FINAL REPORT

CRASH CHARACTERISTICS AT WORK ZONES

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ABSTRACT

Work zones tend to cause hazardous conditions for drivers and construction workers since they generate conflicts between construction activities and traffic. 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 that occurred in Virginia between 1996 and 1999. The information on each crash was obtained from the police crash record. The location of each crash was categorized as being in one of the five areas of a typical work zone: advance warning area, transition area, longitudinal buffer area, activity area, and termination area. An analysis of the percentage distributions was then carried out with respect to area in work zone, severity, type of collision, and type of highway. The proportionality test was used to determine significant differences at the 5 percent significance level. Selected crash characteristics, such as the proportions of single- and multi-vehicle crashes, were compared for work zone and non–work zone crashes.

The results indicated that the activity area was the predominant location for work zone crashes regardless of highway type and that rear-end crashes were the predominant type of crash. The results also indicated that the proportion of sideswipe same direction crashes in the transition area was significantly higher than in the advance warning area and that work zone crashes involved a higher proportion of multi-vehicle crashes and fatal crashes than did non–work zone crashes.

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INTRODUCTION

With the completion of the interstate highway system, roadwork has shifted from new construction to maintenance and rehabilitation. Since the Transportation Equity Act for the 21st Century (TEA 21) provided a significant increase in funding for highway construction and maintenance, rehabilitation work will increase significantly during the next few years. In addition, 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 done, it will be necessary to provide for the flow of increasing volumes of traffic while rehabilitation work is in progress. This 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 for particular locations within work zones 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 termination area (see Figure 1).

PROBLEM STATEMENT

Many research projects[1-12] have been conducted to study crash characteristics 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 crash characteristics at different sites but also in crash reporting from different agencies. In addition, most of the studies were conducted in the 1970s and 1980s.

Most studies considered the complete length of the work zone, without consideration of the location of crashes in the work zone. Among the few studies addressing location, discrepancies exist. In addition, almost none of the studies carried out a detailed analysis of crash characteristics and distributions at different locations in work zones.

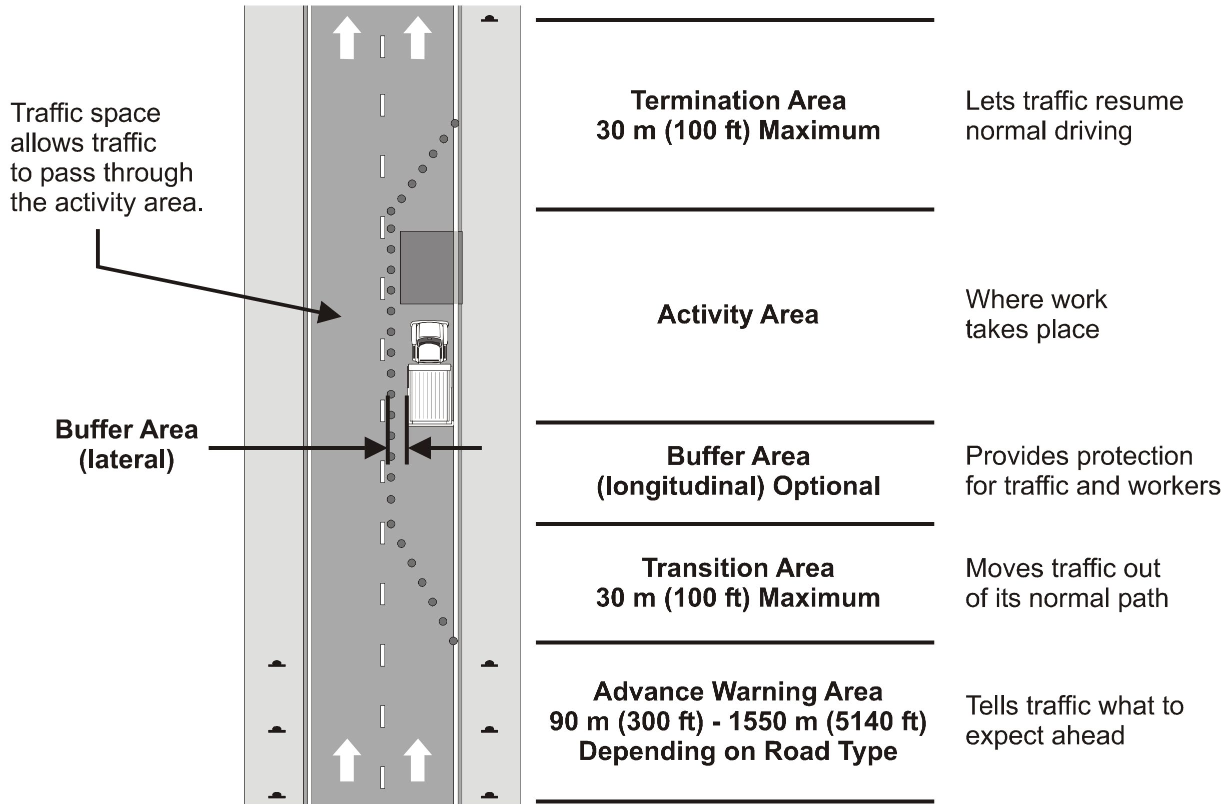

Figure 1. The Five Defined Areas of the Common Work Zone. *Source: Manual on Uniform Traffic Control Devices* (MUTCD) 2000, U.S. Department of Transportation, Federal Highway Administration.

PURPOSE AND SCOPE

The purpose of this study was to determine the distribution and characteristics of crashes at specific areas in work zones and to identify the differences between selected characteristics of work zone and non–work zone crashes. The study was limited to work zone crashes in Virginia that occurred between 1996 and 1999.

The objectives of the study were:

1. to identify the predominant location in work zones where crashes occur

2. to determine the predominant types of crashes and the severity distribution at each location

3. to study the collision type and severity distribution with respect to different road types, different time periods, single- and multiple-vehicle involvement, and heavy vehicle involvement

4. to compare the distributions of work zone and non–work zone crashes

5. to generate ideas for effective countermeasures as a result of the aforementioned analysis.

Only crashes reported to the police were included in the study. Therefore, the crashes were at or exceeded the threshold of a property damage only (PDO) crash with a cost of at least $1,000.

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 were categorized into the following areas:

- crash rates
- crash severity
- crash location
- other crash characteristics
- traffic characteristics
- traffic control devices.

Crash Rates

Hall and Lorenz[1] found that crashes during construction increased by 26 percent compared with crashes in the same period in the previous year when no construction occurred. Rouphail and others[2] showed that the crash rates during construction increased by 88 percent compared to the "before" period at long-term work zones and the crash rates for short-term work zones were not affected by the road work. Garber and Woo[3] found that on average the crash rates at work zones on multilane highways in Virginia increased about 57 percent and on two-lane urban highways about 168 percent when compared with crash rates prior to the installation of the work zones. Pigman and Agent[4] also showed that crash rates during construction exceeded those in the before period at 14 of 19 sites. Nemeth and Migletz [5] also showed that crash 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.

Several studies[3,4,6] also indicated that crash rates depend on the type of traffic control device used. For example, Garber and Woo[3] concluded that a combination of cones, flashing arrows, and flaggers on multilane highway work zones and a combination of cones, flaggers, or static signs and flaggers on two-lane highway work zones resulted in the fewest crashes whereas the use of flaggers at urban work zones resulted in the fewest crashes.

Crash Severity

Two studies[4,7] concluded that work zone crashes were more severe than other crashes, whereas two other studies[1,3] concluded the severity was not significantly different. Four studies[2,5,9,10] found that work zone crashes were (slightly) less severe than all crashes. Hargroves[9] studied the work zone crashes in Virginia in 1977 and concluded that the average work zone crash was slightly less severe than the average crash compared by the percentage of PDO crashes and the number 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 and average property damage.

