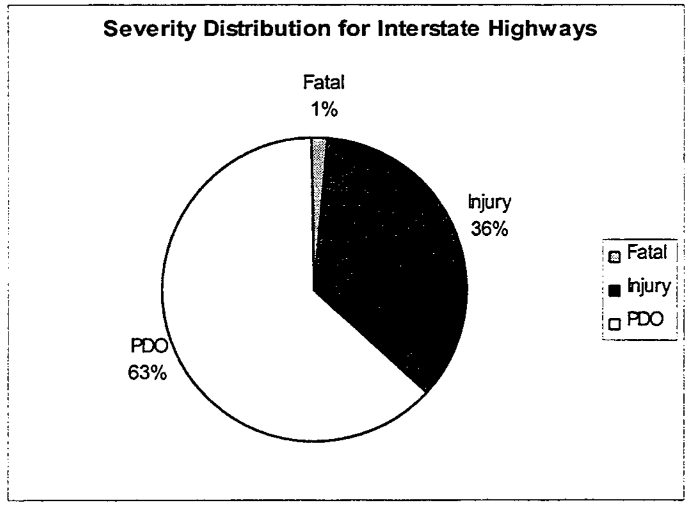


Figure 8 Severity Distribution for Work Zone Crashes Occurring on Interstate Highways

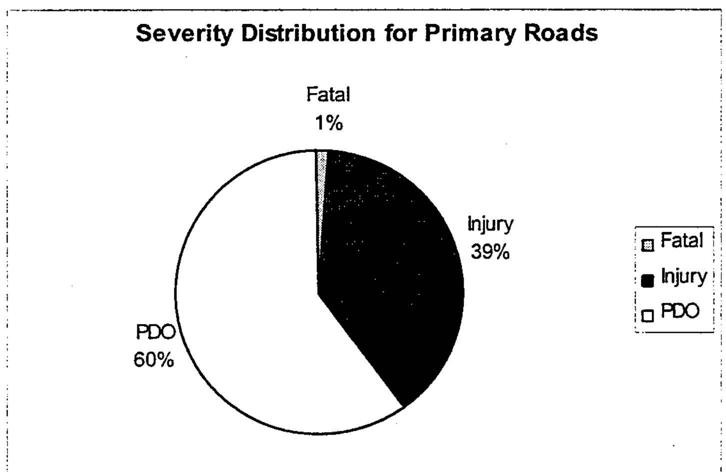


Figure 9 Severity Distribution for Work Zone Crashes Occurring on Primary Roads

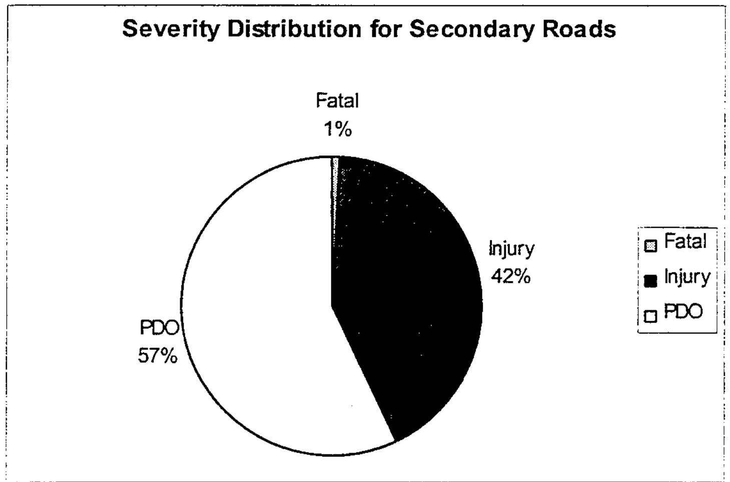


Figure 10 Severity Distribution for Work Zone Crashes Occurring on Secondary Roads

The severity distributions for interstate, primary and secondary roads are shown in figures 8-10 respectively. An in-depth study of the police reports of the fatal crashes indicates that 35% (6) of the fatalities were workers on the roads, classified as PE (collision with pedestrian) crashes. Table 8 shows the percentage of the fatalities that were road workers compared with those that were vehicle occupants and other pedestrians. The location distribution analysis of the fatalities found that 76% (14) of the fatalities occurred in the activity area (area 4). As we know from the result of the location distribution analysis, most work zone crashes also occurred in this area. Therefore, this area demands the highest attention.

Fatal Crashes	Total Fatalities	Vehicle Occupants Fatalities	Workers Fatalities	Other Pedestrian Fatalities
17	17	11 (65%)	6 (35%)	0

Table 8 Percentages of Fatalities for Work Zone Crashes

When comparing the severity distribution for each area and the severity distribution for all crashes, using test 1, the proportion of crashes occurring in each area is compared to the proportion of crashes occurring in the same area for all crashes excluding those occurred in the area considered for the previous proportion. The reason for the exclusion is that that the population for crashes occurring in each area is a part of the population for all crashes and thus it is not reasonable to assume these two proportions are independent. The results of proportionality tests indicate that the proportion of fatal crashes at each work zone area is not significantly different from the proportion of the fatal crashes at the other four areas (See Table 9). Similarly the proportion of crashes occurring on each road type is compared to the proportion of all crashes excluding those occurred on the road type considered for the previous proportion using Test 1. The results proportionality tests indicated that the proportion of fatal crashes on interstate, primary or secondary roads is not significantly different from the proportion of fatal crashes for the other two road types (See Table 10).

	Area a			The Other Areas				
	# of Fatal Crashes	# of Total Crashes	p1	# of Fatal Crashes	# of Total Crashes	p2	Z-Value	Conclusion
a	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
1	2	149	1.34%	15	1335	1.12%	0.2379	p1=p2
2	0	200	0.00%	17	1284	1.32%	-1.6367	p1=p2
3	2	81	2.47%	15	1403	1.07%	1.1513	p1=p2
4	13	1030	1.26%	4	454	0.88%	0.6357	p1=p2
5	0	24	0.00%	17	1460	1.16%	-0.5317	p1=p2

Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

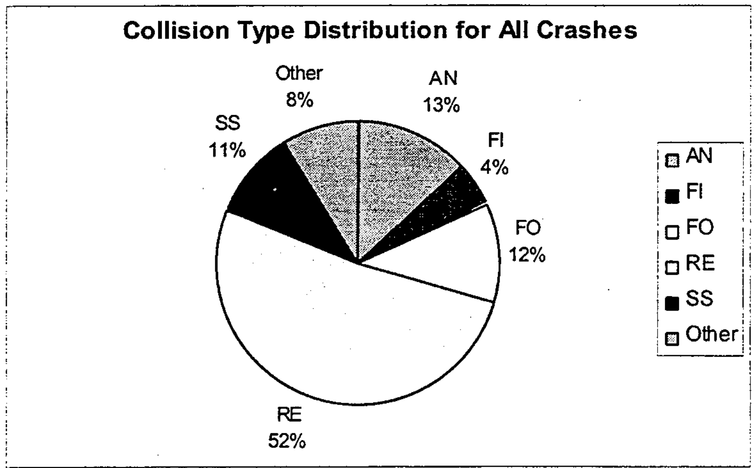
Table 9 Proportionality Test Results between Fatal Crashes in Each Area and Fatal Crashes in The Other Areas (Test 1)

a	Road Type a		p1	The Other Road Types		p2	Z-Value	Conclusion
	# of Fatal Crashes	# of Total Crashes	p1	# of Fatal Crashes	# of Total Crashes	p2		
a	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
Interstate	9	703	1.28%	8	781	1.02%	0.4625	p1=p2
Primary	6	545	1.10%	11	939	1.17%	-0.1231	p1=p2
Secondary	2	236	0.85%	15	1248	1.20%	-0.4693	p1=p2

Table 10 Proportionality Test Results between Fatal Crashes for Each Road Type and The Other Road Types (Test 1)

4.3 Collision Type Distribution

Figure 11 shows the distribution of all crashes by collision type. The collision types with percentages of 3% or less were combined together and categorized as "others". These included BI (Backed Into), HD (Head On), MO (Miscellaneous or Other), NO (Non-Collision), PE (Pedestrian), and SO (Sideswipe: Opposite Direction). The results of proportionality tests (Test 2) indicated that RE (rear end) was the predominant collision type and FI (fixed object in road) was the least prevalent collision type among the five collision types examined. The results of the proportionality tests (Test 2) also indicated that the proportion of FO (fixed object off road) crashes is significantly higher than the proportion of SS (sideswipe in same direction) crashes. However, the proportion of AN (angle) crashes is not significantly different from the proportion of FO (fixed object off road) crashes.

