An Analysis of Speeding and Speed-Related Crashes in North Carolina Work Zones

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Submitted to
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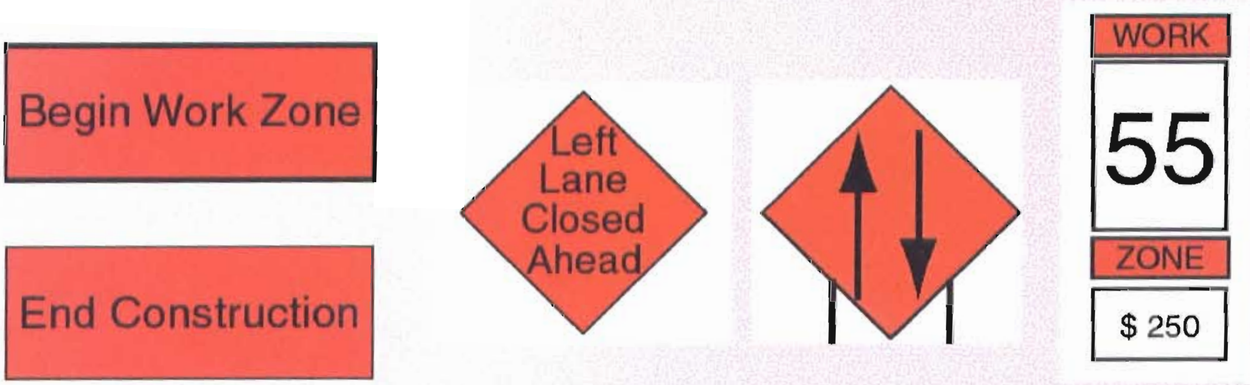

AN ANALYSIS OF SPEEDING AND SPEED-RELATED CRASHES IN NORTH CAROLINA WORK ZONES

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Table 1. North Carolina Crashes on Roads under Construction by Road Class and Whether Speeding Was Involved, 1994-1999.

ROAD CLASS	SPEEDING[1]		NO SPEEDING[1]		TOTAL[1]	
Interstate	3510	(59.0%)	2443	(41.0%)	5953	(25.9%)
US Route	2615	(52.0%)	2413	(48.0%)	5028	(21.8%)
NC Route	1549	(46.7%)	1704	(52.3%)	3253	(14.1%)
Secondary Route	1025	(46.4%)	1181	(53.5%)	2206	(9.6%)
Local Street	2234	(34.3%)	4273	(65.7%)	6507	(28.3%)
Other Public Road	18	(36.0%)	32	(64.0%)	50	(0.2%)
Private Road or Driveway	12	(34.3%)	23	(65.7%)	35	(0.2%)
TOTAL[2]	10963	(47.6%)	11067	(52.4%)	23032	(100.0%)

1 Column percents shown.
2 Row percents shown.

Table 2 shows that the percentages of crashes that resulted in a fatality, an A-level injury, or a B-level injury were approximately the same, whether or not speeding was involved. However, C-level injuries were more common when speeding was involved (35.3 percent) than when speeding was not involved (24.5 percent). "No injury" was more likely when speeding was not involved (62.7 percent) than when speeding was involved (51.7 percent). In other words, crashes involving speeding were more likely to result in an injury, but not a more severe injury, than crashes that did not involve speeding.

Table 2. North Carolina Crashes on Roads Under Construction by Crash Severity and Whether Speeding Was Involved, 1994-1999.

CRASH SEVERITY	SPEEDING[1]		NO SPEEDING[1]		TOTAL[1]	
K (Fatal)	59	(0.5%)	74	(0.6%)	133	(0.6%)
"A" Injury	288	(2.6%)	394	(3.3%)	682	(3.0%)
"B" Injury	1072	(9.8%)	1079	(8.9%)	2151	(9.3%)
"C" Injury	3879	(35.3%)	2961	(24.5%)	6840	(29.7%)
O (No Injury)	5681	(51.7%)	7584	(62.7%)	13265	(57.5%)
TOTAL[2]	10979	(47.6%)	12092	(52.4%)	23071	(100.0%)

1 Column percents shown.
2 Row percents shown.

Passenger cars comprised about two-thirds of the vehicles involved in crashes on roads under construction (Table 3). Less than five percent of the vehicles involved were large trucks. The distributions of vehicles involved in speed-related and non-speed-related crashes were very similar. Because many crashes involve more than one vehicle, the totals are higher than the totals in Tables 1 and 2, which represent crashes.

Table 3. Types of Vehicles Involved in Crashes on Roads Under Construction in North Carolina by Whether Speeding Was Involved, 1994-1999.

VEHICLE TYPE	SPEEDING[1]		NO SPEEDING[1]		TOTAL[1]	
Passenger Cars	7743	(67.8%)	22911	(67.0%)	30654	(67.2%)
SUV's	274	(2.4%)	666	(2.0%)	940	(2.1%)
Truck Tractors + Trailers	504	(4.4%)	1658	(4.9%)	2162	(4.7%)
Light Pickups	1660	(14.5%)	4235	(12.4%)	5895	(12.9%)
Vans	539	(4.7%)	1739	(5.1%)	2278	(5.0%)
All Other Vehicle Types	702	(6.1%)	3009	(8.8%)	3711	(8.1%)
TOTAL[2]	11422	(25.0%)	34218	(75.0%)	45640	(100.0%)

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Drivers in speed-related crashes were more likely to have been drinking than drivers in non-speed-related crashes (4.2 percent vs. 1.3 percent) (Table 4). Speeding may well be the result of drivers' judgment being impaired by alcohol. It is also possible that drivers who exhibit certain risk-taking behaviors, such as speeding, are likely to engage in other risk-taking behaviors, such as drinking and driving.

Table 4. Number of Drivers Involved in Crashes on Roads Under Construction in North Carolina by Whether Alcohol and Speeding Were Involved, 1994-1999.

ALCOHOL USE	SPEEDING[1]		NO SPEEDING[1]		TOTAL[1]	
Drinking	465	(4.2%)	417	(1.3%)	882	(2.0%)
Not Drinking	10564	(95.8%)	32409	(98.7%)	42973	(98.0%)
TOTAL[2]	11029	(25.2%)	32826	(74.9%)	43855	(100.0%)

1 Column percents shown.
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INTRODUCTION

A recent analysis of crash data in North Carolina revealed that 33 percent of all crashes and 44 percent of fatal crashes are speed-related, *i.e.*, speed was indicated as a contributing factor for at least one of the drivers involved. Speeding is present in work zone crashes as well, especially on primary highways. Lower speed limits commonly apply in work zones, where motorists often encounter narrower travel lanes, uneven pavement, and the presence of workers and their equipment. To combat speeding in work zones, the North Carolina Department of Transportation (NCDOT) uses signs such as GIVE 'EM A BRAKE and signs indicating substantial speeding fines.

Crash situations that may be likely in work zones include motor vehicles striking fixed objects (*e.g.*, temporary barriers, crash cushions, barricades, and orange barrels), workers or construction vehicles, as well as vehicle-to-vehicle rear-end and lane-changing / merging collisions.

A revised crash report form was implemented in North Carolina on January 1, 2000. The revised form allows the officer to indicate "work zone" as a *contributing circumstance*. An older crash report form was used through December 31, 1999. "Work zone" is not explicitly mentioned on the older form. However, potential work zone crashes can be identified according to what *road defect* was identified by the officer.

The University of North Carolina Highway Safety Research Center's computerized crash files for North Carolina were analyzed to get background information. Tables 1 through 4 show selected characteristics of crashes that occurred between January 1, 1994 and December 31, 1999 on roads under construction according to whether speeding was involved. A road was considered to be under construction if *road defects* was coded as either "under construction with defects" or "under construction, no defects." Speeding was involved if "exceeding speed limit," "exceeding safe speed," or "failure to reduce speed" were identified as *circumstances contributing to the collision*.

Overall, about 48 percent of crashes on roads under construction involved speeding. A breakdown by road class reveals that more than half of the crashes on Interstates and US routes under construction involved speeding (Table 1).

OBJECTIVES

This one-year study had two objectives:

1. To identify the extent of speeding in work zones by collecting spot speed data on various classes of highways.
2. To determine the characteristics of work zone crashes that involve speeding. This was accomplished by coding available crash data.

The two objectives were totally independent, *i.e.*, the speed data and crash data were *not* associated with the same work zones.

PAST RESEARCH

The work zone literature can be divided into two categories according to emphasis: (1) crash studies and modeling; and (2) countermeasure evaluations. A number of such publications are reviewed below.

Crash Studies and Modeling

Work zone crashes typically account for 1 to 3 percent of all reported crashes (Harkey and Hall, 1998). The actual number of work zone crashes may be three to five times the reported number (Raub and Sawaya, 2000). A limited investigation undertaken by Fenner et al. (1986) found that 77 percent of crashes occurring within work zones were not coded as such. There are several reasons why the reported number of work zone crashes may be less than the actual number (Harkey and Hall, 1998; Wang et al., 1994).

1. Many minor crashes may not be reported at all.
2. Crashes that occur within a work zone's influence area but outside the work zone itself (such as rear-end crashes at the end of the queuing area prior to the work zone) may not be identified as work zone crashes.
3. Many states do not have an explicit code for work zone crashes on their police crash report forms.

Analyses of work zone crashes in several states revealed that the percentages of rear-end and sideswipe crashes were higher in work zones than in non-work zones (Pigman and Agent, 1990; Wang et al., 1994 and 1996; Daniel et al., 2000; Raub and Sawaya, 2000). Many of the rear-end crashes are probably the result of speed differentials: a vehicle collides with another vehicle that has slowed down or stopped in the work zone. The installation of urban work zones in Virginia did not significantly affect the distribution of crash types (Garber and Woo, 1990).

With regard to the crash environment, the percentages of work zone crashes that occurred on freeways and within interchange areas in Minnesota and Illinois were significantly higher than those of non-work zone crashes (Wang et al., 1994). In Georgia, fatal work zone crashes were over-represented on urban Interstates and rural principal arterials, compared to fatal non-work zone crashes. Also, a significantly higher proportion of fatal work zone crashes than fatal non-work zone crashes occurred during darkness (Daniel et al., 2000).