Crash Location

Five studies[4,5,9-11] addressed the locations of crashes in work zones. Two studies[4,9] found that most crashes (44.7%, 54.1%) occurred in the work area (combining the longitudinal buffer and activity areas). Nemeth[5] found that 39.1 and 16.6 percent of accidents occurred in the longitudinal buffer area and the activity area, respectively. In another study,[10] Nemeth used another set of location categories and concluded that most crashes occurred in single-lane, crossover, and bi-directional zones (two-lane two-way operation). Goddin[11] found that 69 percent of the crashes occurred in the activity area.

Other Crash Characteristics

The results of several studies[1-5,8-11] indicated that rear end crashes were the predominant collision type in work zones. Four studies[1-3,7] indicated that multi-vehicle crashes were overrepresented, whereas three studies[1,4,9] indicated that heavy vehicles were overrepresented. Pigman and Agent[4] found that work zone crashes involving heavy vehicles were more severe than those in which heavy vehicles were not involved.

Pigman and Agent[4] also found that crashes during darkness were more severe, whereas Nemeth and Migletz[5] found that crashes during daylight hours were more severe than those at night or at dawn and dusk. Two studies[5,12] concluded that nighttime crashes were especially concentrated at the transition area. Ha and Nemeth[8] also found that night crashes were more likely to be fixed object crashes and that single-vehicle crashes were predominant at night.

Since similar methodologies were used in these studies, the discrepancies cannot be attributed to methodological flaws.

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 were considerably reduced from the normal speed limit. Garber and Gadiraju[14] determined that crashes on freeways and arterials increased as speed variance increased. Garber and Woo[3] found that speed variance generally increased during the periods when work zones were installed and the change in speed variance was related to the change in crash 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 necessarily 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 impacts of higher speeds and the introduction of trucks were eliminated when merging drivers were assumed to respond immediately to the lane closure signs. Their simulation results also showed that the introduction of a speed zone did not improve conditions but early merging behavior minimized both speed variance and probability of disturbance in the transition area. However, the authors 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.

Traffic Control Devices

The traffic control devices used in work zones consist mainly of signs, arrow boards, and channelization devices such as cones, barrels, and jersey barriers. 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 safely through work zones. A flagger is also an important traffic control measure.

A major part of prior research efforts has been to determine the effectiveness of traffic control devices with respect to driver compliance and traffic operations. 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. The study found that flagging and law enforcement are 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. CMSs have similar advantages, are also suitable for long-term applications, and are effective at night and in inclement weather. Other advantages of CMSs included direct control by the contractor over their use and no personnel requirement, averting high labor costs and management responsibilities. Two studies[17,18] showed that a CMS with a radar unit is an effective speed control device for controlling speeds and speed variances both in short-term (1 week or less) and long-term (up to 7 weeks) work zones. Nemeth and Rathi[10] recommended that CMSs be considered for informing drivers of possible stop-and-go conditions to reduce the potential for multiple-vehicle crashes. Garber and Woo[3] also showed that flagging is very effective at work zones on urban two-lane highways.

Summary

The literature review revealed inconsistent results for many of the studies with respect to several crash characteristics. A summary of the results is provided in Table 1. Table 2 shows the different study scopes of several major studies concerning crash characteristics. The

Table 1. Major Study Results Concerning Crash Characteristics

Subject	Results	Remarks
Crash rates	1,2,3,4,5: increase after before period	Results are consistent and show crash rates increase in work zone
	3,6: higher at work zones	
Crash location	4,9,11: most occurred at activity area or combined longitudinal buffer and activity areas	10 is inconsistent with other studies
	10: most occurred in longitudinal buffer area	
Rear end crashes	1,2,3,4,5,8,9,10,11: predominant collision type	Results are consistent
Multiple-vehicle crashes	1,2,3,7: overrepresented at work zones	Results are consistent
Crash severity	4,7: more severe	Results are inconsistent
	1,3: not significantly different	
	2,5,8,9,10: work zone crashes slightly less severe	
Crash severity for nighttime	4: more severe	Results are consistent
	5: less severe than daytime	
Location distribution during nighttime	5,12: especially concentrated in transition area	Results are consistent
Severity of crashes involving heavy vehicles	4: more severe	Only 1 study identified
Collision type distribution during nighttime	8: fixed-object crashes	Only 1 study identified
Multiple-vehicle involvement during nighttime	8: single-vehicle crashes dominant	Only 1 study identified

Table 2. Study Scopes of Major Studies Concerning Crash Characteristics

Ref.	Year	Duration	Length or Number of Sites	Number of Crashes	State	Road Type
1	1982-85	Average 255 days	168 projects, 172 sections, 1,045 mi	631	New Mexico	Rural section of interstate and federal-aid primary
2	1980-85	N/A	4 long-term, 25 intermittent or weekend projects	N/A	Illinois	Chicago area expressway system
3	1982-85	Generally longer than 30 days	26 sites	N/A	Virginia	Urban 2-lane, 3-lane highway with 4 or more lanes without raised median
4	1983-86	4 yr	N/A	2013	Kentucky	All
5	1973	Mostly within 1 yr	21 sites, 384 mi	151	Ohio	Rural interstates
7	1984-85	2 yr	N/A	N/A	30	All
8	1982-86	N/A	All, then 60, then 9 projects	N/A	Ohio	All
9	1977	1 yr	N/A	1,847 of 2,127 selected	Virginia	All
10	Around 1978	28 mo	240 mi	185	Ohio	Ohio Turnpike

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, the types of highways considered, and whether all crashes considered were work-zone related. The authors took these factors into consideration in building up the data used for the analysis in the current study.

METHODOLOGY

Information on each work zone crash in Virginia from 1996 through 1999 was obtained from the police accident report. A review of each report was first undertaken to ascertain that each crash selected for the study was work-zone related. A total of 1,484 crashes of the 1,939 obtained from the database were selected for the study. The basis for excluding a crash included:

1. The crash was not coded as a work zone crash or there was no clue on the police accident report that the crash occurred in a work zone.

2. The crash occurred in a work zone, but it was obvious that it was caused by factors other than those related to the work zone, e.g., driver falls asleep, uses cell phone, or picks up an object from the floor of the vehicle.

3. The crash occurred in a work zone, but the specific location was unclear.

The data are summarized in Table 3.

Table 3. Data Summary of Work Zone Crashes by Severity and Year

	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	1,484

The location of each crash was then identified and noted as being one of the five areas of a work zone (see Figure 1):

1. advance warning area

2. transition area

3. longitudinal buffer area

4. activity area

5. termination area.

In addition, information was obtained on severity (fatal, injury, or PDO), collision type (rear end, angle, sideswipe, fixed object), road type, and time of day. Percentage distributions were determined for the location, severity, and collision type. Each distribution was then determined for road type and time of day. Modeling efforts were explored, but no results were promising because of the unavailability of the speed and volume data for each crash. Therefore, proportionality tests were conducted to compare the distributions of these characteristics. Several previous studies[2,3,5] also used proportionality tests to analyze work zone crashes. Two types of proportionality tests were used in this study. The first type (proportionality test on two proportions, referred to as Type 1) was used when the two proportions were from independent populations. The second type (proportionality test on one proportion, Type 2) was used when the two proportions were from the same population. The NCSS 2000 software package was used for the proportionality tests.

The following null hypotheses were tested at the 5 percent significance level:

1. the proportion of total crashes in each area of the work zone is not significantly different from the proportion of total crashes at each of the other areas

2. the proportion of fatal crashes in each area of the work zone is not significantly different from the proportion of fatal crashes in each of the other areas

3. the proportion of injury crashes in each area of the work zone is not significantly different from the proportion of injury crashes in each of the other areas

4. the proportion of rear end crashes in each area is not significantly different from the proportion of rear end crashes in each of the other areas. This hypothesis was also tested for angle, fixed object in road, fixed object off road, and sideswipe same direction crashes.