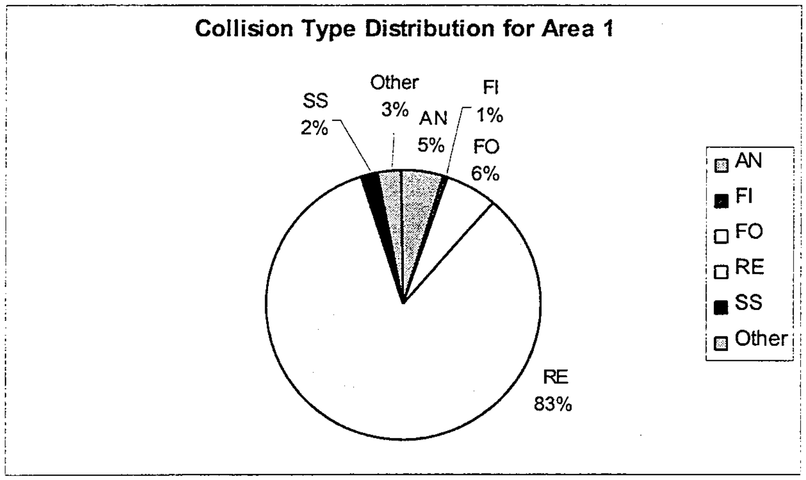


AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 11 Collision Type Distribution for All Work Zone Crashes

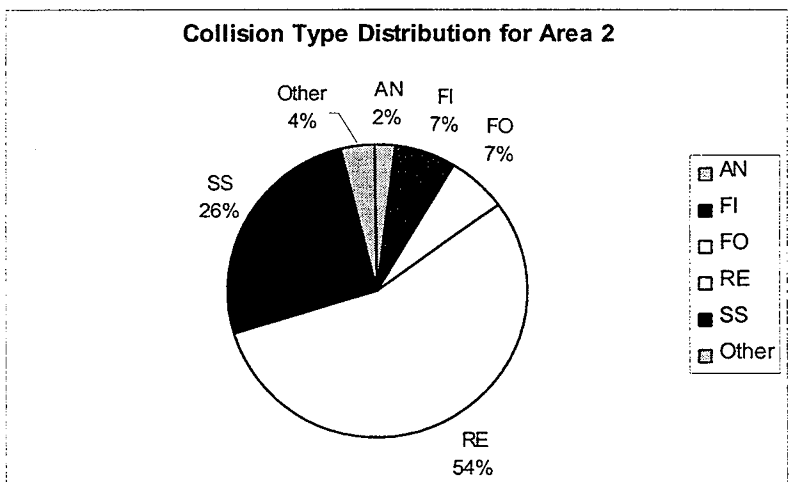
Collision type distributions for areas 1 and 2 are shown in Figures 12 and 13 respectively. Although RE (rear end) is the predominant crash type for all areas except area 5 (Termination Area), the proportion of this crash type in area 1 is significantly higher than the corresponding proportion for each of the other areas. The high percentage of RE (rear end) crashes in area 1 may be due to increased speed variance in this area, caused by some drivers observing the speed reduction signs and reducing their speeds, while others do not. Although RE (rear end) crash is the predominant crash type in area 2, the percentage (26%) of the SS (sideswipe in same direction) crashes has increased to a level much higher than that for area 1. This increase in SS (sideswipe in same direction) crashes may be due to the increase in merging maneuvers necessitated by the reduction of the number of through lanes.



AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 12 Collision Type Distribution for Work Zone Crashes Occurring in Area 1 (Advance Warning Area)

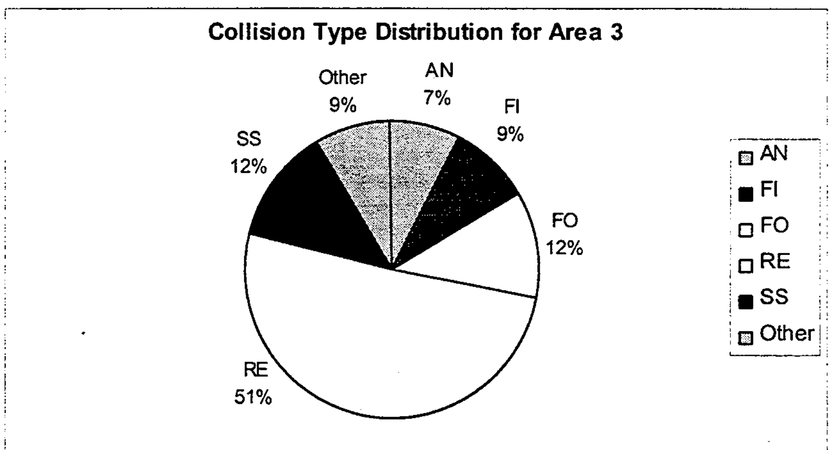


AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 13 Collision Type Distribution for Work Zone Crashes Occurring in Area 2 (Transition Area)

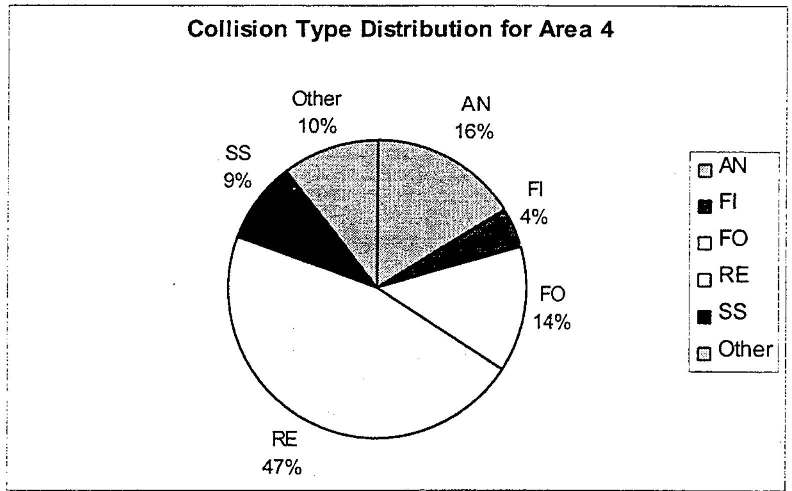
Collision type distributions for areas 3 and 4 are shown in Figures 14 and 15 respectively. The results of proportionality tests (Test 1) show that the percentage distribution of crashes by collision type is not significantly different for areas 3 and 4. It is therefore reasonable to combine these two locations in carrying out an analysis of crash type at work zones. As one moves from the transition area (area 2) to work area (combing areas 3 and 4), the proportions of RE (rear end) and SS (sideswipe in same direction) crashes decrease and the proportion of FO (fixed object off road) and AN (angle) crashes increase. This may be due to the increase of conflicts between traffic and the construction activities.