From 1983 through 1986, approximately 500 work zone crashes were reported each year in Kentucky. These were more likely to result in injuries and fatalities (28 percent) than non-work zone crashes (22 percent) (Pigman and Agent, 1990). In Maine, work zone crashes were slightly more severe than non-work zone crashes, but in Minnesota and Illinois, work zone crashes were slightly *less* severe than non-work zone crashes (Wang et al, 1994). In Virginia, the installation of work zones in urban areas did not significantly affect crash severity (Garber and Woo, 1990). When all work zone crashes are considered, instead of just reported work zone crashes, then work zone crashes may be no more likely to result in injuries or fatalities than non-work zone crashes (Raub and Sawaya, 2000).

In Washington State and Michigan, crashes involving temporary concrete barriers in work zones were *not* more likely to result in severe injuries than crashes involving permanent concrete barriers not in work zones. A substantial number of crashes involving temporary concrete barriers resulted in some level of occupant injury: 49 percent in Washington State and 29 percent in Michigan (Harkey and Hall, 1998)

About 9 percent of work zone crashes in New York State were intrusion crashes, in which a vehicle entered the work space or buffer space. The most frequent objects struck were construction vehicles and equipment. Injury severity was somewhat less for intrusion crashes than for work zone crashes in general. Excessive speed was a contributing factor in one-fourth of all intrusion crashes (Bryden et al., 2000).

In mathematical modeling, the observed number of work zone crashes can be expressed as a function of work zone characteristics. The resulting model allows researchers and engineers to identify the most important factors in work zone crashes. The model can also be used to predict the expected number of crashes in a work zone given its unique characteristics. In turn, results from modeling may be used to implement changes in the work zone to reduce the number of crashes. The following paragraphs discuss several examples of modeling.

Garber and Woo (1990) modeled the effects of various traffic control devices on work zone crash rates. They found that the most effective combinations of traffic control devices were (1) cones, flashing arrows, and flagmen on multi-lane highways, and (2) flagmen and either cones or static signs on two-lane highways.

Venugopal and Tarko (2000) used five years of Indiana work zone crash data to develop regression models that predict the expected number of crashes in work zones on rural two-lane roads. Traffic volume, length, and duration of work (all exposure-to-risk variables), as well as whether a lane closure was involved, were significant factors for crashes in work zones.

Elias and Herbsman (2000) used the Monte Carlo method to simulate work zone crash rates according to the observed number of crashes, the number of days that the work zone is in effect, the ADT, and the length of the work zone. The simulation performed favorably when compared against actual crash data from Florida.

Countermeasure Evaluations

Countermeasures to combat speeding in work zones are usually enforcement-related, such as radar and increased speeding fines. Engineering and enforcement countermeasures could also be implemented, but these have not been evaluated as extensively as enforcement. This section discusses several countermeasures and their effects on speeds.

Police officers routinely use radar to measure vehicle speeds. Some motorists use radar detectors to avoid speeding citations: they will slow down when the radar detector indicates the presence of radar enforcement. Nearby drivers may slow down as well. Radar may be attended (by a police officer) or unattended (referred to as "drone radar"). Drone radar provides an indication to motorists of potential police presence and is relatively inexpensive compared to having actual police presence (Benekohal et al., 1993). Drone radar reduced passenger car speeds by 1 to 3 miles per hour in Texas and by up to 3.4 miles per hour in Missouri (Carlson et al., 2000 and Freedman et al., 1994). However, drone radar did not reduce speeds when drivers knew that it was drone radar and that police officers were not present (Benekohal et al., 1993). A combination of attended and drone radar can be used to keep drivers "guessing" as to whether police officers are present (Benekohal et al., 1993).

In Texas, speed trailers that displayed speeds to oncoming motorists and contained an advisory speed limit sign were evaluated. The speed trailers reduced speeds in rural work zones by about 5 miles per hour. By comparison, a combination of drone radar and speed advisory signs reduced speeds by 1 to 3 miles per hour. The speed trailers had a greater impact on reducing truck speeds than on reducing car speeds upstream from the work zone, but the impacts were the same inside the work zone (Carlson et al., 2000). Speed reductions continue as long as the speed trailers are in place; after they are removed, speeds quickly increase back to their original level (Perrillo, 1997).

Many states impose stiffer penalties for speeding in work zones than for speeding in non-work zones. For example, the fine for speeding in work zones in North Carolina was increased from $100 to $250 in 1999. In Texas, the fines for speeding in work zones were doubled in 1998; speeds were essentially unchanged four to six months later (Ullman et al., 2000). The lack of effectiveness may be the result of no change in enforcement efforts: the number of speeding citations that were issued, and the fines that were actually levied, were generally unchanged.

Rumble strips placed in the travel lanes provide visual and audible cues to drivers that they are approaching a work zone. Orange removable rumble strips at a rural bridge repair site in Kansas reduced mean passenger car speeds by up to 2.7 miles per hour and truck speeds, by up to 5.2 miles per hour (Meyer, 2000).

DATA COLLECTION AND RESULTS

Speed Study

The work zones of interest for the speed study were major projects such as construction or addition of new lanes and bridges, as well as resurfacing. Short-term and moving work zones (such as pothole filling, utility repair or extensions, and restriping) were not included.

A list of active work zones was available from the NCDOT web site. Candidate work zones for this study were selected. Area Traffic Engineers were contacted to obtain information about these candidate work zones and others. After these discussions, seven work zones were chosen for the speed study. The work zones were picked to represent a variety of conditions: Interstate and non-Interstate freeways, rural and urban areas, and three levels of speed limit reduction inside the work zone.

Objectives of the Speed Study

The speed study was undertaken to answer two basic questions:

1. How fast are motorists traveling in and near work zones?
2. How many motorists are exceeding the posted speed limit?

How Speed Data Were Collected

Vehicle speeds were measured by using a laser radar gun. These speeds were obtained by targeting the laser radar on the rear license plate.

Speeds were measured at five locations along each work zone:
Location 1: Well upstream (approximately 1 - 2 miles) from the work zone
Location 2: Where the lanes begin to shift
Location 3: In the work zone
Location 4: Where the lanes shift back to a "normal" configuration
Location 5: Well downstream (approximately 1 - 2 miles) from the work zone

All speeds were associated with vehicles moving in the same direction, so that a speed profile through the work zone could be obtained. For comparison, speed data were sometimes collected for the opposite side of the roadway if no lane closures or speed limit changes were in effect.

To minimize the possibility of motorists slowing down in reaction to someone measuring speeds, the data collector remained inside a white van that used tinted plexiglass panels to conceal the operation of the laser radar gun. A rectangular magnet, measuring 2 feet by 1 foot, was placed on both the driver's and passenger's doors. A square magnet, 1 foot by 1 foot, was placed on the rear of the van. All three magnets had the message, "NC Survey Crew" in black letters against an orange background. An attempt was made to have the van blend in with other construction vehicles in the work zone.

Data collection took place on weekdays in March - June 2000. Speeds were measured during daylight hours, under dry conditions, and when work zone activities were in place. Speeds were not measured at night or under wet conditions because it was thought motorists would be traveling more slowly and the speeds would not be representative. At each of the five locations, speeds were measured for 100 vehicles as they passed the observation point. The vehicle types (passenger car, pick-up, truck-tractor, etc.) were recorded. When traffic was free-flowing, speeds were measured for each vehicle as it passed by, whenever practical. When vehicles were in a platoon, the speed was recorded only for the lead vehicle, because the speeds of following vehicles were constrained by the speed of the lead vehicle (Figure 1).

In the analysis, vehicles were grouped into two categories, passenger vehicles and large trucks. Passenger vehicles consisted of cars, pickups, sport utility vehicles, and vans. Large trucks consisted of truck tractors with trailers. Fewer than 100 vehicles were used in the comparisons of passenger and large truck speeds at each location because other types of vehicles (buses, motorcycles, etc.) were not included. However, at each location, all 100 vehicles were included in the discussions of how many vehicles exceeded the speed limit.

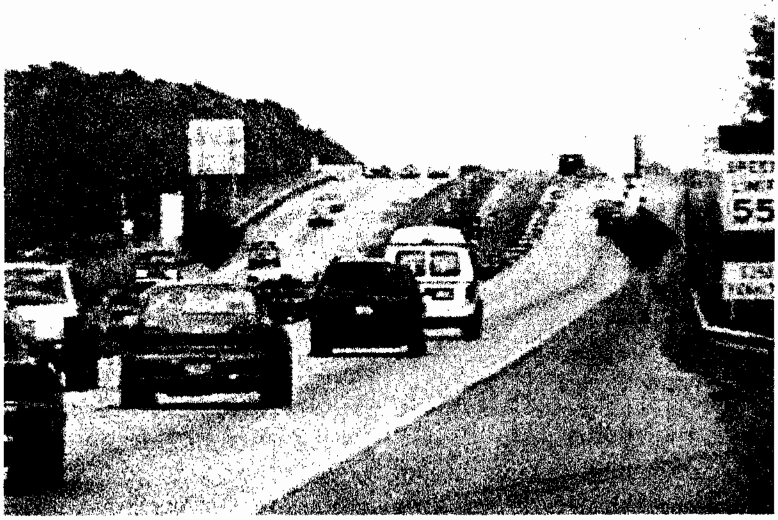


Figure 1. Speeds were measured from inside a van that had tinted windows. When vehicles were in a platoon, the speed was recorded only for the lead vehicle.

Work Zone Descriptions and Observed Vehicle Speeds

I-95 at US 70, Johnston County

I-95 is a four-lane divided highway with a grass median. This section is in a rural area. The roadway was being rehabilitated, with old concrete being removed and replaced with asphalt. New concrete median barrier was also being installed. When speed data were collected, a concrete median barrier was used to close the passing lane for northbound traffic (Figures 2 and 3). The lane closure extended for about two miles in the vicinity of the US 70 interchange. The passing lane re-opened for the weekend at 12:00 noon on Fridays. Both southbound lanes remained open. The regular speed limit of 65 miles per hour was reduced to 55 miles per hour in the work zone.