These 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 level for single-vehicle crashes is not significantly different than that for multi-vehicle crashes

2. the proportion of each severity level for work zone crashes is not significantly different than that for non–work zone crashes

3. the proportion of each collision type for work zone crashes is not significantly different than that for non–work zone crashes.

RESULTS

Location Distribution

The location distribution for the 1,484 work zone crashes is shown in Figure 2. The activity area was the predominant crash location, followed by the transition area, the advance warning area, the longitudinal buffer area, and the termination area. The results of the proportionality tests shown in Table 4 indicated that these proportions were significantly different. Although it would have been useful to apply a measure of travel exposure (e.g., average annual daily traffic, duration of work activities) in the comparison, existing data include neither the length of time for the construction activities nor the length of the work zones.

To determine the effect of highway type on these distributions, the highways were first classified as interstate, primary, or 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 placed in a separate category as some of these roads carry volumes as high as those on

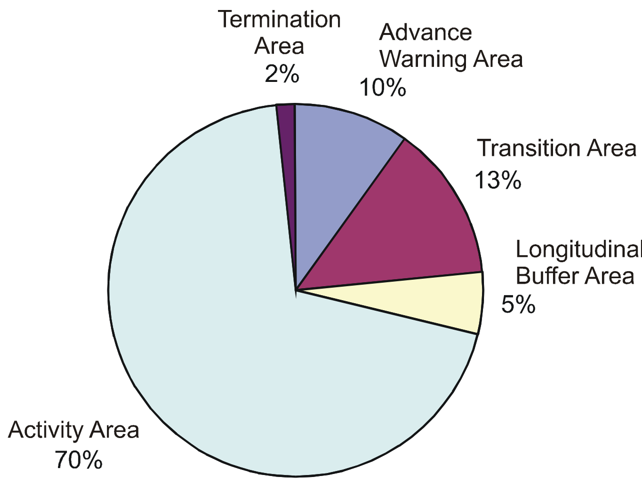

Figure 2. Location Distribution for All Work Zone Crashes

Table 4. Type 2 Proportionality Tests Results Between Crashes in Different Areas

Work Zone Area (a)	No. Crashes at Area a	Y/n (%)	Work Zone Area (b)	No. Crashes at Area b	P_0	Z	Conclusion
	Y			Y_0	Y_0/n (%)		
Activity	1,030	69.41	Transition	200	13.48	63.06	P1>P2
Transition	200	13.48	Advance warning	149	10.04	4.36	P1>P2
Advance warning	149	10.04	Longitudinal buffer	81	5.46	7.71	P1>P2
Longitudinal buffer	81	5.46	Termination	24	1.62	11.63	P1>P2

n = 1,484.

primary roads. Figure 3 shows the distribution of work zone crashes by road type. Although the highest percentage of work zone crashes occurred on urban interstate highways, it cannot be concluded that these highways are more susceptible to work zone crashes; these crashes were not normalized for traffic volumes or for the number of work zones on each type of road. The data that would be required for such an analysis are not available.

Table 5 shows the percentage distribution of crashes by road type and location in the work zone. Table 6 shows the results of the Type 1 proportionality tests between crashes in each area for each road type and crashes in each area for the other road types. For example, when the location distributions for interstate highways and all crashes were compared, the proportion of crashes in each area for interstate highways was compared to the proportion of crashes in the same area for all crashes excluding those on interstate highways. The reason for the exclusion was that the population of crashes on interstate highways is a part of the population of all crashes and it is not reasonable to assume that these two proportions are independent. The results indicate that the respective proportion of the crashes in the activity area for each road type

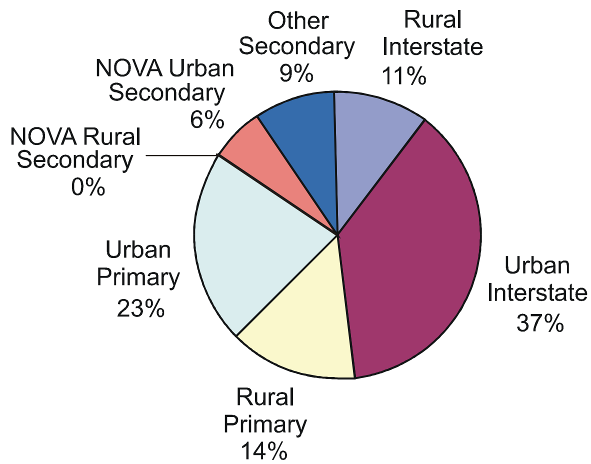

Figure 3. Road Type Distribution for All Work Zone Crashes

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

Road Type	No. Crashes	Work Zone Location				
		Advance Warning Area (%)	Transition Area (%)	Longitudinal Buffer Area (%)	Activity Area (%)	Termination Area (%)
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

was not significantly different from the proportion of crashes in the area for the other two road types. This indicates that this area is more susceptible to crashes regardless of road type. However, the proportion of total crashes in the advance warning area in work zones on primary and secondary roads is higher than that for interstate highways. Only 24 crashes of the 1,484 occurred in the termination area. This indicates that the termination area is the safest area in a work zone.

Table 6. Type 1 Proportionality Test Results Between Crashes in Each Area for Each Road Type and Crashes in Each Area for Other Two Road Types

Work Zone Area (a)	Interstate Highways Total No. Crashes n1=703 No. Crashes at Area a Y1	p1 (%) Y1/n1	Primary and Secondary Roads Total No. Crashes n2=781 No. Crashes at Area a Y2	p2 (%) Y2/n2	Z	Conclusion
Advance warning area	61	8.68	88	11.27	-1.6579	p1<p2
Transition area	114	16.22	86	11.01	2.9317	p1>p2
Longitudinal buffer area	46	6.54	35	4.48	1.7459	p1>p2
Activity area	480	68.28	550	70.42	-0.8948	p1=p2
Termination area	2	0.28	22	2.82	-3.8616	p1<p2

Work Zone Area (a)	Primary Roads Total No. Crashes n1=545 No. Crashes at Area a Y1	p1 (%) Y1/n1	Interstate Highways and Secondary Roads Total No. Crashes n2=939 No. Crashes at Area a Y2	p2 (%) Y2/n2	Z	Conclusion
Advance warning area	60	11.01	89	9.48	0.6436	p1=p2
Transition area	67	12.29	133	14.16	-1.0172	p1=p2
Longitudinal buffer area	26	4.77	55	5.86	-0.8883	p1=p2
Activity area	377	69.17	653	69.54	-0.1482	p1=p2
Termination area	15	2.75	9	0.96	2.6409	p1>p2

Work Zone Area (a)	Secondary Roads Total No. Crashes n1=236 No. Crashes at Area a Y1	p1 (%) Y1/n1	Interstate Highways and Primary Roads Total No. Crashes n2=1248 No. Crashes at Area a Y2	p2 (%) Y2/n2	Z	Conclusion
Advance warning area	28	11.86	121	9.70	1.0167	p1=p2
Transition area	19	8.05	181	14.50	-2.662	p1<p2
Longitudinal buffer area	9	3.81	72	5.77	-1.2128	p1=p2
Activity area	173	73.31	857	68.67	1.4171	p1=p2
Termination area	7	2.97	17	1.36	1.7914	p1>p2

Severity Distribution

Figure 4 shows the severity distribution for all crashes. The prevalent severity type was PDO crashes. The number of crashes at each severity level, in each area in the work zone, and for each highway type was also determined and expressed as a percentage of all work zone crashes for the highway type. Table 7 shows the results. For example, of the 544 crashes on urban interstate highway work zones, the percentage that were fatal and also occurred in the advance warning area was 0.2 percent whereas the percentage that were injury crashes and also