AN (Angle)   FI (Fixed object In road)   FO (Fixed object Off road)

RE (Rear End)   SS (Sideswipe in Same direction)

Figure 14 Collision Type Distribution for Work Zone Crashes Occurring in Area 3 (Longitudinal Buffer Area)

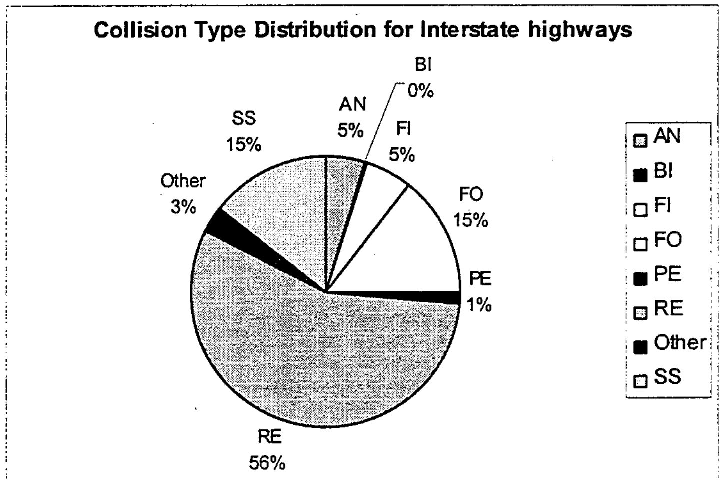


AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 15 Collision Type Distribution for Work Zone Crashes Occurring in Area 4 (Activity Area)

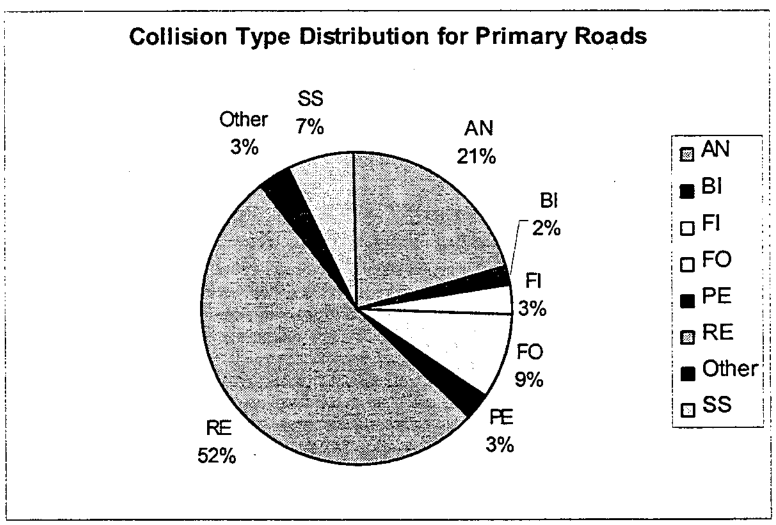
Collision type distributions for interstate, primary and secondary roads are shown in Figures 16 through 18 respectively. The results of proportionality tests (Test 2) show that RE (rear end) is the predominant collision type for interstate highways, followed by FO (fixed object off road), SS (sideswipe in same direction), FI (fixed object in road) and AN (angle). However, the proportion of FO (fixed object off road) crashes is not significantly different from the proportion of SS (sideswipe in same direction) crashes. Similarly the proportion of FI (fixed object in road) crashes is not significantly different from the proportion of AN (angle) crashes. For primary roads, RE (rear end) is also the predominant collision type, followed by AN (angle), FO (fixed object off road), SS (sideswipe in same direction) and FI (fixed object in road). However, the proportion of FO (fixed object off road) crashes is not significantly different from the proportion of SS (sideswipe in same direction) crashes. For secondary roads, RE (rear end) is also the predominant collision type, followed by AN (angle), FO (fixed object off road) then SS (sideswipe in same direction), BI (backed into) and PE (collision with pedestrian). In this case the proportions of SS (sideswipe in same direction), BI (backed into), and PE (collision with pedestrian) crashes are not significantly different from each other.



AN (Angle) BI (Backed Into) FI (Fixed object In road) FO (Fixed object Off road)

PE (Collision with Pedestrian) RE (Rear End) SS (Sideswipe in Same direction)

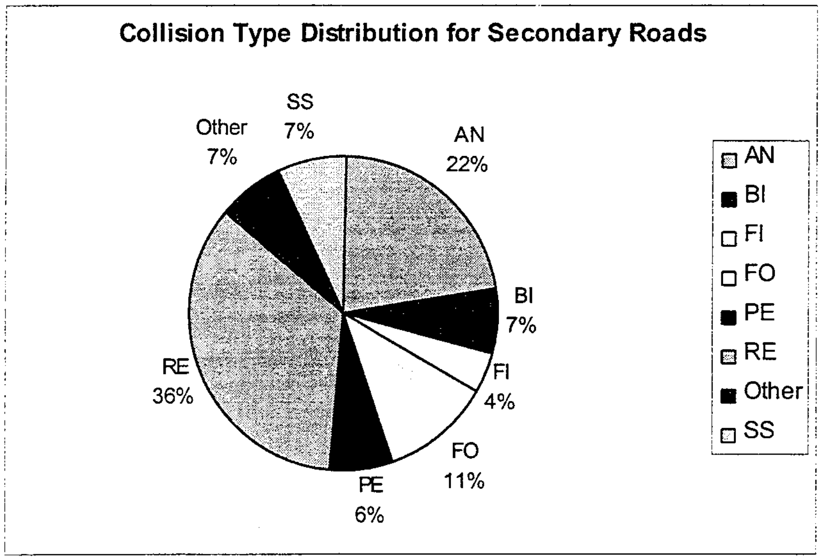
Figure 16 Collision Type Distribution for Work Zone Crashes Occurring on Interstate Highways



AN (Angle) BI (Backed Into) FI (Fixed object In road) FO (Fixed object Off road)

PE (Collision with Pedestrian) RE (Rear End) SS (Sideswipe in Same direction)

Figure 17 Collision Type Distribution for Work Zone Crashes Occurring on Primary Roads



AN (Angle) BI (Backed Into) FI (Fixed object In road) FO (Fixed object Off road)

PE (Collision with Pedestrian) RE (Rear End) SS (Sideswipe in Same direction)

Figure 18 Collision Type Distribution for Work Zone Crashes Occurring on Secondary Roads

In order to test whether the proportion of a collision type is influenced by the type of highways, the proportionality test (Test 1) was conducted on the distributions by collision type for the different types of highways. The following results were obtained:

(1) The proportions of RE (rear end) crashes on interstate and primary roads are significantly higher than the proportion of RE crashes on secondary roads.

(2) The proportions of AN (angle) crashes on primary and secondary roads are significantly higher than the proportion of AN crashes on interstates.

(3) The proportion of SS (sideswipe in same direction) crashes for interstates is significantly higher than the proportions of SS crashes on primary and secondary roads.

(4) The proportion of BI (backed into) crashes on secondary roads is significantly higher than the proportion of BI crashes on interstates.

(5) The proportion of FO (fixed object off road) crashes on interstates is significantly higher than the proportion of FO crashes on primary roads.

(6) The proportions of FI (fixed object in road) crashes for different road types are not significantly different from each other.

(7) The proportion of PE (collision with pedestrian) on secondary roads is the highest, followed by the proportion on primary roads, then the proportion on interstate highways.

In comparing urban roads with rural roads, the results of the proportionality tests (Test 1) indicated the following:

(1) The proportion of each collision type for urban interstates is not significantly different from that for the rural interstates.

(2) The proportions of AN (Angle), FI (fixed object in road), PE (collision with pedestrian) and RE (rear end) crashes for urban primary roads are not significantly different from those for rural primary roads, while the proportions of BI (backed into) and FO (fixed object off road) crashes for urban primary roads are significantly lower than those for rural primary roads and the proportion for SS (sideswipe in same direction) crashes for urban primary roads is significantly higher than those for rural primary roads.

Collision Type	Number of Crashes	Severity		
		Fatal	Injury	PDO
AN	198	3	69	126
FI	65	1	22	42
FO	178	0	75	295
RE	761	3	295	463
SS	157	0	31	126
Other	125	10	74	41
Sum	1484	17	566	901

AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Table 11 Distribution of Crashes by Collision Type and Severity

Table 11 shows the severity distribution for each collision type examined. The proportion of crashes for each collision type is compared to the proportion of all crashes excluding the collision type considered for the previous proportion using Test 1. The reason for the exclusion is that that the population of crashes for each collision type is a part of the population for all crashes and thus it is not reasonable to assume these two proportions are independent. The results of the proportionality tests indicate the following (See Table 12):

(1) The proportion of the fatal crashes for RE (Rear End) crashes is significantly lower than the proportion of the fatal crashes for the other collision types. The proportions of the injury and PDO crashes for RE crashes are not significantly different from the proportions of the injury and PDO crashes for the other collision types.