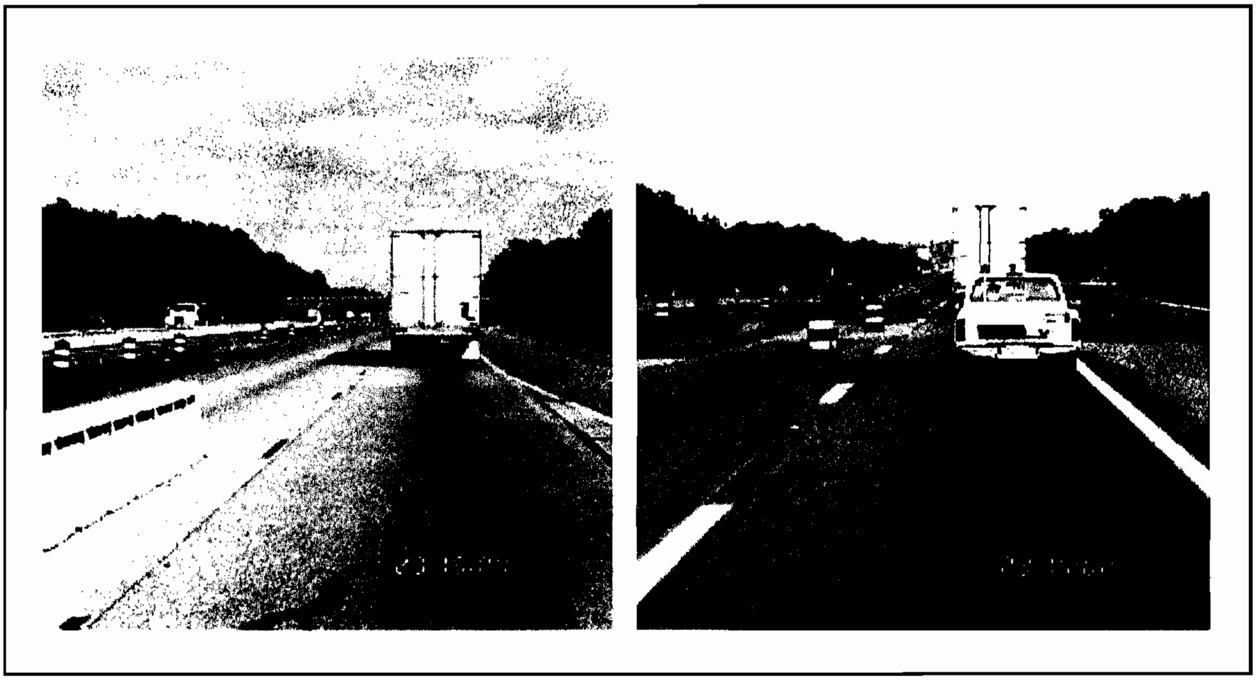


Figure 2. I-95 at US 70, Johnston County, looking north.

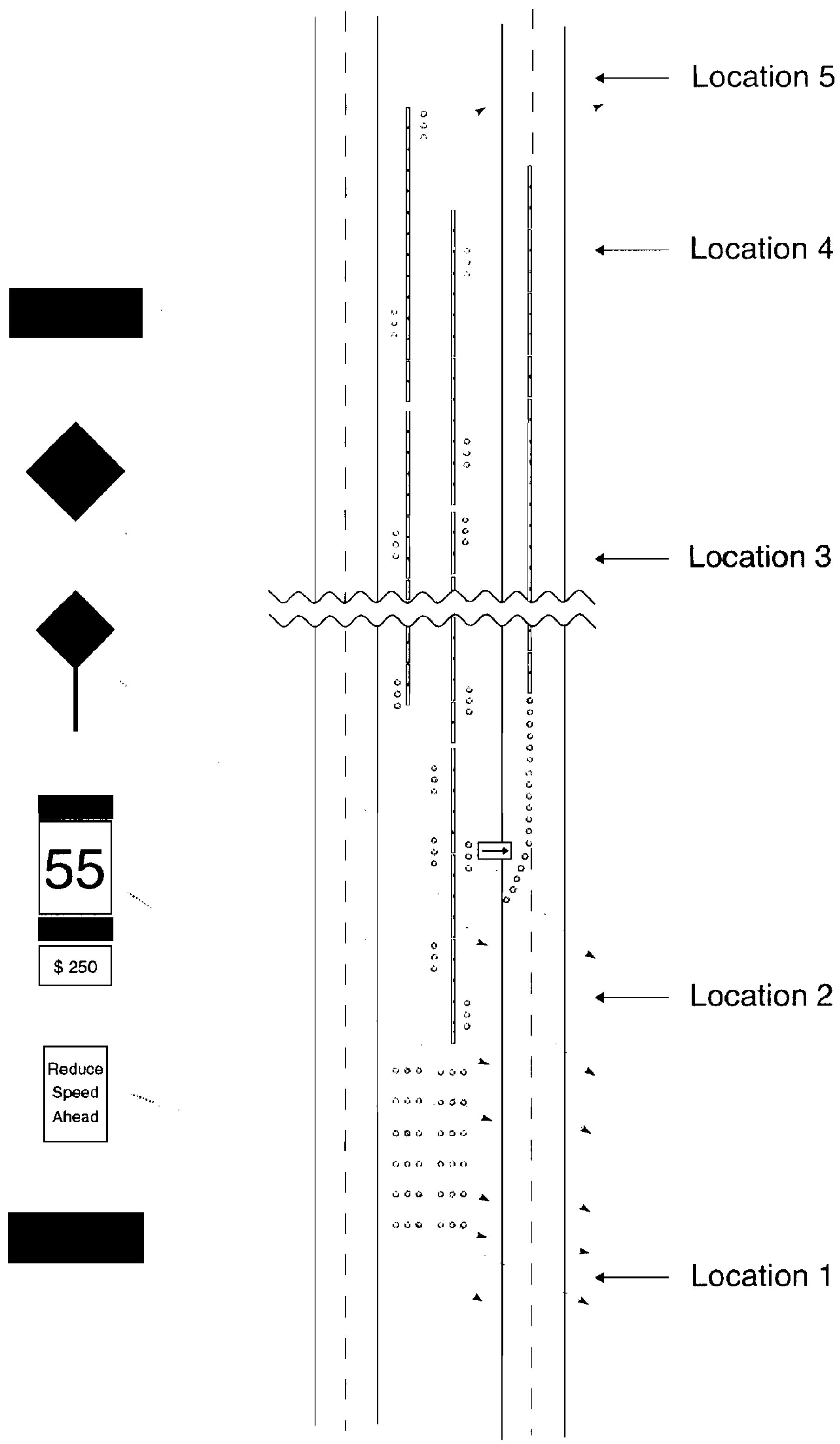


Figure 3. I-95, Johnston County.

In Johnston County, the work zone affected northbound traffic on I-95; southbound traffic had both lanes open, but a lower speed limit was still in effect. The work zone had a definite effect on the speeds of northbound traffic, as evidenced by the dip in speeds in the middle of the work zone (Figure 4). For each work zone in this study, the mean speed profiles for passenger vehicles and large trucks are shown as connected lines at the top of the figures.

At Location 1, where the speed limit was 65 miles per hour, 39 percent of the free-flowing vehicles exceeded the posted limit. At Locations 2 and 4, about 70 percent of the vehicles exceeded the speed limit of 55 miles per hour. At Location 3, only 31 percent of the vehicles exceeded the 55 mile-per-hour speed limit. At Location 5, where the speed limit was again 65 miles per hour, 45 percent of the vehicles exceeded the posted limit. Passenger vehicles and large trucks had the same speed profiles, but large trucks were traveling 0.6 to 3.1 miles per hour *slower* than passenger vehicles (Figure 4).

Because both lanes were open to southbound traffic, speeds remained constant through all five locations (Figure 5). Four-fifths of the motorists at Location 1, and all of the motorists at Locations 2-5 exceeded the speed limit (Table 5). At Locations 1, 2, 3, and 5, large trucks were traveling as much as 4.3 miles per hour *slower* than passenger vehicles. However, at Location 4, large trucks averaged 1.0 mile per hour *faster* than passenger vehicles (Figure 5).

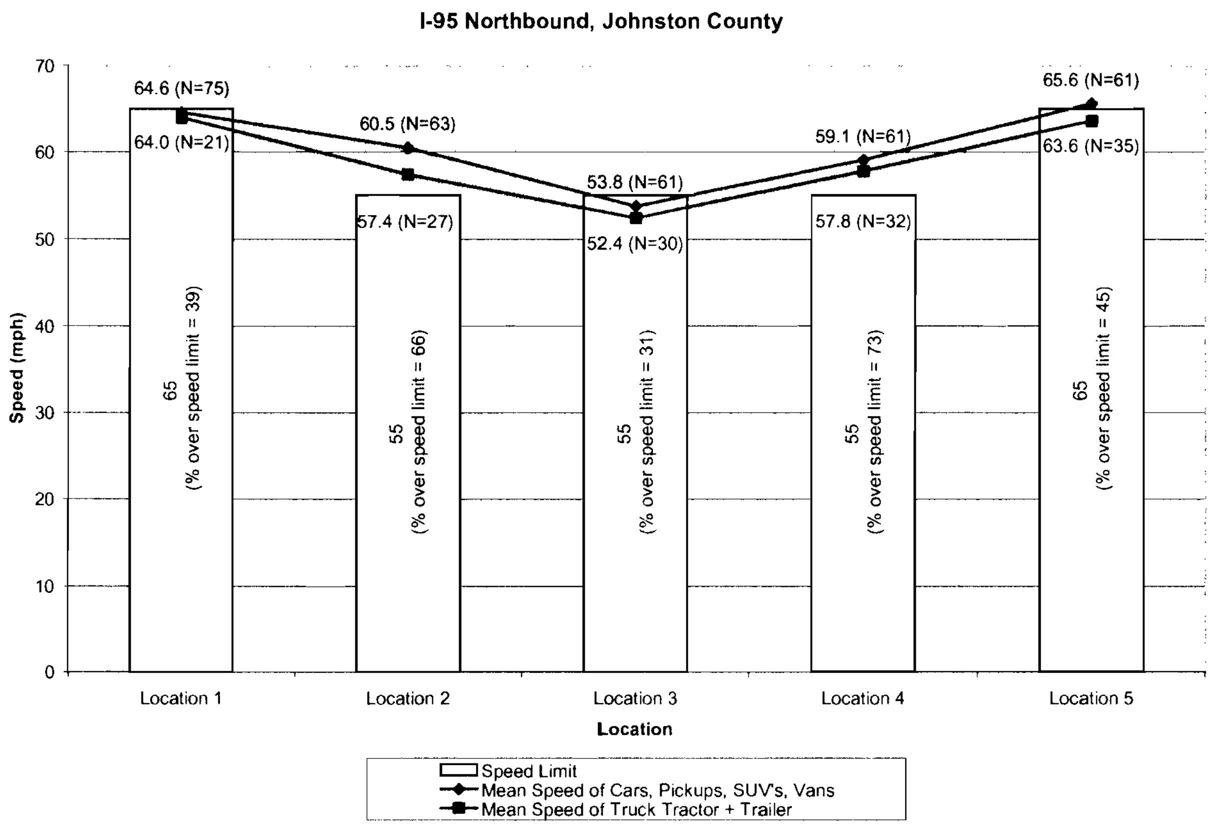


Figure 4. I-95 northbound, Johnston County.