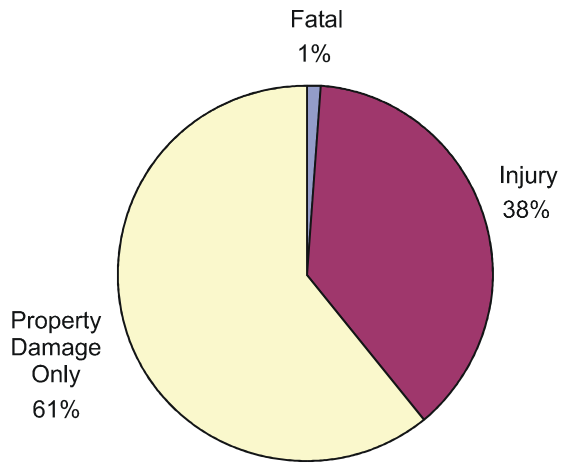

Figure 4. Severity Distribution for All Work Zone Crashes

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

Road Type	No. Crashes	Work Zone Location														
		Advance Warning			Transition			Longitudinal Buffer			Activity			Termination		
		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	3.2	3.6	0.0	2.3	8.0	0.0	1.7	2.7	0.6	25.9	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

occurred in this area was 2.6 percent. Using the Type 2 proportionality test, it was determined that the prevalent severity type was PDO for all road types except for “rural primary” and “other secondary” roads, where the proportions for injury and PDO crashes were not significantly different.

An in-depth study of the police reports of the fatal crashes showed that about 35 percent (6) of the fatalities were workers on the roads, but the crashes were classified as 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. Further analysis of the fatal crashes showed that about 76 percent occurred in the activity area. This is slightly higher than the percentage (70) of total crashes that occurred in the activity area. However, the proportion of fatal crashes at each work zone area was not significantly different from the proportion in the other four areas (see Table 9). In addition, the proportion of fatal crashes on each road type was not significantly different from the proportions on the other road types (see Table 10).

Table 8. Fatalities by Type of Work Zone Crash

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

Table 9. Type 1 Proportionality Test Results Between Fatal Crashes in Each Area and Fatal Crashes in Other Areas

	Work Zone Area a			Other Areas				
	No. Fatal Crashes	No. Total Crashes	p1	No. Fatal Crashes	No. Total Crashes	p2	Z	Conclusion
Work Zone Area (a)	Y1	n1	Y1/n1	Y2	n2	Y2/n2		
Advance warning	2	149	1.34	15	1335	1.12	0.2379	p1=p2
Transition	0	200	0.00	17	1284	1.32	-1.6367	p1=p2
Longitudinal buffer	2	81	2.47	15	1403	1.07	1.1513	p1=p2
Activity	13	1030	1.26	4	454	0.88	0.6357	p1=p2
Termination	0	24	0.00	17	1460	1.16	-0.5317	p1=p2

Table 10. Type 1 Proportionality Test Results Between Fatal Crashes for Each Road Type and Other Road Types

	Road Type a			Other Road Types				
	No. Fatal Crashes	No. Total Crashes	p1 (%)	No. Fatal Crashes	No. Total Crashes	p2 (%)		Conclusion
Road Type (a)	Y1	n1	Y1/n1	Y2	n2	Y2/n2	Z	
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	1.2	-0.4693	p1=p2

Collision Type Distribution

Figure 5 shows the distribution of crashes by collision type. The types with percentages of 3 percent or less were combined and categorized as "others." These included backed into, head on, miscellaneous or other, non-collision, pedestrian, and sideswipe opposite direction. Rear end was the predominant and fixed object in road was the least prevalent collision type among the five types examined. The results also indicated that the proportion of fixed object off road crashes was significantly higher than the proportion of sideswipe same direction crashes. However, the proportion of angle crashes was not significantly different from the proportion of fixed object off road crashes.

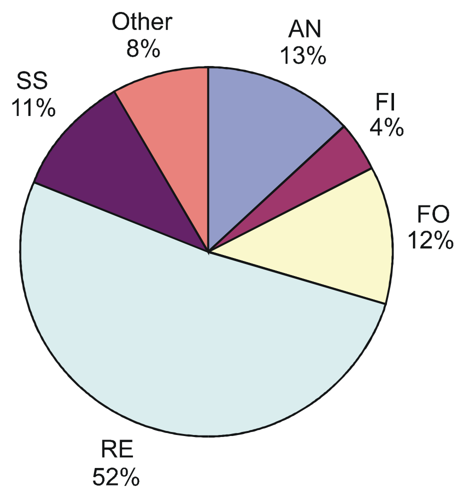

Figure 5. Collision Type Distribution for All Work Zone Crashes. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

Collision type distributions for the advance warning and transition areas are shown in Figures 6 and 7, respectively. Although rear end was the predominant crash type for all areas except the termination area, where all the crashes were angle crashes, the proportion of this crash

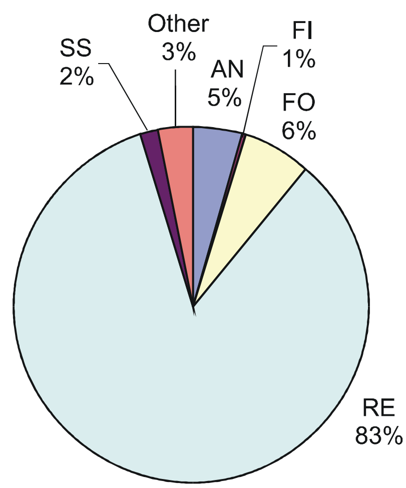

Figure 6. Collision Type Distribution for Work Zone Crashes in Advance Warning Area. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

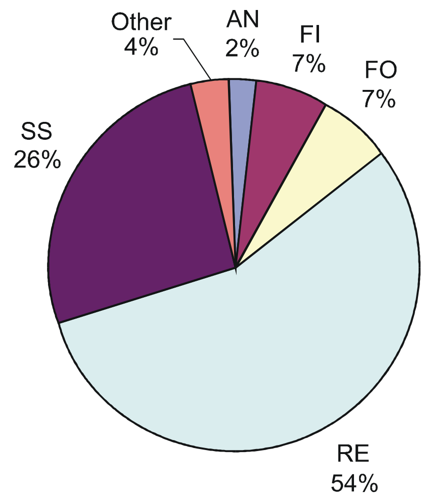

Figure 7. Collision Type Distribution for Work Zone Crashes in Transition Area. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

type in the advance warning area was significantly higher than in each of the other areas. This 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 rear end was the predominant crash type in the transition area, the percentage (26%) of sideswipe same direction crashes was much higher than for the advance warning area. This may be due to the increase in merging maneuvers necessitated by the reduction of the number of through lanes.

Collision type distributions for the longitudinal buffer and activity areas are shown in Figures 8 and 9, respectively. The results of the Type 1 proportionality tests showed that the percentage distribution of crashes by collision type was not significantly different for the two areas. It was therefore reasonable to combine these locations in carrying out an analysis of crash type. As traffic moved from the transition area to the work area (combining the longitudinal buffer and activity areas), the proportions of rear end and sideswipe same direction crashes decreased and the proportions of fixed object off road and angle crashes increased. This may be due to the increase in conflicts between traffic and construction activities.

Collision type distributions for interstate, primary, and secondary roads are shown in Figures 10, 11, and 12, respectively. The results of the Type 2 proportionality tests indicated that rear end was the predominant collision type for interstate highways, followed by fixed object off road, sideswipe same direction, fixed object in road, and angle. However, the proportion of fixed object off road crashes was not significantly different from that of sideswipe same direction crashes. Similarly, the proportion of fixed object in road crashes was not significantly different from that of angle crashes.