(2) The proportion of the injury crashes for SS (Sideswipe in Same Direction) crashes is significantly lower than the proportion of the injury crashes for the other collision types. The proportion of the PDO crashes for SS crashes is

significantly higher than the proportion of the PDO crashes for the other collision types. The proportion of the fatal crashes for SS crashes is not significantly different from the proportion of the fatal crashes for the other collision types.

(3) The distribution by severity for AN (Angle), FI (fixed object in road) and FO (fixed object off road) crashes separately is not significantly different from that for the other collision types.

	Collision Type a			The Other Collision Types				
	# of Fatal Crashes	# of Total Crashes	p1	# of Fatal Crashes	# of Total Crashes	p2	Z-Value	Conclusion
a	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
AN	3	198	1.52%	14	1286	1.09%	0.525	p1=p2
FI	1	65	1.54%	16	1419	1.13%	0.3044	p1=p2
FO	0	178	0.00%	17	1306	1.30%	-1.531	p1=p2
RE	3	761	0.39%	14	723	1.94%	-2.7904	p1<p2
SS	0	157	0.00%	17	1327	1.28%	-1.4264	p1=p2
	Collision Type a			The Other Collision Types				
	# of Injury Crashes	# of Total Crashes	p1	# of Injury Crashes	# of Total Crashes	p2	Z-Value	Conclusion
a	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
AN	69	198	34.85%	497	1286	38.65%	-1.0244	p1=p2
FI	22	65	33.85%	544	1419	38.34%	-0.7289	p1=p2
FO	75	178	42.13%	491	1306	37.60%	1.1696	p1=p2
RE	295	761	38.76%	271	723	37.48%	0.5082	p1=p2
SS	31	157	19.75%	535	1327	40.32%	-5.018	p1<p2
	Collision Type a			The Other Collision Types				
	# of PDO Crashes	# of Total Crashes	p1	# of PDO Crashes	# of Total Crashes	p2	Z-Value	Conclusion
a	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
AN	126	198	63.64%	775	1286	60.26%	0.9044	p1=p2
FI	42	65	64.62%	859	1419	60.54%	0.6586	p1=p2
FO	103	178	57.87%	798	1306	61.10%	-0.8297	p1=p2
RE	463	761	60.84%	438	723	60.58%	0.1025	p1=p2
SS	126	157	80.25%	775	1327	58.40%	5.3016	p1>p2

AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Table 12 Proportionality Tests Results between Fatal, Injury or PDO Crashes for Each Collision Type and The Other Collision Types (Test 1)

4.4 Severity and Collision Type Distribution by Time

In order to determine the effect of time of day on the crash characteristics at work zones, the crashes were classified into six groups based on the time of day that the crash occurred. The following time periods were used: 6:00-10:00, 10:00-13:00, 13:00-16:00, 16:00-19:00, 19:00-22:00, and 22:00-6:00. The time ranges were selected to allow the evaluation of the effect of the peak volume periods.

The severity distribution of crashes occurring in Area 4 (Activity Area) for different time periods is shown in Table 13. Proportional tests (Test 1) show that the proportion of injury crashes for the time intervals of 6:00 - 10:00 and 16:00 - 19:00 are significantly lower than the corresponding proportions for the time intervals between 10:00 and 16:00. The proportions of fatal and PDO crashes for the time of 6:00 - 10:00 and 16:00 - 19:00 are not significantly different from the corresponding proportions for the time intervals between 10:00 and 16:00. The possible reason for this may be that there are higher volume and lower driving speed during the morning peak and evening peak than the time intervals of between 10:00 and 16:00. The proportions of each collision type for other time intervals are not significantly different from each other.

Time Intervals	Number of Crashes	Severity		
		Fatal	Injury	PDO
6:00-10:00	165	2	53	110
10:00-13:00	195	2	86	107
13:00-16:00	213	3	85	125
16:00-19:00	164	2	49	113
19:00-22:00	124	1	54	69
22:00-6:00	169	3	73	93

Table 13 Distribution of Crashes Occurring in Area 4 by Different Time Periods

RE crashes were the predominant crashes for all time zones. Also it was found out that most of the crashes occurred in area 4 for all time periods. The results of proportionality tests (Test 1) also show:

(1) The proportion of AN (angle) crashes occurring during 22:00-6:00 in area 4 is significantly lower than the proportion for the other time intervals.

(2) The proportion of FI (fixed object in road) crashes occurring during 22:00-6:00 in area 4 is significantly higher than the proportion for the time interval of 10:00-19:00, but is not significantly different from those for other time intervals.

(3) The proportion of FO (fixed object off road) crashes occurring during 19:00-6:00 in area 4 is significantly higher than the proportion for other time intervals.

(4) The proportion of RE (rear end) crashes during 19:00-6:00 is significantly lower than the proportion for other time intervals.

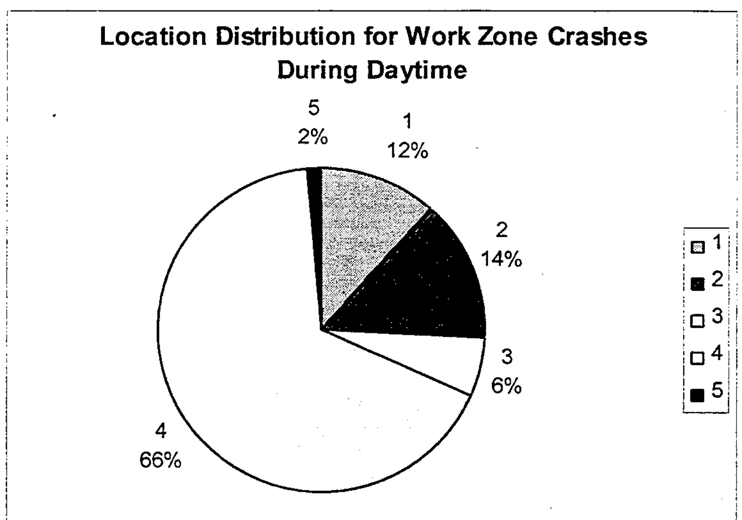
(5) The proportion of SS (sideswipe in same direction) crashes is not significantly different between different time intervals.

The possible reason for more fixed object crashes during nighttime than daytime may be due to insufficient lighting and visibility, and driver fatigue during nighttime. The possible reason for less AN (angle) and RE (rear end) crashes during nighttime than daytime may be due to less traffic volume and less traffic conflicts during nighttime than during daytime.

4.5 Nighttime and Daytime Distribution

4.5.1 Location Distributions during Nighttime and Daytime

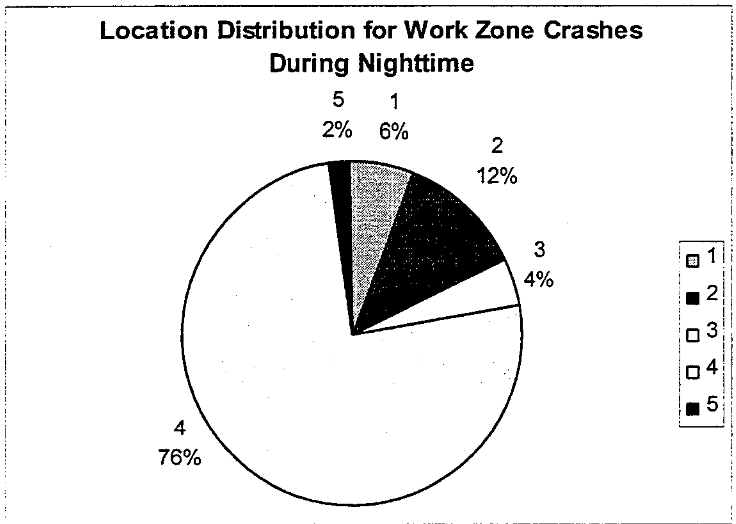
Although two studies *(5, 12)* showed that nighttime crashes at work zones tend to occur more often in the transition areas, this study does not show similar results. 7 A.M. and 7 P.M. were used as the dividing points for daytime and nighttime. The location distributions for daytime and nighttime are shown in Figure 19 and 20 respectively. Out of the 399 crashes occurring during nighttime, 75% (304) occurred in the activity area (area 4) and only 12% (47) occurred in the transition area; while out of the 1085 crashes occurring during daytime, 66% (726) occurred in the activity area and 14% (153) occurred in the transition area.