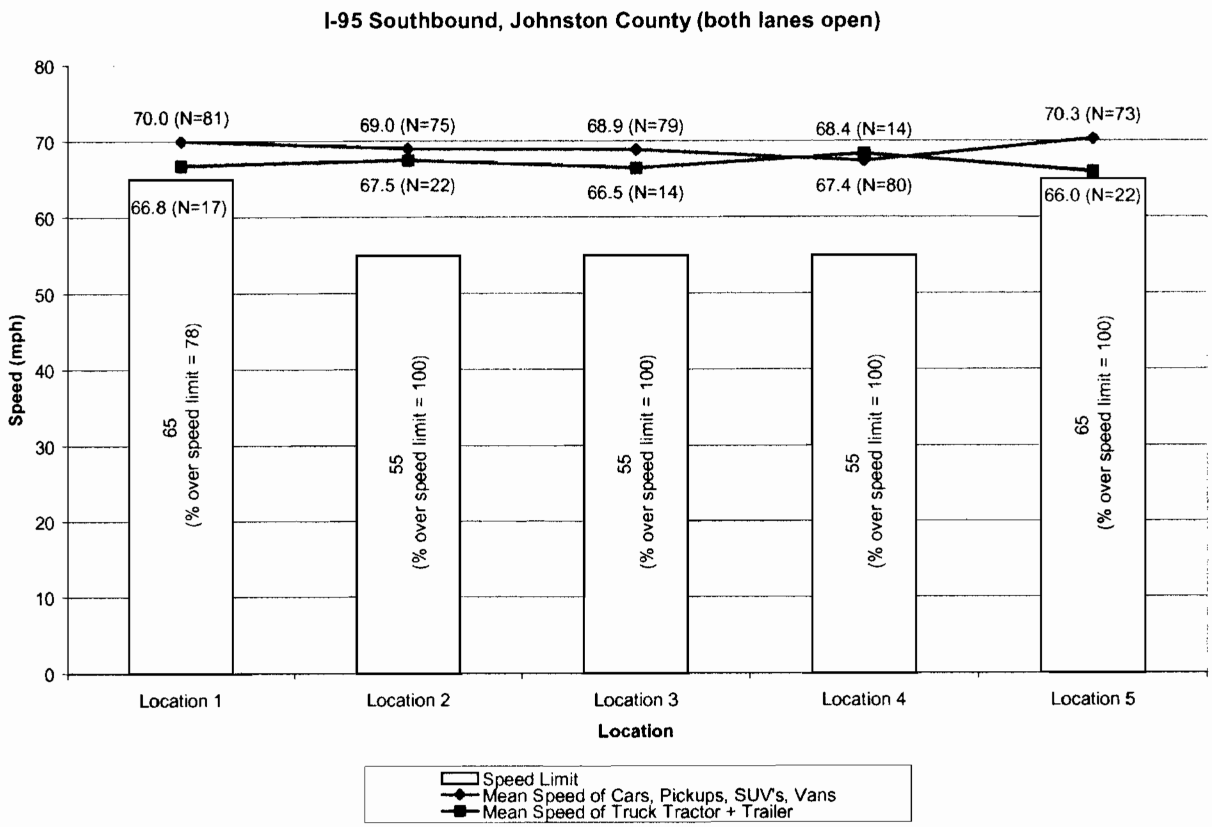


Figure 5. I-95 southbound, Johnston County.

I-95, Robeson County

This is a four-lane divided highway with a grass median. The work zone extended south from Milepost 19 for about five miles or so and passed through the city limits of Lumberton. The work consisted of rehabilitating the roadway and preparing it for eventual widening (Figures 6 and 7). The northbound passing lane was closed for median work and lane widening. Both southbound lanes were open. Three or four sets of rumble strips alerted drivers to the start of the work zone. The regular speed limit of 65 miles per hour was reduced to 55 miles per hour in the work zone.

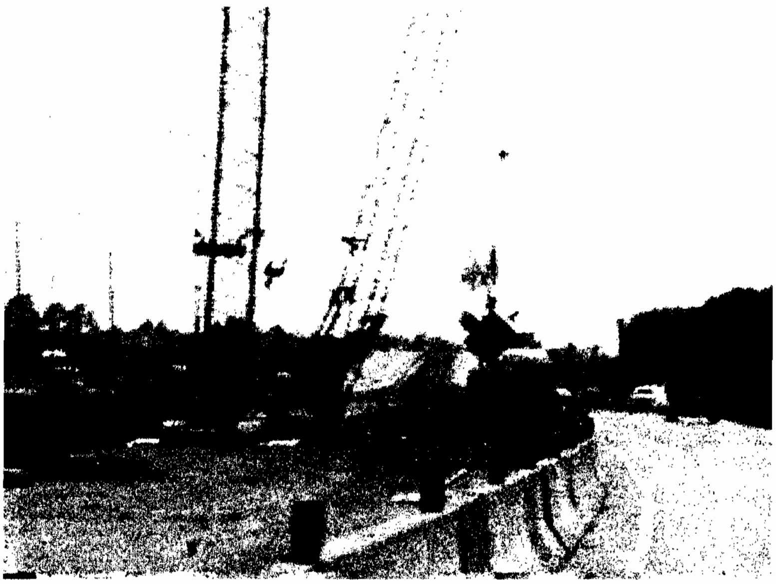


Figure 6. I-95, Robeson County, looking south.

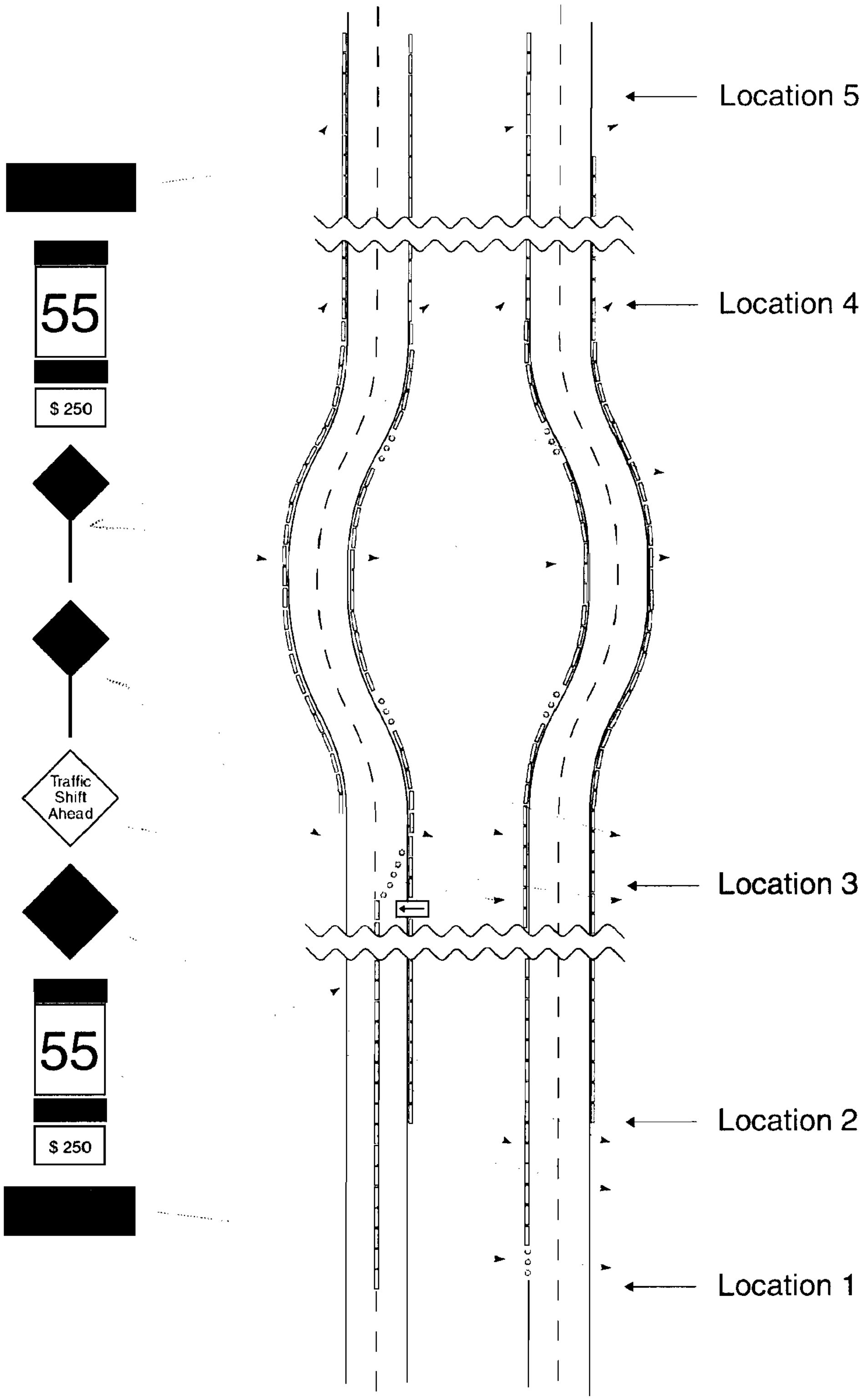


Figure 7. I-95, Robeson County.