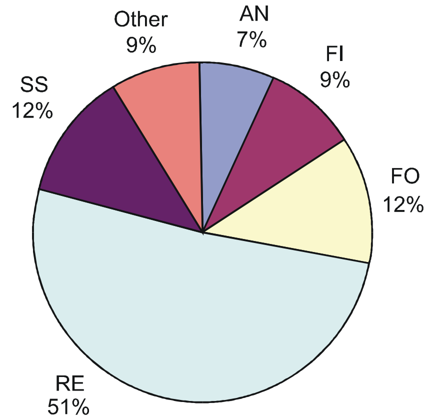

Figure 8. Collision Type Distribution for Work Zone Crashes in Longitudinal Buffer Area. AN (angle), FI -(fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

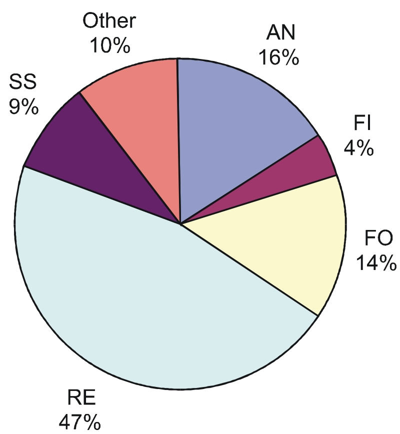

Figure 9. Collision Type Distribution for Work Zone Crashes in Activity Area. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

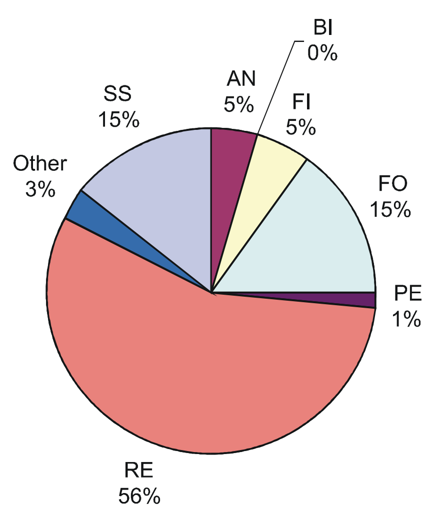

Figure 10. Collision Type Distribution for Work Zone Crashes on Interstate Highways. AN (angle), BI (backed into), FI (fixed object in road), FO (fixed object off road), PE (collision with pedestrian), RE (rear end), SS (sideswipe same direction).

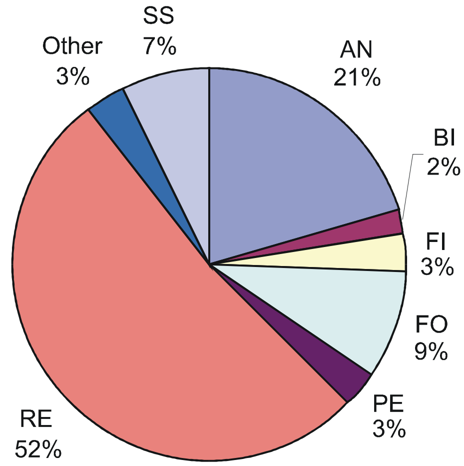

Figure 11. Collision Type Distribution for Work Zone Crashes on Primary Roads. AN (angle), BI (backed into), FI (fixed object in road), FO (fixed object off road), PE (collision with pedestrian), RE (rear end), SS (sideswipe same direction).

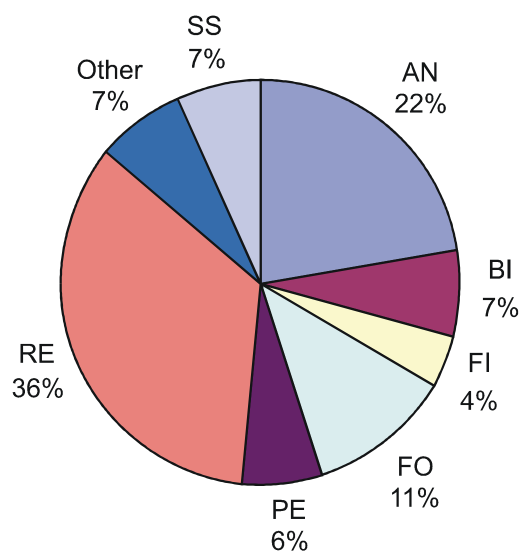

Figure 12. Collision Type Distribution for Work Zone Crashes on Secondary Roads. AN (angle), BI (backed into), FI (fixed object in road), FO (fixed object off road), PE (collision with pedestrian), RE (rear end), SS (sideswipe same direction).

For primary roads, rear end crashes were the predominant collision type, followed by angle, fixed object off road, sideswipe same direction, and fixed object in road. However, the proportion of fixed object off road crashes was not significantly different from that of sideswipe same direction crashes.

For secondary roads, rear end was the predominant collision type, followed by angle, fixed object off road, sideswipe same direction, backed into, and collision with pedestrian. The proportions of sideswipe same direction, backed into, and collision with pedestrian crashes were not significantly different.

To determine whether the proportion of a collision type was influenced by the type of highway, the Type 1 proportionality test was conducted on the distributions by collision type for the different types of highways. The following results were obtained:

1. The proportions of rear end crashes for interstate and primary roads were significantly higher than for secondary roads.

2. The proportions of angle crashes for primary and secondary roads were significantly higher than for interstates.

3. The proportion of sideswipe same direction crashes for interstates was significantly higher than for primary and secondary roads.

4. The proportion of backed into crashes for secondary roads was significantly higher than for interstates.

5. The proportion of fixed object off road crashes for interstates was significantly higher than for primary roads.

6. The proportions of fixed object in road crashes for different road types were not significantly different.

7. The proportion of collisions with pedestrians for secondary roads was the highest, followed by the proportion for primary roads, and then the proportion for interstate highways.

In comparing urban and rural roads, the results of the Type 1 proportionality tests indicated the following:

1. The proportion of each collision type for urban and rural interstates was not significantly different.

2. The proportions of angle, fixed object in road, collision with pedestrian, and rear end crashes for urban and rural primary roads were not significantly different. However, the proportions of backed into and fixed object off road crashes for urban primary roads were significantly lower than for rural primary roads. The proportion for sideswipe same direction crashes for urban primary roads was significantly higher than for rural primary roads.

Table 11 shows the severity distribution for each collision type examined using the Type 1 proportionality test. The proportion of crashes by severity for each collision type was compared to the proportion by severity for the same collision type for all crashes but excluding the crashes for the collision type under consideration. This was necessary to ensure that the proportions being compared were independent. The results of the proportionality tests indicated the following (see Table 12):

1. The proportion of the fatal crashes for rear end crashes was significantly lower than for all other crashes combined. The proportions of injury and PDO crashes for rear end crashes were not significantly different from the proportions for all other crashes combined.

2. The proportion of the injury crashes for sideswipe same direction crashes was significantly lower than for all other crashes combined. The proportion of PDO crashes for sideswipe same direction crashes was significantly higher than for all crashes combined. The proportion of fatal crashes for sideswipe same direction crashes was not significantly different from the proportion for all crashes combined.

3. The distribution by severity for angle, fixed object in road, and fixed object off road crashes separately was not significantly different from that for all other crashes combined.