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Figure 19 Location Distribution for Work Zone Crashes During Daytime



Area 1 (Advance Warning Area) Area 2 (Transition Area) Area 3 (Longitudinal Buffer Area)

Area 4 (Activity Area) Area 5 (Termination Area)

Figure 20 Location Distribution for Work Zone Crashes During Nighttime

By comparing the location distribution of work zone crashes occurring during daytime and nighttime, we can draw the following conclusions from the proportionality tests (Test 1):

(1) The proportion of nighttime work zone crashes occurring in area 4 (activity area) is significantly higher than the proportion of daytime work zone crashes occurring in this area.

(2) The proportion of nighttime work zone crashes occurring in area 1 (advance warning area) is significantly lower than the proportion of daytime work zone crashes occurring in this area.

(3) The proportions of work zone crashes occurring in the other areas during daytime and nighttime are not significant different from each other.

4.5.2 Severity Distributions during Nighttime and Daytime

Severity distributions for nighttime and daytime periods were also examined respectively. The percentages for fatal, injury and PDO crashes occurring during daytime are 0.9%, 37.9%, 61.2% respectively; while the percentages for fatal, injury and PDO crashes occurring during nighttime are 1.8%, 38.8%, 59.4% respectively. The proportion of fatal crashes during nighttime doubled the proportion of fatal crashes during daytime. However, Proportionality tests (Test 1) show that the proportions of each severity type for daytime and nighttime are not significantly different from each other.

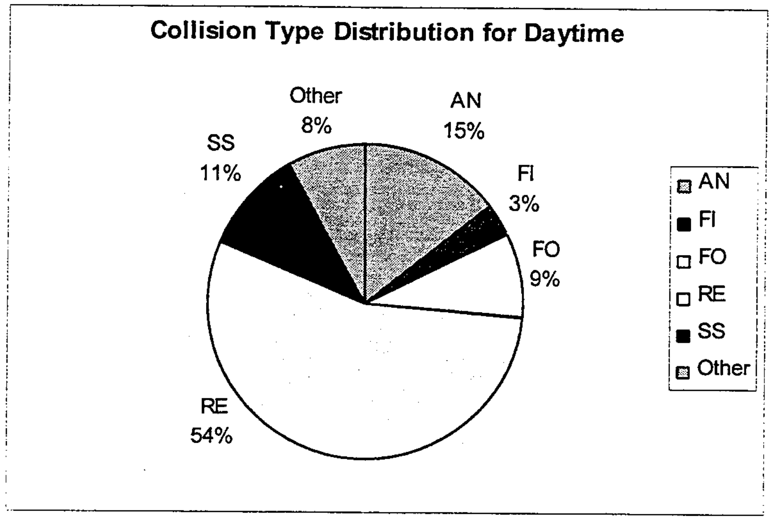
4.5.3 Collision Type Distributions during Nighttime and Daytime

Ha and Nemeth *(8)* concluded that night crashes were most likely to be fixed object crashes. The collision type distribution for daytime and nighttime periods were also examined and are shown in Figure 21 and 22 respectively. The results of the proportionality tests (Test 1) show:

(1) The proportions of FI (fixed object in road) and FO (fixed object off road) crashes during nighttime are significantly higher than the corresponding proportions during daytime.

(2) The proportions of AN (angle) and RE (rear end) crashes during nighttime are significantly lower than the corresponding proportions during daytime.

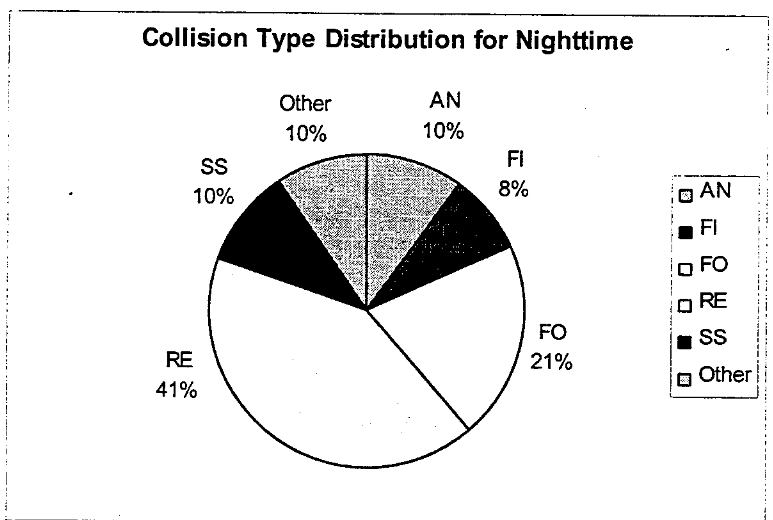
(3) The proportion of SS (sideswipe in same direction) crashes during nighttime is not significantly different from that during daytime.



AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 21 Collision Type Distribution for Work Zone Crashes During Daytime



AN (Angle) FI (Fixed object In road) FO (Fixed object Off road)

RE (Rear End) SS (Sideswipe in Same direction)

Figure 22 Collision Type Distribution for Work Zone Crashes During Nighttime

The proportions of fixed object crashes did increase significantly during nighttime, but the RE (rear end) crashes are still the predominant collision type (42%). By examining the numbers of fixed object crashes during nighttime and daytime, it is found that 121 out of 430 crashes occurring during nighttime is fixed object crashes; while 120 out of 1054 crashes occurring during daytime is fixed object crashes. There're more fixed object crashes during nighttime, not only in proportions but also in exact numbers.

4.5.4 Single Vehicle and Multiple Vehicle Distribution during Nighttime and Daytime

Ha and Nemeth *(8)* also concluded that single vehicle crashes were dominant at night. The results of the proportionality tests (Test 1) show that the proportion of single vehicle crashes occurred during nighttime is significantly higher than the corresponding proportion occurred during daytime. In fact, out of 430 crashes occurring during nighttime, 86 are single vehicle crashes, whereas out of 1054 crashes occurring during daytime, 71 are single vehicle crashes. As we can see, 344 crashes (80%) occurring during nighttime are multiple vehicle crashes. Therefore, we can conclude multiple vehicle crashes are predominant during nighttime.

4.6 Weather Condition Distribution

The weather condition distribution for all crashes is illustrated in Figure 23. Proportional tests show that most work zone crashes occurring in clear weather condition.

The reason for that may be that most work zone activities are conducted under favorable weather conditions although work zones are there continuously.