Coincidentally, nearly identical mean and 85th percentile speeds were recorded in Robeson County as in Johnston County. Northbound motorists slowed down as they entered the work zone and then sped up as they left the work zone. At Location 3, about one-third of the motorists exceeded the speed limit. By comparison, almost three-fourths of the motorists exceeded the speed limit at Locations 2 and 4 (Figure 8). Large trucks had the same speed profile as passenger vehicles, but were up to 3.4 miles per hour *slower*.

Southbound passenger vehicle speeds remained nearly constant through all five points (Figure 9). At Locations 1, 2, 3, and 5, large trucks were traveling as much as 4.3 miles per hour *slower* than passenger vehicles. However, at Location 4, large trucks averaged 1.0 mile per hour *faster* than passenger vehicles. Most, if not all, motorists were over the speed limit at each location (Table 5).

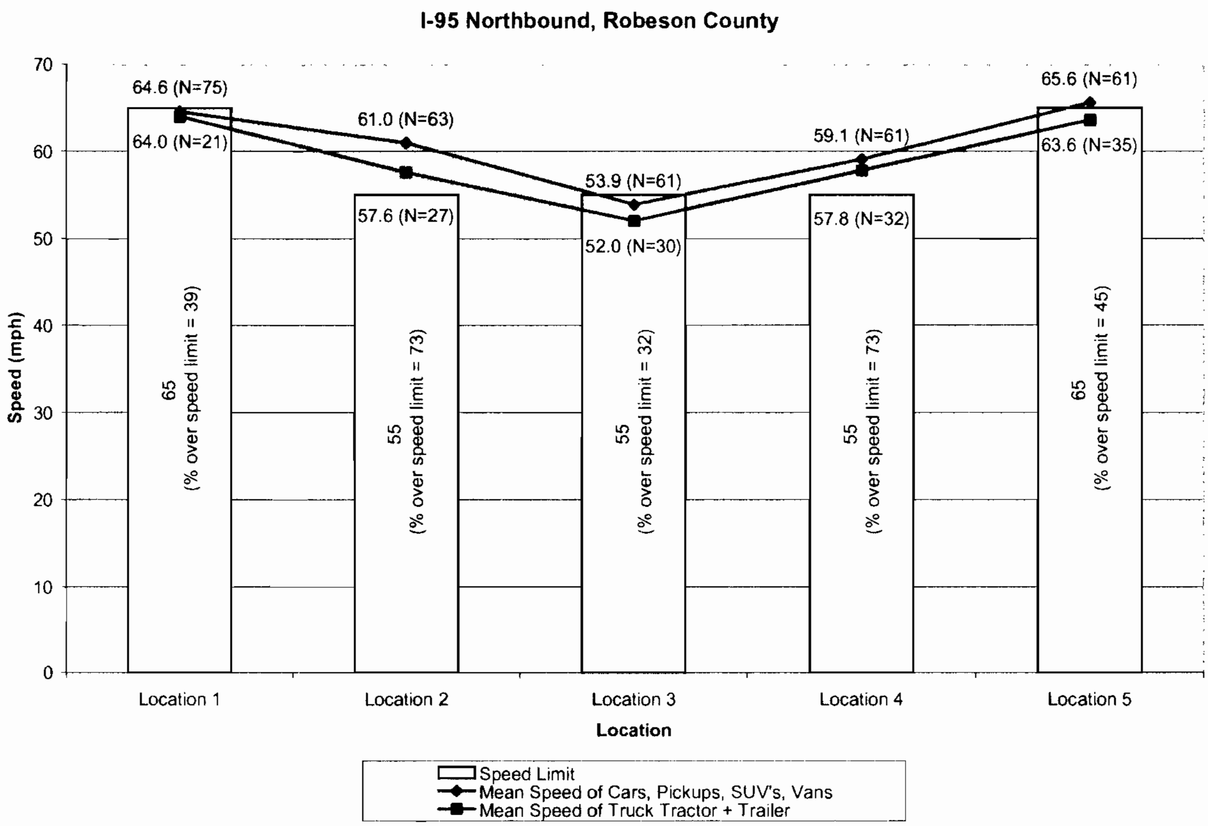


Figure 8. I-95 northbound, Robeson County.

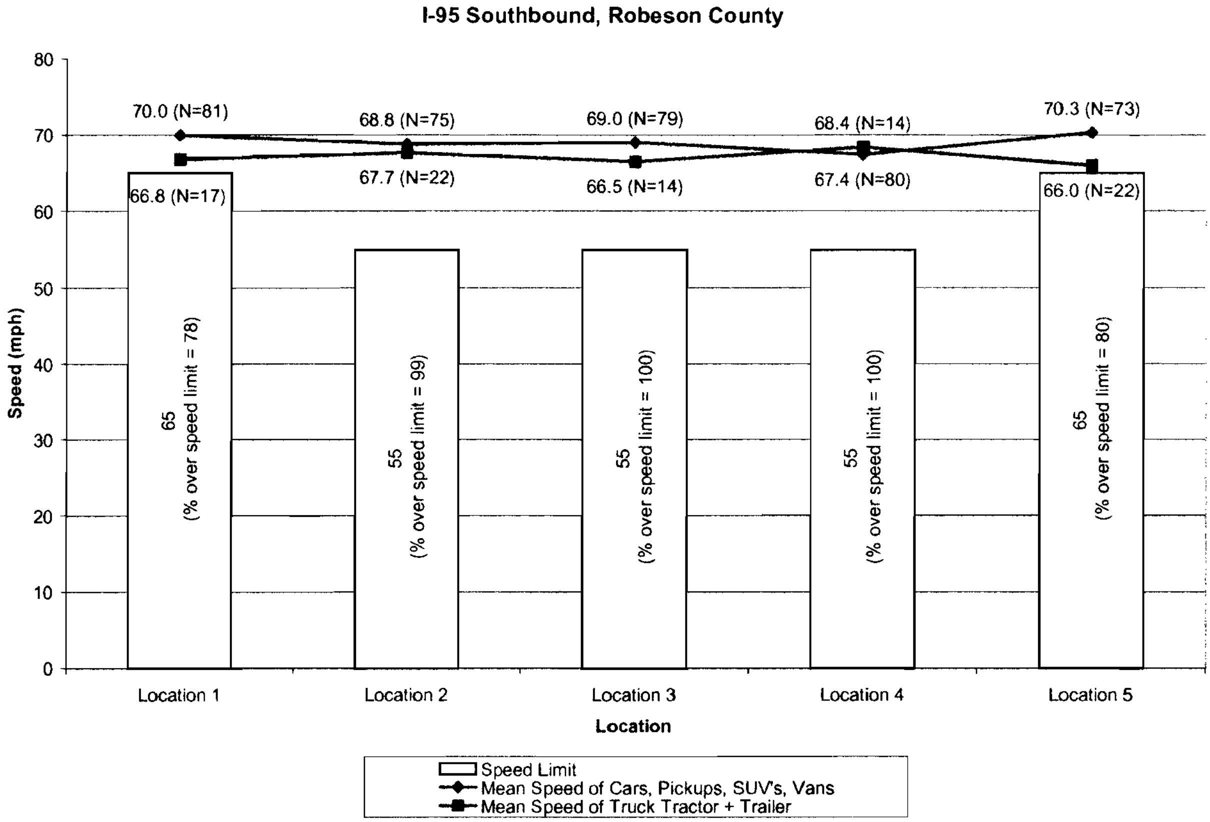


Figure 9. I-95 southbound, Robeson County.

NC 147, Durham County

NC 147, more commonly known as the Durham Freeway, is a four-lane divided highway with a grass median. The work zone was in the city limits of Durham. Median guardrail and cable guardrail were being installed over a project length of 8.79 miles. When speed data were collected, the active work zone was in the vicinity of Ellis Road. Cable guardrail was being installed at the locations where speed data were collected. Barrels were used to close off the passing lane for northbound traffic (Figures 10 and 11). The lane was closed during off-peak travel hours, 9:00 AM to 4:00 PM and 7:00 PM to 6:00 PM. No southbound lanes were closed when speed data were collected. The speed limit was not reduced and remained at 55 miles per hour in the work zone.

Figure 10. NC 147, Durham County, looking north.