Table 11. Distribution of Crashes by Collision Type and Severity

Collision Type	No. Crashes	Severity (%)		
		Fatal	Injury	PDO
Angle	198	1.5	34.8	63.7
Fixed object in road	65	1.5	33.8	64.7
Fixed object off road	178	0.0	42.1	57.9
Rear end	761	0.4	38.8	60.8
Sideswipe same direction	157	0.0	19.7	80.3
Other	125	8.0	59.2	32.8
Total	1,484	1.1	38.1	60.7

Severity and Collision Type Distribution by Time

To determine the effect of time of day on crash characteristics at work zones, crashes were classified into six groups based on the time of day 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. These ranges were selected to allow evaluation of the effect of the peak volume periods. A majority of the crashes was in the activity area for all time zones. The results for this area are presented here.

The severity distribution of crashes is shown in Table 13. The Type 1 proportionality tests showed that the proportions of injury crashes for 6:00–10:00 and 16:00–19:00 were significantly lower than the corresponding proportions for the intervals between 10:00 and 16:00. The reason may be the higher volumes and lower driving speeds during the morning and evening peaks. The proportions of fatal and PDO crashes for 6:00–10:00 and 16:00–19:00 were not significantly different from the corresponding proportions for the intervals between 10:00 and 16:00. The proportions of each collision type for other time intervals were not significantly different. The results also showed that rear end crashes were predominant for all time zones.

Table 12. Type 1 Proportionality Tests Results Between Fatal, Injury, or PDO Crashes for Each Collision Type and Other Collision Types

Collision Type a	Collision Type a		p1 (%)	Other Collision Types		p2 (%)	Z	Conclusion
	No. Fatal Crashes	No. Total Crashes		No. Fatal Crashes	No. Total Crashes			
	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	Collision Type a		p1 (%)	Other Collision Types		p2 (%)	Z	Conclusion
	No. Injury Crashes	No. Total Crashes		No. Injury Crashes	No. Total Crashes			
	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	Collision Type a		p1 (%)	Other Collision Types		p2 (%)	Z	Conclusion
	No. PDO Crashes	No. Total Crashes		No. PDO Crashes	No. Total Crashes			
	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 same direction).

Table 13. Distribution of Crashes in Activity Area by Time Period

Time	No. Crashes	Severity		
		Fatal (%)	Injury (%)	PDO (%)
6:00–10:00	165	1.2	32.1	66.7
10:00–13:00	195	1.0	44.1	54.9
13:00–16:00	213	1.4	39.9	58.7
16:00–19:00	164	1.2	29.9	68.9
19:00–22:00	124	0.8	43.5	55.7
22:00–6:00	169	1.8	43.2	55.0

The Type 1 proportionality tests also show the following for the activity area:

1. The proportion of angle crashes for 22:00–6:00 was significantly lower than for the other time intervals.

2. The proportion of fixed object in road crashes for 22:00–6:00 was significantly higher than the proportion between 10:00 and 19:00 but was not significantly different than those for other time intervals.

3. The proportion of fixed object off road crashes between 19:00 and 6:00 was significantly higher than for other time intervals.

4. The proportion of rear end crashes between 19:00 and 6:00 was significantly lower than for other time intervals.

5. The proportion of sideswipe same direction crashes was not significantly different between time intervals.

The reasons for more fixed object crashes during nighttime may be insufficient lighting and visibility, drivers being under the influence of alcohol, and driver fatigue. The reason for fewer angle and rear end crashes during nighttime may be a lower traffic volume and fewer traffic conflicts.

Nighttime and Daytime Distribution

Location

Although two studies[5,12] showed that nighttime crashes at work zones tend to occur more often in the transition area, this study did not have similar results. This study used the dividing points for daytime and nighttime as 7 A.M. and 7 P.M. The location distributions are shown in Figures 13 and 14. Of the 399 crashes during nighttime, 76 percent (304) were in the activity area and only 12 percent (47) were in the transition area; of the 1,085 crashes during daytime, 66 percent (726) were in the activity area and 14 percent (153) were in the transition area.

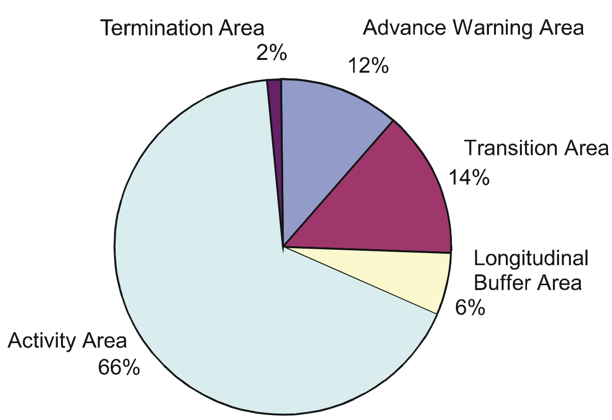

Figure 13: Location Distribution for Work Zone Crashes During Daytime

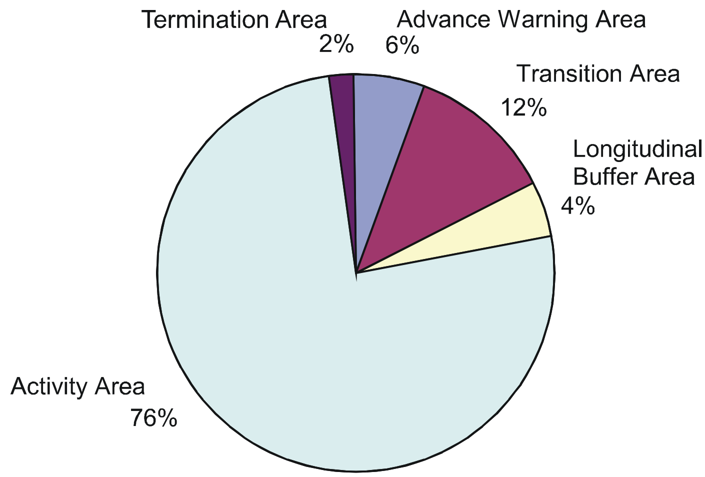

Figure 14. Location Distribution for Work Zone Crashes During Nighttime

By comparing the location distribution of work zone crashes during daytime and nighttime, one can draw the following conclusions from the Type 1 proportionality tests:

1. The proportion of nighttime work zone crashes in the activity area was significantly higher than the proportion of daytime work zone crashes in this area.

2. The proportion of nighttime work zone crashes in the transition area was significantly lower than the proportion of daytime work zone crashes in this area.

3. The proportions of work zone crashes in the other areas during daytime and nighttime were not significantly different.

Severity

The percentages for fatal, injury, and PDO crashes during daytime were 0.9, 37.9, and 61.2, respectively; the percentages during nighttime were 1.8, 38.8, and 59.4, respectively. The proportion of fatal crashes during nighttime was double the proportion during daytime. However, the Type 1 proportionality tests showed that the proportions of each severity type for daytime and nighttime were not significantly different.

Collision Type

Ha and Nemeth[8] concluded that night crashes were most likely to be fixed object crashes. The collision type distribution for daytime and nighttime for the current study are shown in Figure 15 and 16, respectively. The results of the Type 1 proportionality tests were as follows:

1. The proportions of fixed object in road and fixed object off road crashes for nighttime were significantly higher than for daytime.

2. The proportions of angle and rear end crashes during nighttime were significantly lower than for daytime.

3. The proportions of sideswipe same direction crashes were not significantly different between nighttime and daytime.

Although the proportions of fixed object crashes did increase significantly during nighttime, rear end crashes were still predominant (42%); 121 (28%) of 430 nighttime crashes were fixed object crashes, and 120 (11%) of 1,054 daytime crashes were fixed object crashes.