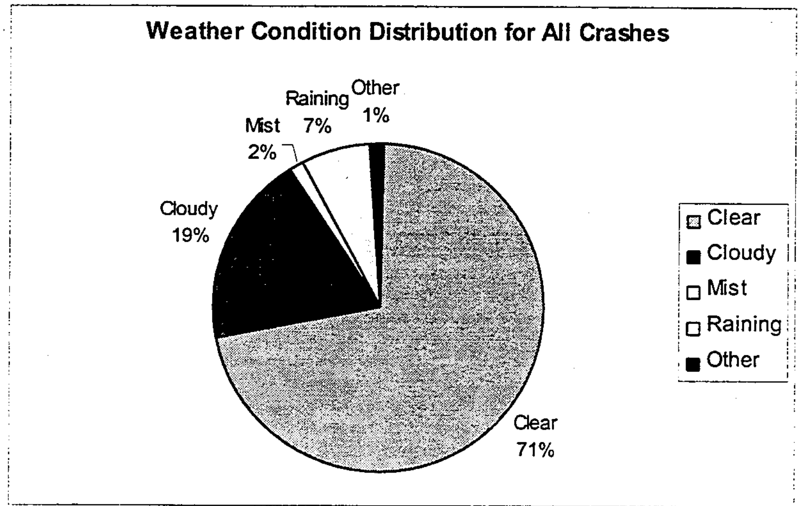


Figure 23 Weather Condition Distribution for All Work Zone Crashes

4.7 Severity and Collision Type Distribution by Heavy Vehicle Involvement

The severity distributions for car only crashes and for crashes involving heavy vehicles are shown in Figure 24 and 25. Heavy vehicle in this study is defined to include: straight truck, tractor trailer, tractor double trailer, oversized vehicle, motorhome/recreational vehicle, school bus, and commercial bus. A slightly higher percentage of fatal crashes occur for crashes involving heavy vehicles than for car only crashes. Proportionality tests (Test 1) however indicated that there is no significant difference between the two proportions.

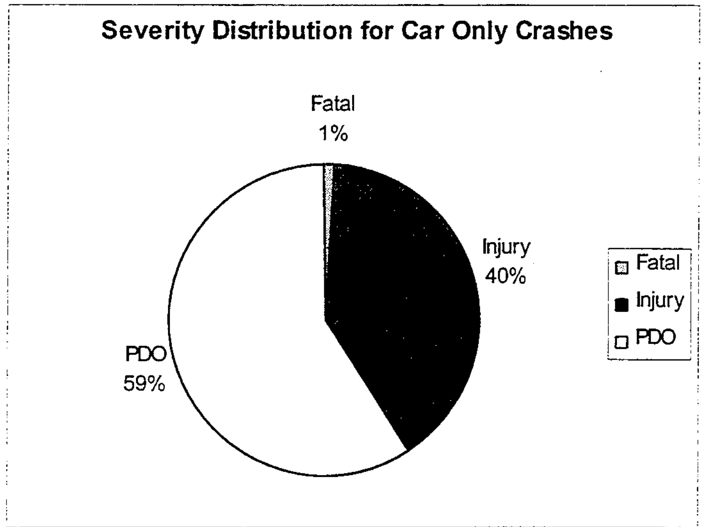


Figure 24 Severity Distribution for Car Only Crashes in Work Zone

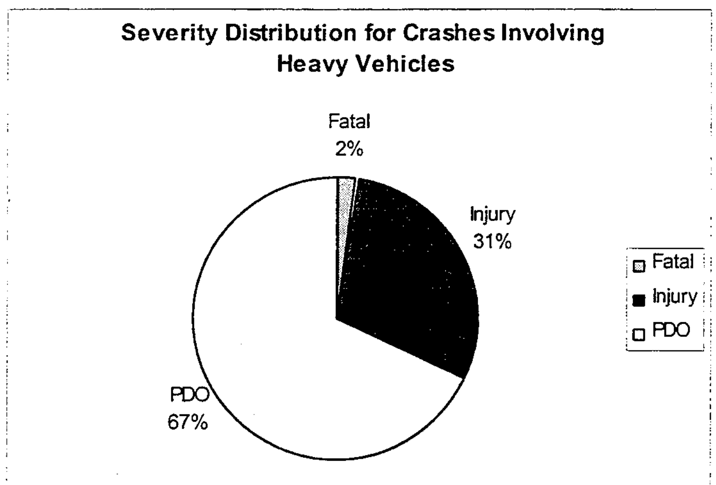


Figure 25 Severity Distribution for Crashes Involving Heavy Vehicles in Work Zone

The collision type distributions for car only crashes and crashes involving heavy vehicles are illustrated in Figures 26 and 27. The proportionality tests (Test 1) show that the proportions of FI and SS crashes for crashes involving heavy vehicles are significantly higher than the corresponding proportions for car only crashes. The proportions of AN and RE crashes for crashes involving heavy vehicles are significantly lower than the corresponding proportions for car only crashes. There are also higher proportions of FI and SS and lower proportions of AN and RE crashes for multiple vehicle crashes involving only cars than for multiple vehicle crashes involving heavy vehicles.

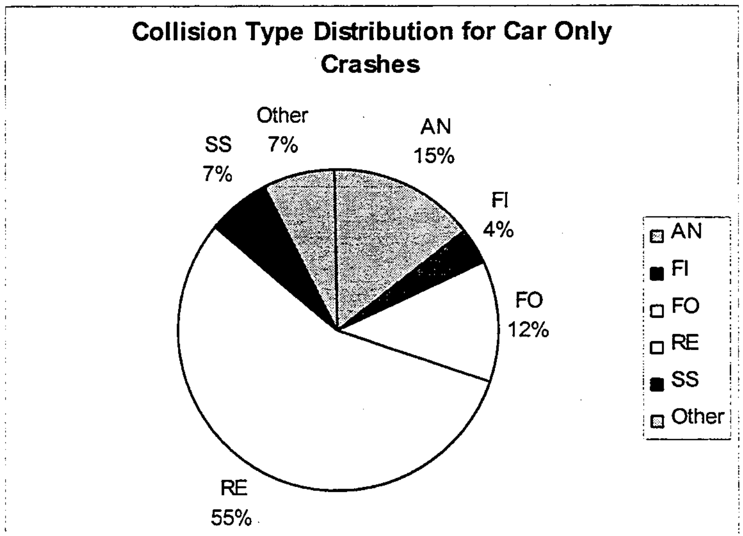


Figure 26 Collision Type Distribution for Car Only Crashes in Work Zone

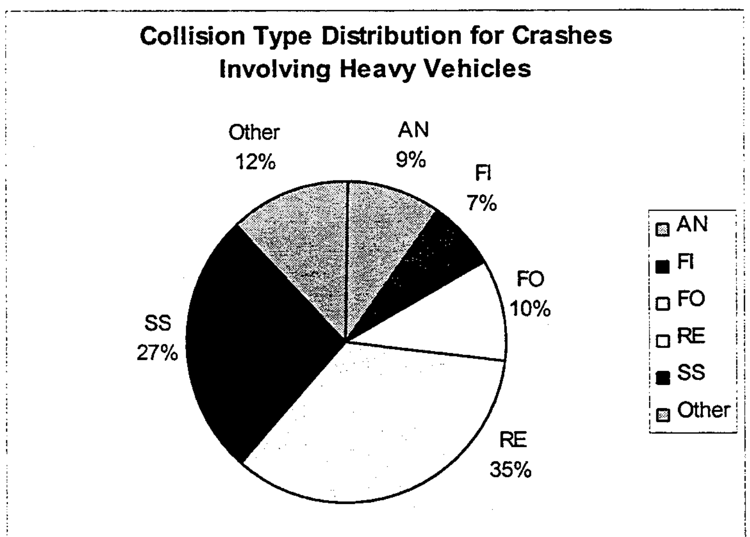


Figure 27 Collision Type Distribution for Crashes Involving Heavy Vehicles in Work Zone

4.8 Severity Distribution by Single & Multiple Vehicle Involvement

The severity distributions for single vehicle crashes and for multiple vehicle crashes are shown in figures 28 and 29. All 17 fatal crashes studied are multiple vehicle crashes. The proportionality tests (Test 1) also show that the proportion of the injury crashes for single vehicle crashes is significantly higher than that for multiple vehicle crashes and the proportion of the PDO crashes for single vehicle crashes is significantly lower than that for multiple vehicle crashes.