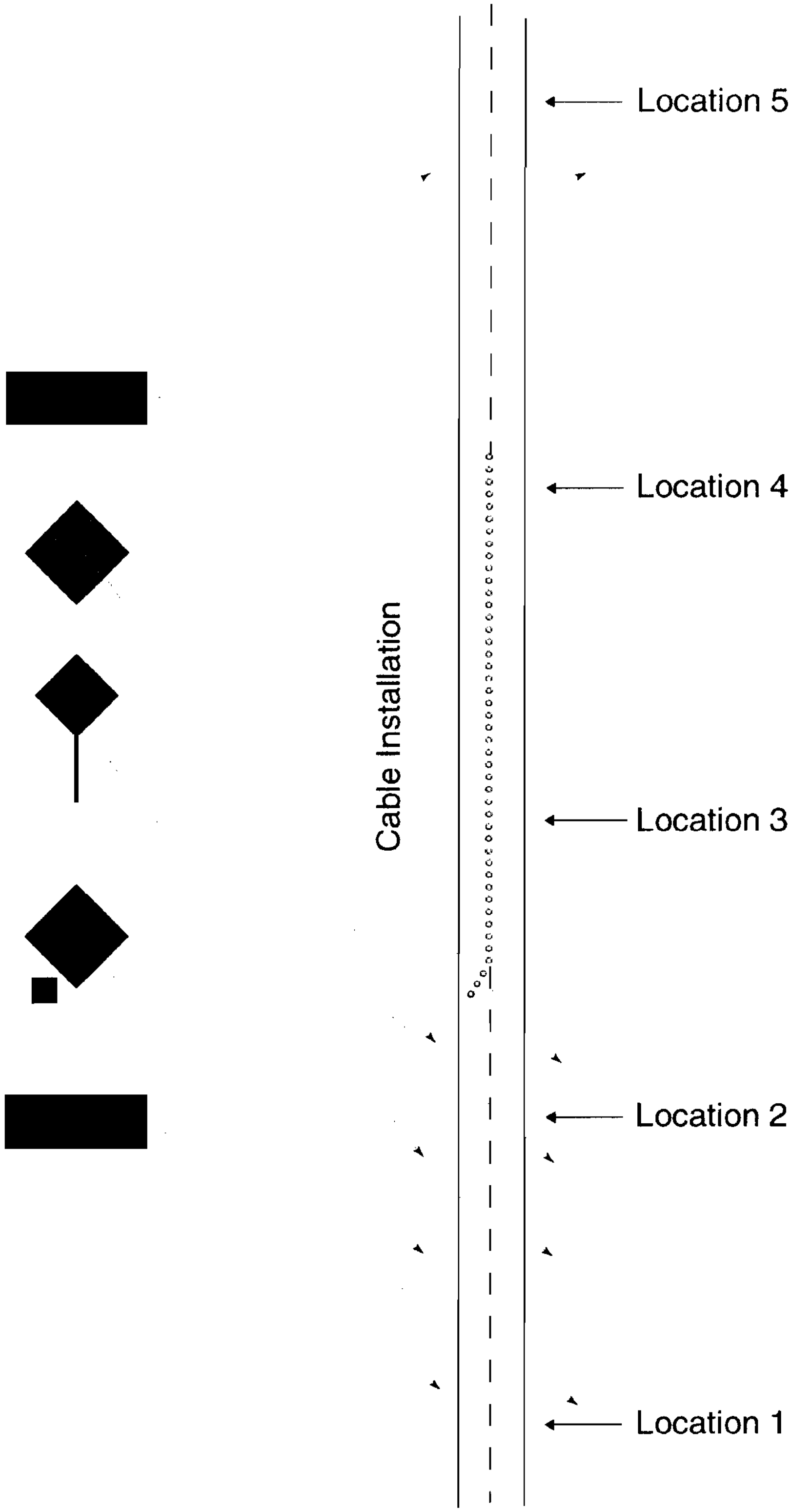


Figure 11. NC 147, Durham County.

A similar reduction in speeds was seen on NC 147 in Durham County. The mean speed of passenger vehicles fell from 67.3 miles per hour at Location 1 to 57.5 miles per hour at Location 3, and then increased back to 65.4 miles per hour at Location 5 (Figure 12). Compared to passenger vehicles, large trucks had *slower* speeds as they entered the work zone (Location 2) and while they were in the work zone (Location 3). These large truck findings may or may not be reliable because no more than eight large trucks were observed at any of the five locations.

The posted speed limit was 55 miles per hour at all five locations, *i.e.*, there was no reduction in the speed limit. Sixty percent of the vehicles at Location 3 were traveling faster than the speed limit. At Locations 1, 2, 4, and 5, 90 percent or more were traveling in excess of the speed limit (Table 5).

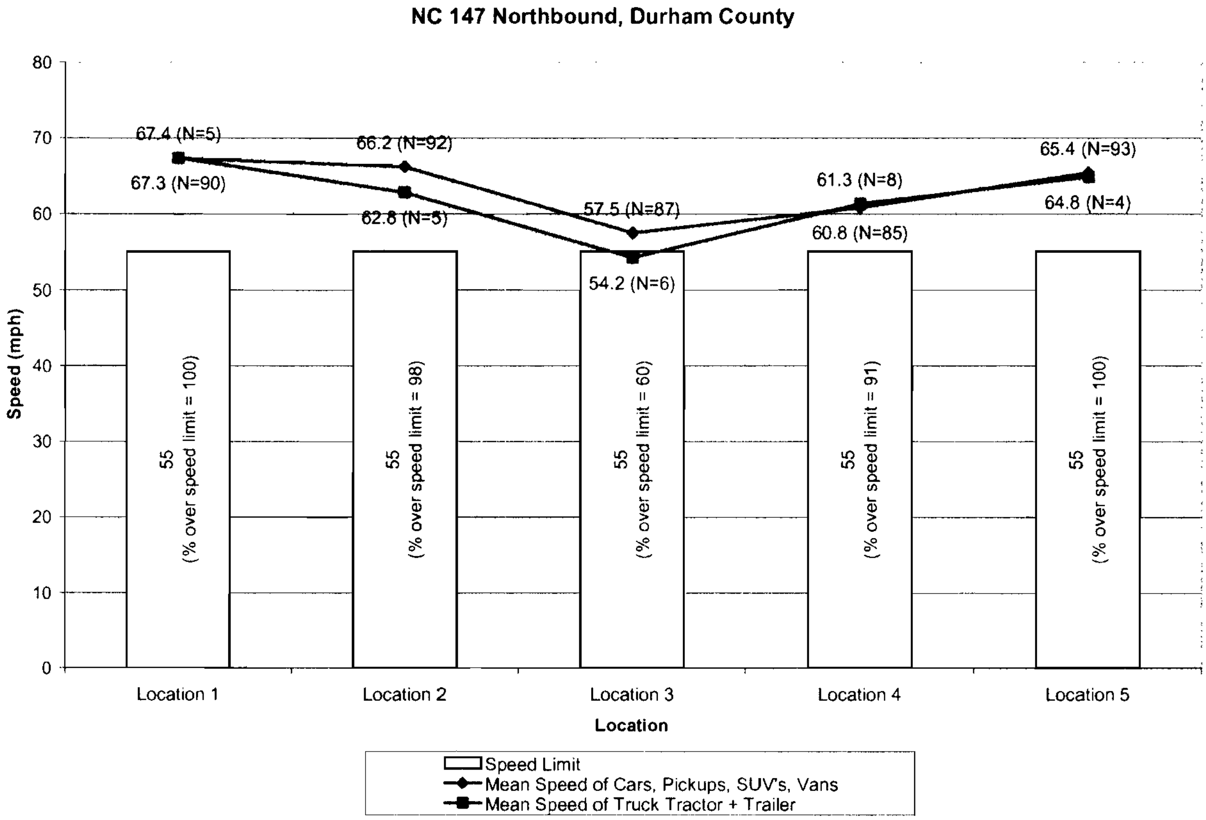


Figure 12. NC 147 northbound, Durham County.

US 421, Lee County

This is a four-lane divided highway with a grass median. The work zone was in a rural area, 5 miles north of Sanford. A new bridge across the Deep River was being built here (Figures 13 and 14). Both southbound lanes were closed, so southbound vehicles were diverted across the median and onto the passing lane on the northbound side. Northbound vehicles in the passing lane were shifted over into the right lane. The regular speed limit of 55 miles per hour was reduced to 45 miles per hour in the work zone.

Figure 13. US 421, Lee County.

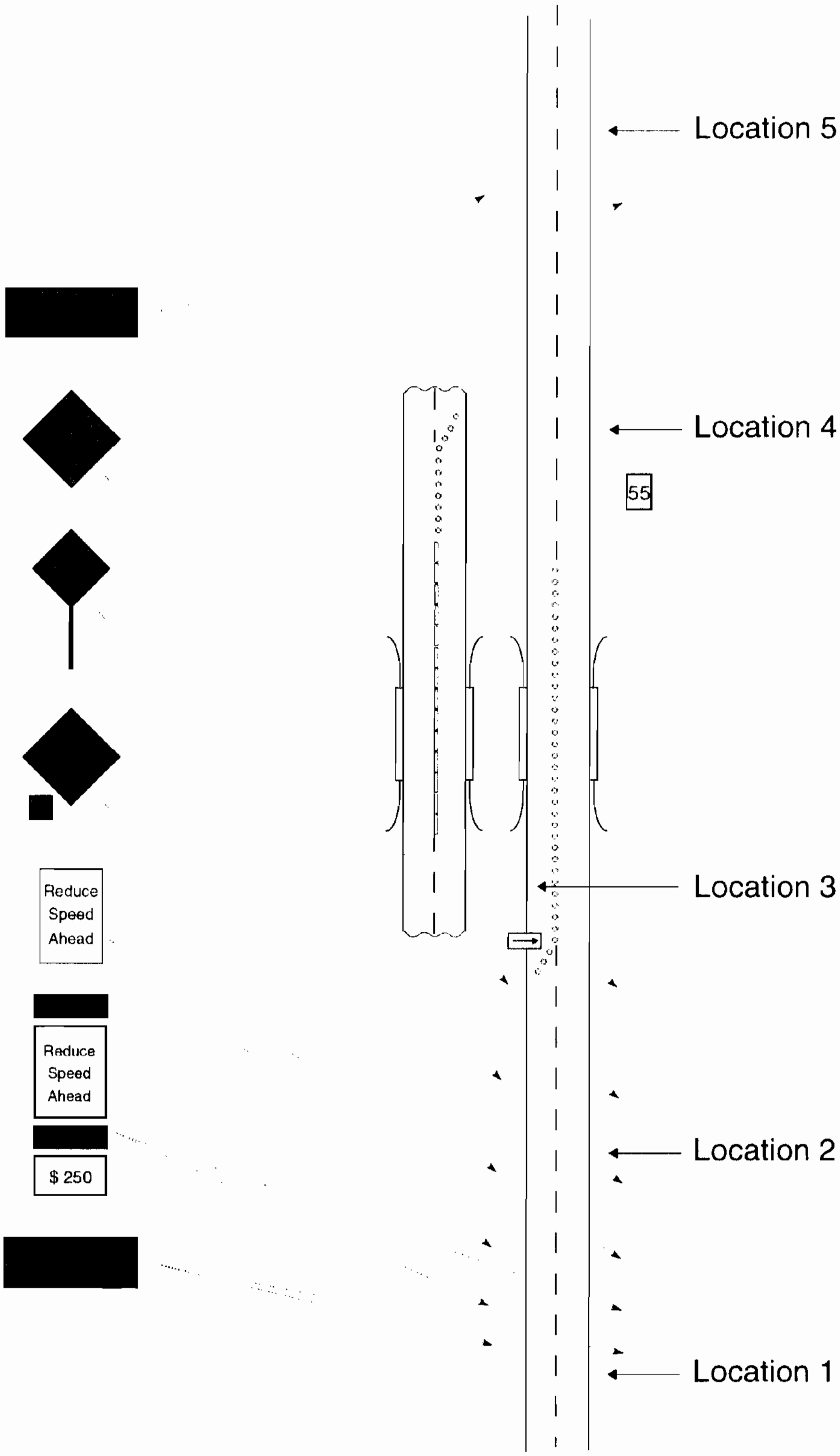


Figure 14. US 421, Lee County.