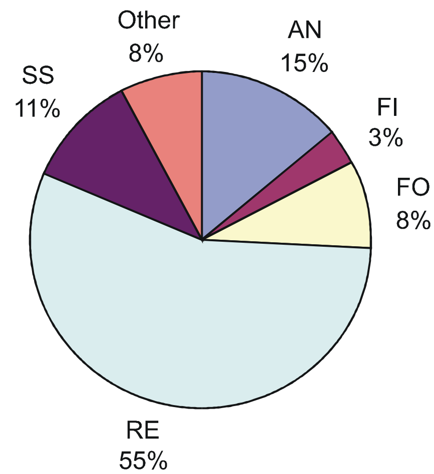

Figure 15. Collision Type Distribution for Work Zone Crashes During Daytime. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

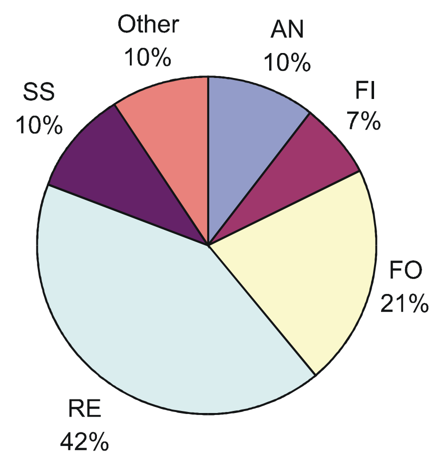

Figure 16. Collision Type Distribution for Work Zone Crashes During Nighttime. AN (angle), FI (fixed object in road), FO (fixed object off road), RE (rear end), SS (sideswipe same direction).

Single-Vehicle and Multi-Vehicle Distribution

The results of the Type 1 proportionality tests showed that the proportion of single-vehicle crashes during nighttime was significantly higher than during daytime. In fact, of 430 nighttime crashes, 86 (20%) were single-vehicle crashes; of 1,054 daytime crashes, only 71 (7%) were single-vehicle crashes.

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 Figures 17 and 18, respectively. Heavy vehicles in this study were defined to include straight trucks, tractor trailers, tractor double trailers, oversized vehicles, motor-home/recreational vehicles, school buses, and commercial buses. A slightly higher percentage of the fatal crashes involved heavy vehicles. The Type 1 proportionality tests, however, showed that the difference was not significant.

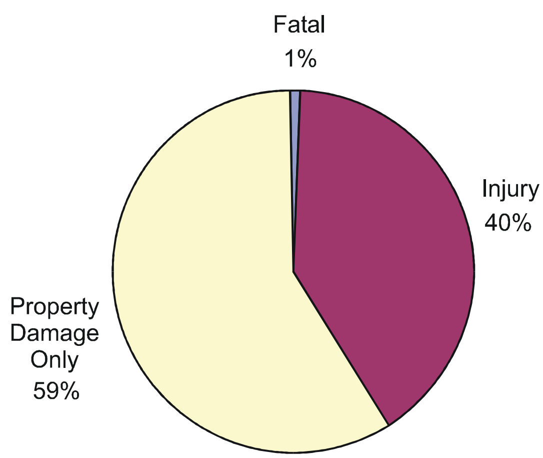

Figure 17. Severity Distribution for Car Only Crashes in Work Zones

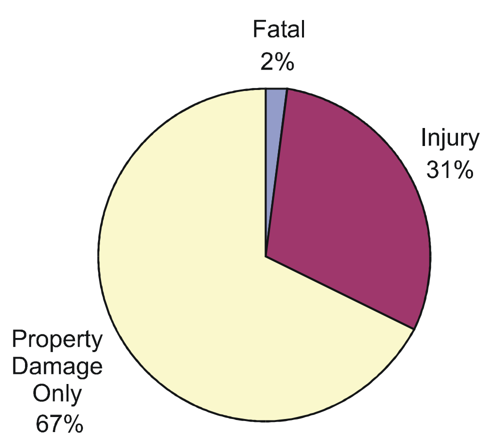

Figure 18. Severity Distribution for Crashes Involving Heavy Vehicles in Work Zones

The collision type distributions are shown in Figures 19 and 20. The Type 1 proportionality tests showed that the proportions of fixed object in road and sideswipe same direction crashes for crashes involving heavy vehicles were significantly higher than for car only crashes and the proportions of angle and rear end crashes were significantly lower. Results also showed higher proportions of fixed object in road and sideswipe same direction crashes and lower proportions of angle and rear end crashes for multiple-vehicle crashes involving cars only than for multiple-vehicle crashes involving heavy vehicles.

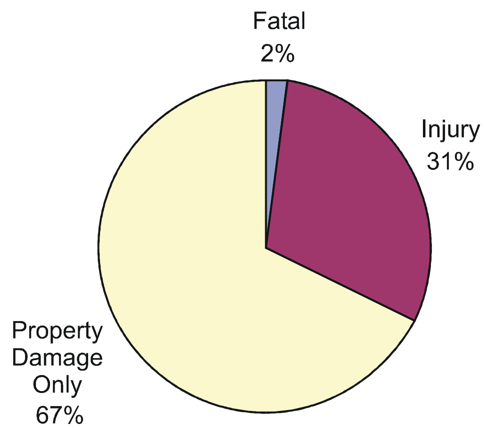

Figure 19. Collision Type Distribution for Car Only Crashes in Work Zones. AN (angle), BI (backed into), FI (fixed object in road), FO (fixed object off road), PE (collision with pedestrian), RE (rear end), SS (sideswipe same direction).

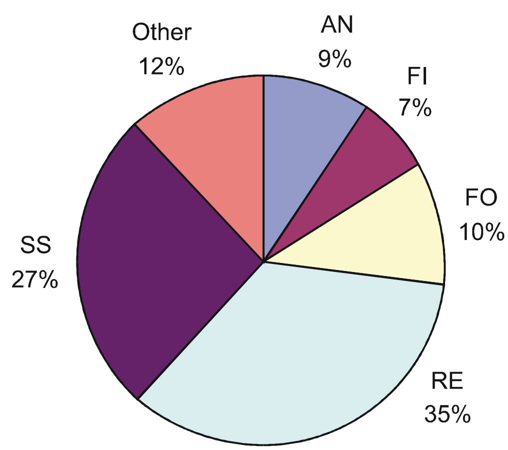

Figure 20. Collision Type Distribution for Crashes Involving Heavy Vehicles in Work Zones. AN (angle), BI (backed into), FI (fixed object in road), FO (fixed object off road), PE (collision with pedestrian), RE (rear end), SS (sideswipe same direction).

Severity Distribution for Single- and Multiple-Vehicle Involvement

The severity distributions for single-vehicle and multiple-vehicle crashes are shown in Figures 21 and 22, respectively. All 17 fatal crashes were multiple-vehicle crashes. The Type 1 proportionality tests also showed that the proportion of injury crashes for single-vehicle crashes was significantly higher than for multiple-vehicle crashes and that the proportion of PDO crashes for single-vehicle crashes was significantly lower.

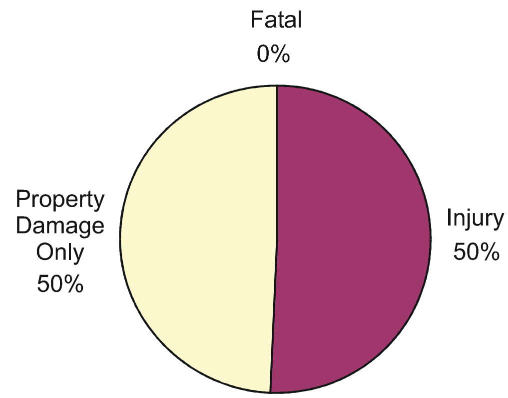

Figure 21. Severity Distribution for Single-Vehicle Crashes in Work Zones

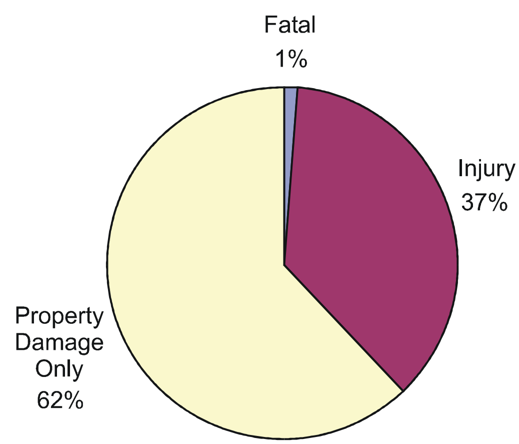

Figure 22. Severity Distribution for Multiple-Vehicle Crashes in Work Zones

Comparisons of Work Zone and Non–Work Zone Crashes

Single- and Multiple-Vehicle Involvement

The number of crashes from 1996 to 1999 was obtained from the 1996–1999 *Virginia Traffic Crash Facts* prepared by the Virginia Department of Motor Vehicles. The number of non–work zone crashes was obtained by subtracting work zone crashes from the total number of crashes. The Type 1 proportionality tests showed that the proportion of multiple-vehicle crashes was significantly higher in work zones (see Table 14).