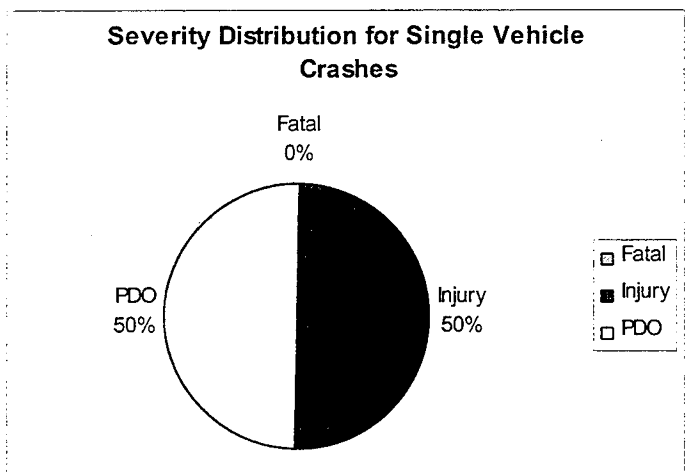


Figure 28 Severity Distribution for Single Vehicle Crashes in Work Zone

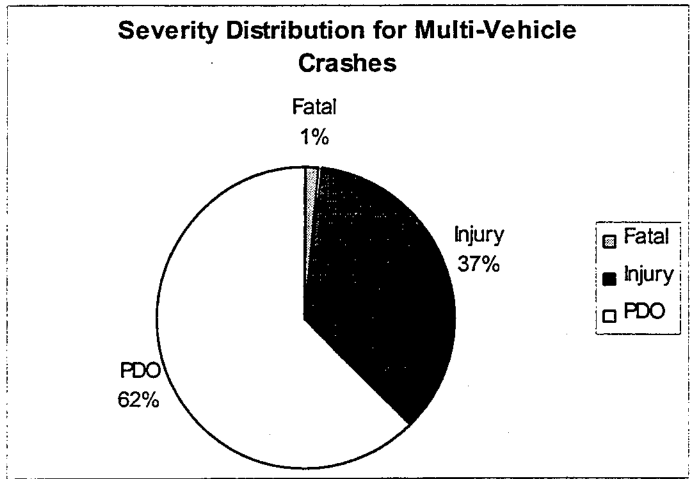


Figure 29 Severity Distribution for Multiple Vehicle Crashes in Work Zone

4.9 Comparisons of Work-Zone Crashes and Non-Work-Zone Crashes

4.9.1 Single and Multiple Vehicle Involvement

Total number of crashes from 1996 to 1999 was obtained from the 1996 – 1999 Virginia Traffic Crash Facts by Virginia Department of Motor Vehicles. Then the number of non-work-zone crashes was obtained by subtracting work-zone crashes from the total number of crashes. The proportionality tests (Test 1) show that the proportion of multiple vehicle involved crashes for work-zone crashes is significantly higher than that for non-work-zone crashes and the proportion of single vehicle involved crashes for work-zone crashes is significantly lower than that for non-work-zone crashes. The results of the proportionality tests are shown in Table 14.

	Total Crashes	Work-Zone Crashes	Non-Work-Zone Crashes	Alternative hypothesis	Z Value
Single Vehicle Crashes	150405	157	150248	Pw<Pn	-10.546
Multiple Vehicle Crashes	536779	1327	535452	Pw>Pn	10.546

Table 14 Proportionality Test Results of Single & Multiple Vehicle Involvement for Work-Zone and Non-Work-Zone Crashes (Test 1)

4.9.2 Comparison of Severity and Collision Types

The severity distribution for work-zone crashes is shown in figure 7. The severity distribution for non-work-zone crashes is shown in figure 30.

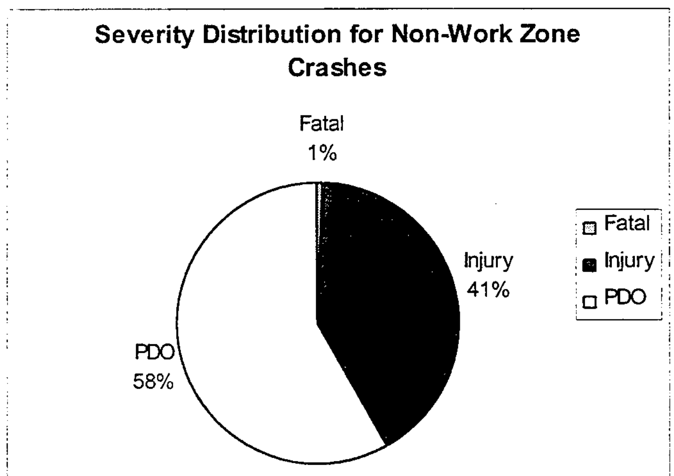


Figure 30 Severity Distribution for Non-Work-Zone Crashes

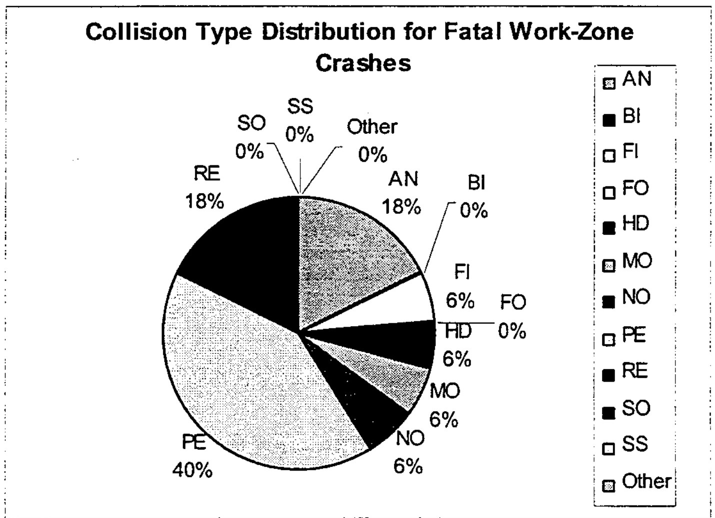
The following results were obtained from the proportionality tests (Test 1):

(1) The proportion of fatal crashes for work-zone crashes is significantly higher than that for non-work-zone crashes

(2) The proportion of injury crashes for work-zone crashes is significantly lower than that for non-work-zone crashes

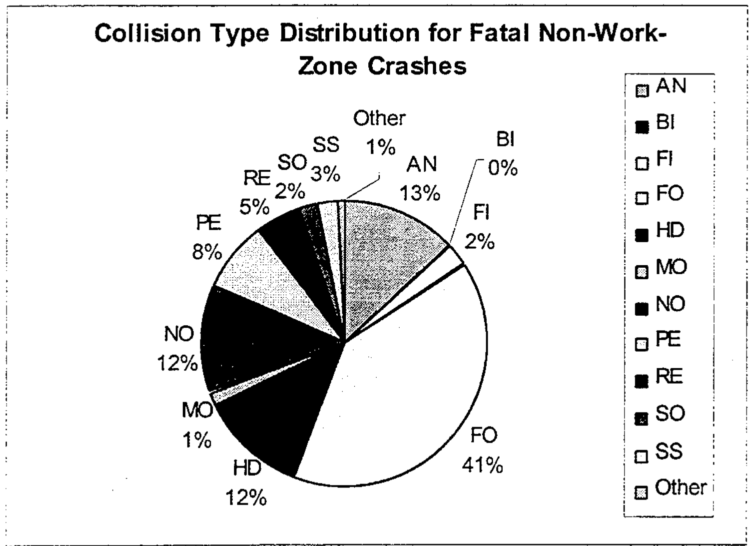
(3) The proportion of PDO crashes for work-zone crashes is significantly higher than that for non-work-zone crashes

The collision type distributions of fatal crashes for work-zone crashes and non-work-zone crashes are shown in figures 31 and 32 respectively.