The work zone on US 421 in Lee County had a more modest effect on speeds compared to the work zones in Johnston, Robeson, and Durham Counties. Between Locations 1 and 3, the mean speed of passenger vehicles fell by 5.0 miles per hour (Figure 15). This compares with a reduction of 8.5 miles per hour for large trucks. At Location 3, large trucks were traveling 3.2 miles per hour *slower* than passenger vehicles. Nearly everyone was over the speed limit at each location (Table 5). The speed profiles were comparable to those of I-85 in Rowan County (Figure 24).

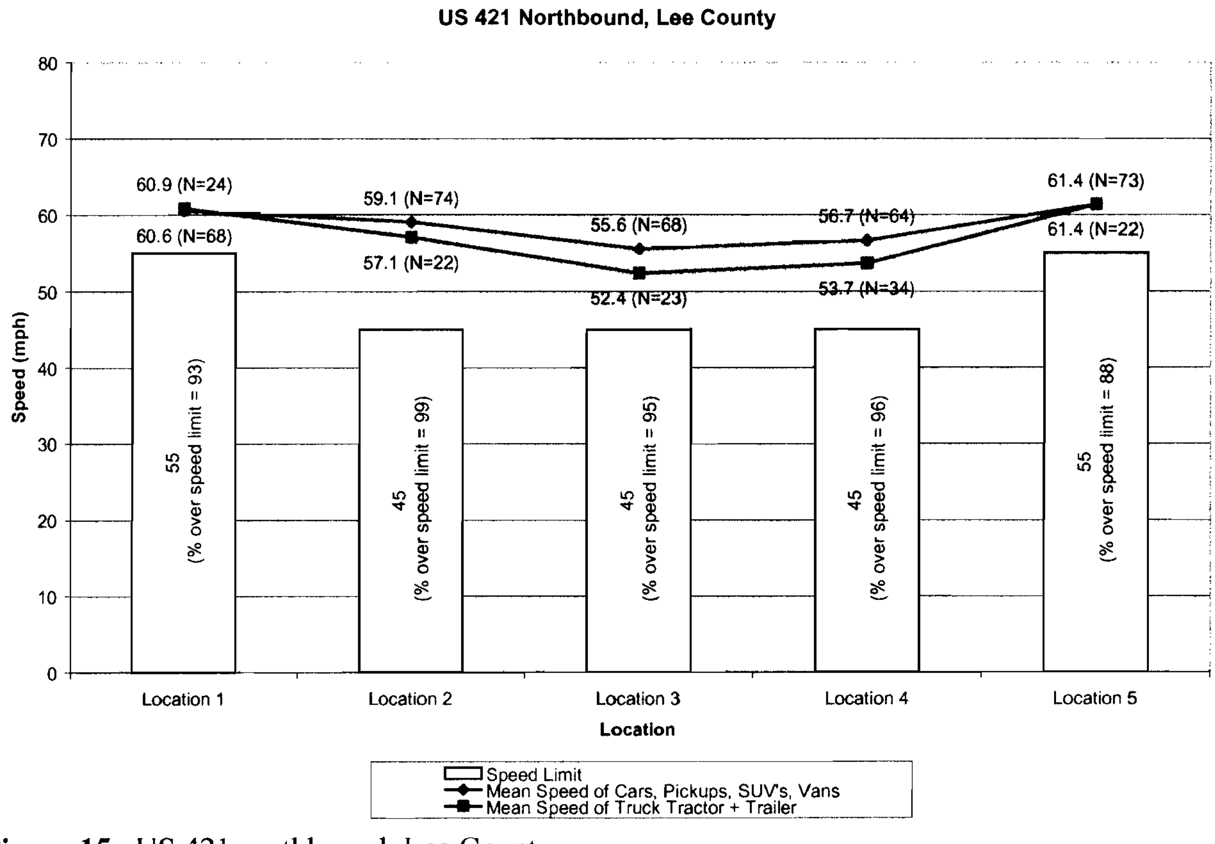


Figure 15. US 421 northbound, Lee County.

I-40, McDowell and Burke Counties

I-40 is a four-lane divided highway with a grass median and median guardrail. The work zone stretched for eight miles in rural McDowell and Burke Counties. Roadway rehabilitation, repaving, and new bridge construction were taking place in this work zone (Figure 16). Both eastbound lanes were closed, so eastbound vehicles were diverted across the median and onto the passing lane on the westbound side. Westbound vehicles in the passing lane were shifted over into the right lane. The speed limit outside the work zone was 65 miles per hour. A lower speed limit of 55 miles per hour was in effect in the work zone.

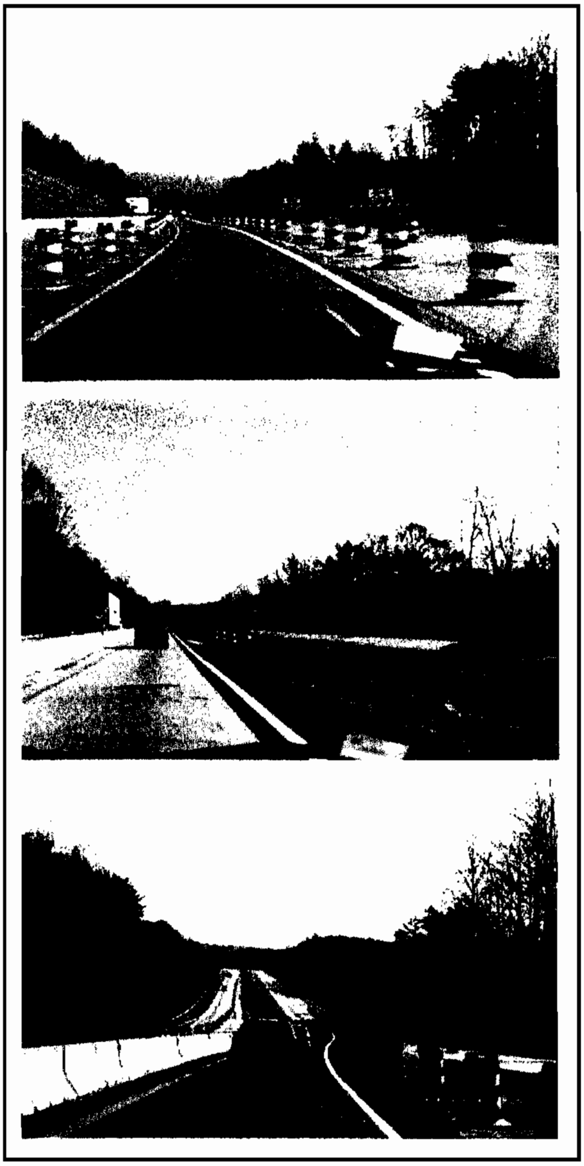


Figure 16. I-40, McDowell and Burke Counties, looking east.

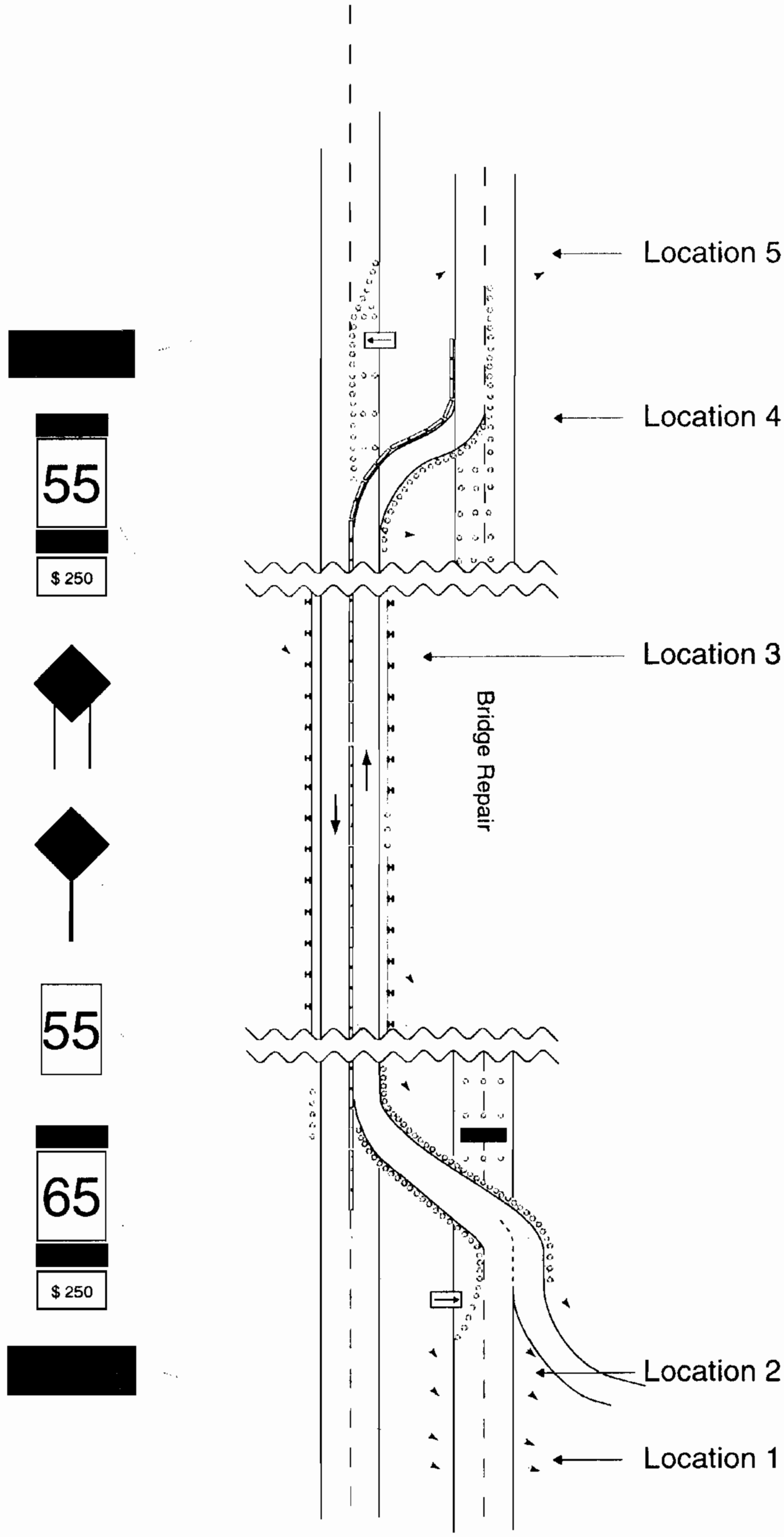


Figure 17. I-40, McDowell and Burke Counties.