Table 14. Type 1 Proportionality Test Results for Single- and Multiple-Vehicle Crashes for Work Zone and Non–Work Zone Crashes

Crash Type	Total Crashes	Work Zone Crashes	Non–Work Zone Crashes	Alternative Hypothesis	Z
Single vehicle	150,405	157	150,248	Pw<Pn	-10.546
Multiple vehicle	536,779	1,327	535,452	Pw>Pn	10.546

Severity

The severity distribution for work zone crashes is shown in Figure 4. The severity distribution for non–work zone crashes is shown in Figure 23.

The following results were obtained from the Type 1 proportionality tests:

1. The proportion of fatal crashes was significantly higher in work zones.
2. The proportion of injury crashes was significantly lower in work zones.
3. The proportion of PDO crashes was significantly higher in work zones.

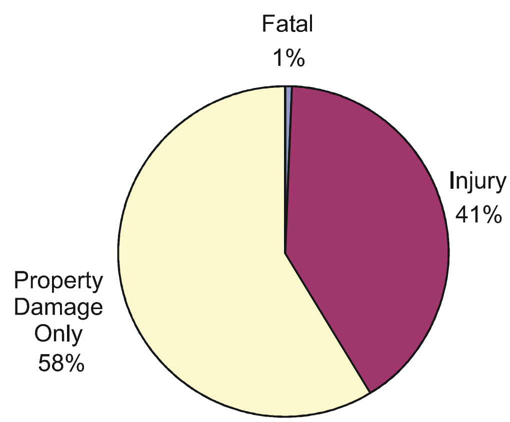

Figure 23. Severity Distribution for Non–Work Zone Crashes

Linkages of Study Results with Those of Previous Studies

Although this study did not include an analysis of speed variances, it did show that rear end crashes were predominant at each location for all road types. In addition, multiple-vehicle crashes were predominant in work zones and the proportion of these crashes was significantly higher in work zones. Rouphail and others[2] indicated the significant increase in the proportion of multiple-vehicle crashes during construction and the higher occurrence of rear end collisions and pointed to the problem of increased speed variations in work zones. Garber and Woo[3] found that speed variances generally increased during the period when work zones were installed and that the crash rate increased as speed variance increased. Paulsen[13] and others also showed that one of the major problems at work zones was 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. In addition, two previous studies[17,18] showed that the use of a CMS with a radar unit informing drivers they were speeding was an effective speed control device for controlling speeds and speed variances. It is therefore highly probable that the use of such a system would be an effective way of reducing speed variances. Thus, rear end crashes might be significantly reduced.

This study showed that there were more fixed object crashes during nighttime. This conclusion is valid with respect to both the proportion and the number. Although 73 percent of the work zone crashes occurred during daytime, more than half of the fixed object crashes occurred during nighttime. Two previous studies[5,7] showed similar results. These results suggest 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.

SUMMARY OF RESULTS

- The activity area had the highest number of crashes and the highest number of fatal crashes.
- The termination area was the safest with respect to numbers of crashes.
- For all crashes studied, PDO crashes were the predominant severity type, followed by injury crashes. Fatal crashes comprised the smallest fraction of crashes.
- Rear end crashes were predominant for all areas and all road types except for the termination area, where all crashes were angle crashes.
- The vast majority (83%) of crashes in the advance warning area were rear end crashes.
- The proportion of sideswipe same direction crashes increased as traffic moved from the advance warning area to the transition area, resulting in these crashes being the second largest crash category in the transition area.
- As traffic moved from the transition area to the work area, the proportions of rear end and sideswipe same direction crashes decreased and the proportions of fixed object off road and angle crashes increased, although rear end crashes were still predominant.
- Most nighttime work zone crashes were in the activity area. The severity of nighttime and daytime work zone crashes was not significantly different.
- There were more fixed object crashes and fewer angle and rear end crashes in work zones during nighttime than during daytime.

- Work zone crashes involved a higher proportion of multiple-vehicle crashes than did non–work zone crashes.

- There were higher proportions of fixed object in road and sideswipe same direction crashes and lower proportions of angle and rear end crashes for crashes involving heavy vehicles than for car only crashes.

- There were higher proportions of fixed object in road and sideswipe same direction and lower proportions of angle and rear end crashes for multiple vehicle crashes involving only cars than for multiple vehicle crashes involving heavy vehicles.

- Work zone crashes involved a higher proportion of fatal crashes than non–work zone crashes.

CONCLUSIONS

- *The most dangerous area in a work zone is the activity area, in both the total number of crashes and the number of fatal crashes.* Therefore, any countermeasure that will significantly reduce crashes in the activity area will have a significant improvement on safety in the work zone.

- *The predominance of rear end crashes in work zones strongly suggests that a major causal factor of work zone crashes is speed related.* As discussed previously, rear end crashes are mainly caused by vehicles driving at different speeds, resulting in a high speed variance. In addition, the higher proportion of multiple-vehicle crashes in work zones indicated a higher interaction of vehicles within work zones, which can be attributed to the higher speed variances. The implementation of a countermeasure that reduces speed variance or that causes drivers to drive at approximately the same speed throughout a work zone will increase safety significantly. This does not necessarily mean lowering the speed limit in 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 nighttime (in both proportions and numbers) suggests that problems may exist in the lighting conditions at work zones or in the illumination conditions of channelizing devices during nighttime. The significant increase in collision with pedestrian fatal crashes in work zones also indicates that more effective strategies should be implemented to separate traffic and work activities. All the involved pedestrians in this study were highway workers. The higher proportion of fatal crashes in work zones indicates that safety is still a major problem in work zones.*

RECOMMENDATIONS

- *To allow a more detailed analysis of crashes in work zones, the following fields should be added to the Police Accident Report (FR-300):*

- whether construction activities were going on when the crash occurred
- the configuration of the work zone
- the exact location of the crash
- types of traffic control devices used and their configurations
- the posted speed limit for the work zone
- whether workers were involved in the crash.

- *VDOT's resident engineers should record the start and end dates of work zones to allow for a more detailed analysis.*

- *After these additional data items become available, the topics covered in this study should be revisited.*

- *Given the significant increase in fixed object crashes during nighttime, a detailed study should be conducted on the causal factors of nighttime crashes in work zones.* Lighting, the visibility of channelizing devices, and the effect of alcohol should be studied in detail.

- *Since rear end crashes are strongly related to the speed variances of vehicles in the traffic stream, CMSs with radar units should be more widely used as a speed control device in work zones.*

- *More effective strategies should be implemented to separate traffic and the work area in work zones.*

- *Since the transition area of the work zones has a unique crash pattern featuring the significant increase of sideswipe same direction crashes, a detailed study of this area should be conducted, particularly with respect to signing procedures that will encourage early merging.*

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