AN (Angle) BI (Backed Into) FI (Fixed object In road) FO (Fixed object Off road) HD (Head On) MO (Misc. or Other) NO (Non-Collision) PE (Collision with Pedestrian) RE (Rear End) SO (Sideswipe in Opposite Direction) SS (Sideswipe in Same direction) Other (None of Above)

Figure 31 Collision Type Distribution for Fatal Work-Zone Crashes



AN (Angle) BI (Backed Into) FI (Fixed object In road) FO (Fixed object Off road) HD (Head On)

MO (Misc. or Other) NO (Non-Collision) PE (Collision with Pedestrian) RE (Rear End)

SO (Sideswipe in Opposite Direction) SS (Sideswipe in Same direction) Other (None of Above)

Figure 32 Collision Type Distribution for Fatal Non-Work-Zone Crashes

The proportionality tests (Test 1) show the following results:

(1) The proportion of PE (collision with pedestrian) fatal crashes for work-zone crashes is significantly higher than that for non-work-zone crashes. This may be due to the more intense conflicts of traffic flow and the working activities. All pedestrians involved in this study are highway workers.

(2) The proportion of FO (fixed object off road) fatal crashes for work-zone crashes is significantly lower than that for non-work-zone crashes. The possible reason for this may be due to the more frequent existence of the traffic control devices at work zones than at other locations.

(3) The proportions of fatal crashes of other collision type for work-zone crashes and non-work-zone crashes are not significantly different from each other.

4.10 Linkages of The Study Results With Previous Studies

Although this study did not include any analysis about speed variances, this study does show that RE (rear end) crashes are predominant at each location of the work zones for different road types. Additionally, this study also shows that multiple vehicle crashes are predominant at work zones and the proportion of multiple vehicle crashes at work zones is significantly higher than the proportion of multiple vehicle crashes at non-work-zones. Rouphail and others *(2)* show that the significant increase of the proportion of multiple-vehicle crashes during construction and the higher occurrence of rear end collisions and points to the problem of increased speed variations at work zones. Garber and Woo *(3)* found that there were generally increases in speed variances during the periods when work zone were installed and the accident rate increased as speed variance increased. Paulsen *(13)* and others also show that one of the major problems at work zones is the large speed variance among vehicles. The results of these studies strongly suggest that the occurrence of crashes can be reduced by reducing speed variances in work zones. Also, two previous studies *(17, 18)* have shown that the use of a changeable message sign (CMS) with a radar unit informing drivers when they are speeding is an effective speed control device for controlling speeds and speed variances. It is therefore highly probable that the use of such a system will be an effective way of reducing speed variances. Thus, RE (rear end) crashes may be significantly reduced.

This study shows that there were more fixed object crashes during nighttime. This conclusion is valid with respect to both the proportion and the number of fixed object crashes during nighttime. Although 73% of the work zone crashes occurred during daytime, more than half of the fixed object occurred during nighttime. Two previous studies *(5, 7)* show similar results. These results suggest a detailed study should be conducted on the casual factors of nighttime crashes in work zones, particularly with respect to lighting and visibility of channelizing devices.

CHAPTER 5: SUMMARY OF RESULTS

- Activity area (Area 4) is the work zone location having the highest number of crashes and the highest number of fatal crashes
- Termination area (area 5) is the safest area in a work zone with respect to numbers of crashes.
- For all the crashes studied, PDO is the predominant severity type, followed by injury and fatal. Fatal crashes comprise the smallest fraction of crashes.
- RE is the predominant collision type for each of the five areas and for different road types.
- The vast majority (83%) of the crashes occurring in advance warning area (area 1) is RE (rear end).
- The proportion of SS (sideswipe in same direction) crashes increases as the traffic moves from the advance warning area (area 1) to the transition area (area 2) resulting in SS crashes becoming the second largest population in the crashes in the transition area.
- As one moves from the transition area (area 2) to work area (combining areas 3 and 4), the proportions of RE (rear end) and SS (sideswipe in same direction) crashes decrease and the proportion of FO (fixed object off road) and AN (angle) crashes increase although RE (rear end) crashes are still predominant.
- Most nighttime work zone crashes occurred in area 4 (activity area). The severity of nighttime and daytime work zone crashes are not significantly different from each other.

- There are more fixed object crashes and less AN (angle) and RE (rear end) crashes during nighttime than during daytime. This conclusion is valid for both the proportion and the number of crashes.
- Most work zone crashes occurring in clear weather condition, followed by cloudy, raining and mist condition. The possible reason may be that most construction activities are conducted under favorable weather conditions.
- Work-zone crashes involve a higher proportion of multiple vehicle crashes than non-work-zone crashes. The multiple vehicle crashes are still predominant during nighttime.
- There are higher proportions of FI (fixed object in road) and SS (sideswipe in same direction) crashes and lower proportions of AN (angle) and RE (rear end) crashes for crashes involving heavy vehicle than for car only crashes.
- There are also higher proportions of FI and SS and lower proportions of AN and RE crashes for multiple vehicle crashes involving only cars than for multiple vehicle crashes involving heavy vehicles.
- Work-zone crashes involve a higher proportion of fatal crashes than non-work-zone crashes.
- There is a higher proportion of PE (collision with pedestrian who are workers) and a lower proportion of FO (fixed object off road) crashes for work-zone fatal crashes than for non-work-zone fatal crashes.

CHAPTER 6: CONCLUSIONS

The results of the study clearly show that the most dangerous area within a work zone is the activity area (Area 4), both in the total number of crashes and in the number of fatal crashes. Therefore any countermeasure that will significantly reduce crashes in area 4 will have a significant improvement on safety in the work zone.

The predominance of rear end crashes in work zones, strongly indicate that a major causal factor for work zone crashes is speed related. As discussed in the section 4.10, RE (rear end) crashes are mainly caused by vehicles driving at different speeds, resulting in high speed variance. In addition, the higher proportion of multiple vehicle crashes in work zones indicate a higher interaction of vehicles within work zones, which can be attributed to higher speed variances in work zones. The implementation of a countermeasure that reduces speed variance or that causes drivers to drive at approximately the same speeds throughout the work zones will therefore increase safety at work zones significantly. It should be noted that this does not necessarily mean lowering the speed limit at the work zone, as a lower speed limit does not necessarily result in a lower speed variance.

The significant increase in fixed object crashes during the night period (both in proportions and exact numbers) suggested that problems may exist in the lighting conditions at work zones or in the illumination conditions of channelizing devices during nighttime. The significant increase of PE (collision with pedestrian) fatal crashes in work zones than non-work-zones also indicated that more effective strategies should be implemented to separate the traffic flow and the working activities (All the involved pedestrians in this study are highway workers). The higher proportion of fatal crashes at work-zones compared with non-work-zones indicates that safety is still a major problem in work zones.

CHAPTER 7: RECOMMENDATIONS

Additional information on the start and end dates of construction projects, work zone configuration, exact location of crashes, traffic speeds, etc., would have considerably enhanced a more detailed analysis. The opportunity for collecting these data in the field has arisen as efforts are now being made to revise the format of FR-300 (Police Accident Report). It is therefore recommended that the following fields should be added in the format of FR-300:

- Whether there is construction activities going on when the crash occurs
- The configuration of the work zones
- The exact location of the crashes
- Types of traffic control devices used and their configurations
- The posted speed limit for the work zones
- Whether workers are involved in the crash

In addition, it is recommended that resident engineers record the start and end dates of work zones. It is also recommended that this topic be revisited after the data are available.

The significant increase in fixed object crashes during nighttime suggested that a detailed study should be conducted on the casual factors of nighttime crashes in work zones, particularly with respect to lighting and visibility of channelizing devices.

Since RE (rear end) crashes are strongly related to speed variances of vehicles in the traffic stream as discussed before, control of speed variances will enhance safety at work zones. Previous studies *(17, 18)* have shown that changeable message sign (CMS) with radar unit is an effective speed control device to be used in work zones to decrease speed variances. Thus, the changeable message sign with radar unit is recommended to be more widely used as a speed control device in work zones.

Compared with the other four areas, the transition area of the work zones has its unique crash pattern, featuring the significant increase of the SS (sideswipe in same direction) crashes in this area. A detailed study on this area is recommended, particularly with respect to signing procedures that will encourage early merging.

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