The mean speed of passenger vehicles fell from 67.4 miles per hour at Location 1 to 54.1 miles per hour at Location 3, then rose to 66.5 miles per hour at Location 5 (Figure 18). Large truck speeds also fell, from 65.5 miles per hour at Location 1 to 55.6 miles per hour at Location 3. Large trucks were traveling *faster* than passenger vehicles at Locations 3 and 4. The percent of speeders ranged from 38 percent at Location 3 to 91 percent at Location 2 (Table 5).

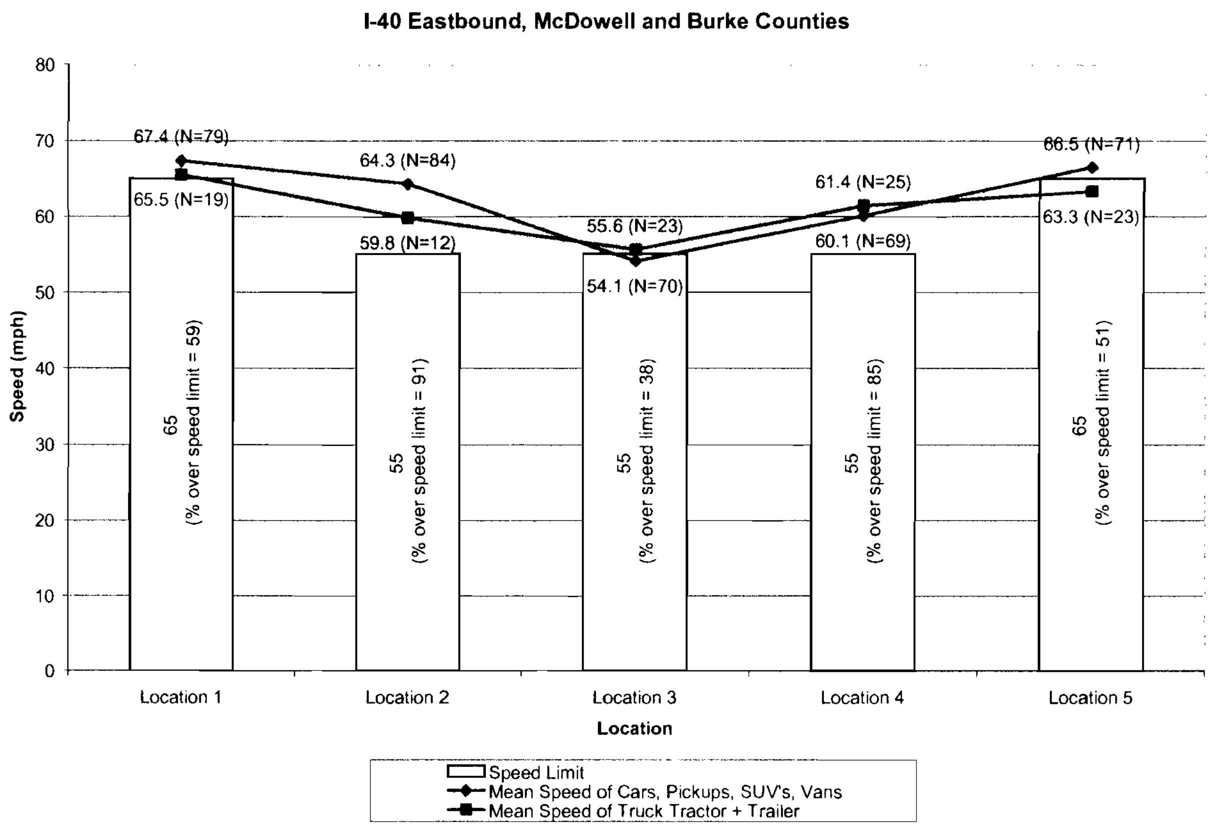


Figure 18. I-40 eastbound, McDowell and Burke Counties.

I-77, Surry County

This is a four-lane divided highway with a grass median. The roadway was undergoing extensive rehabilitation (Figures 19 and 20). The southbound lanes were closed, and traffic was diverted onto the northbound passing lane. When speeds were measured, most of the work was taking place between Mileposts 101 and 104, just south of the Virginia state line. This work zone was selected because the regular speed limit is 70 miles per hour. The speed limit was reduced to 55 miles per hour inside the work zone.

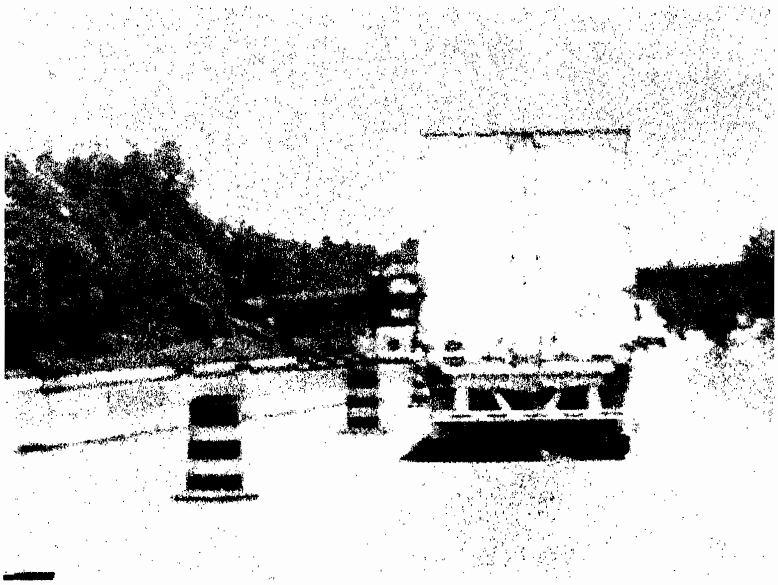


Figure 19. I-77, Surry County.

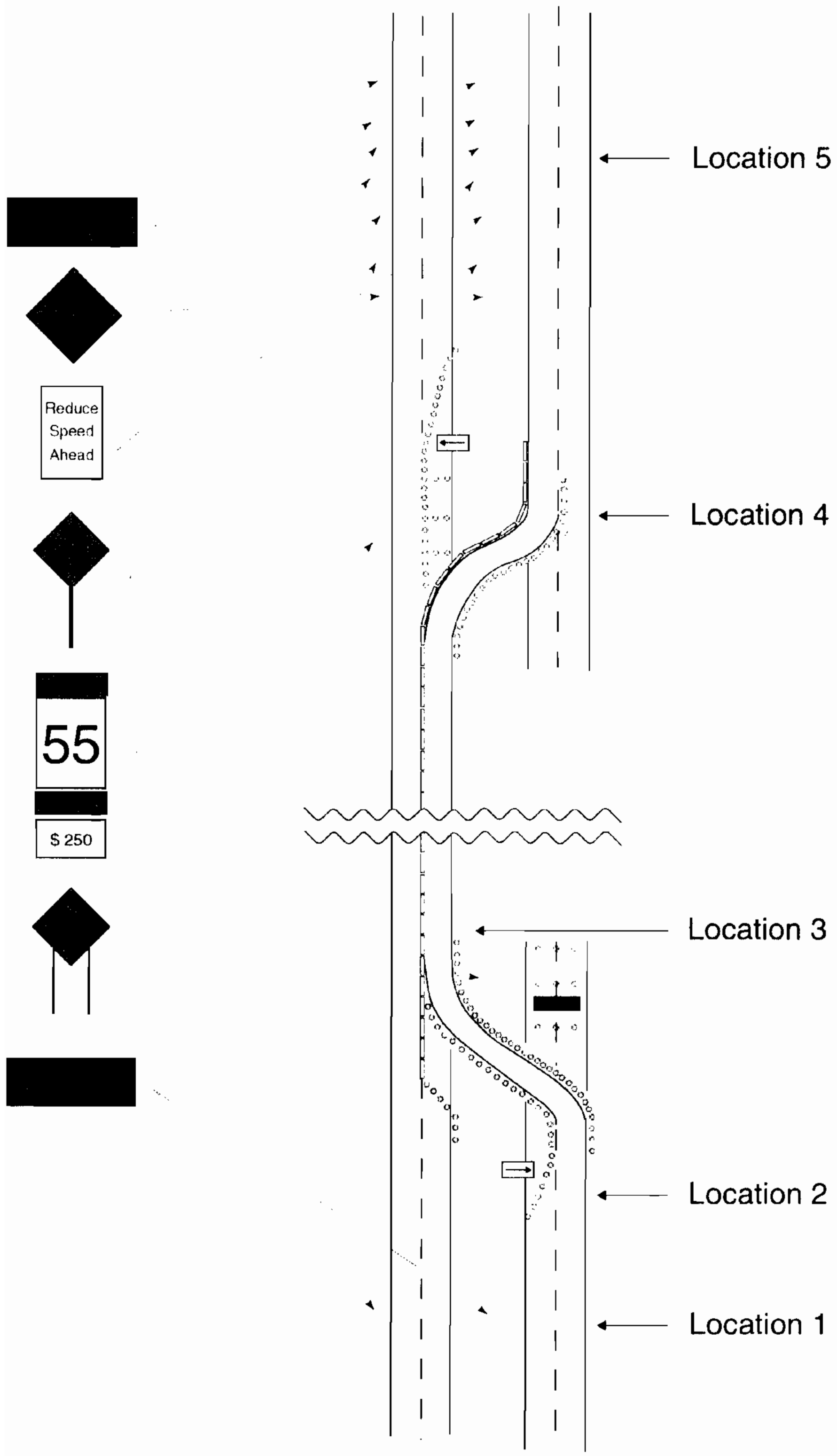


Figure 20. I-77, Surry County.

On I-77 in Surry County, the speed limit was reduced by 15 miles per hour (from 70 to 55) in the work zone. There was a corresponding steep decline in the mean speed of passenger vehicles, from 63.1 miles per hour at Location 1 to 48.6 miles per hour at Location 3. The mean speed increased sharply to 67.8 miles per hour at Location 5 (Figure 21). In fact, among the work zones studied, this work zone had the lowest mean speed at Location 3. This work zone also had the second lowest mean speed at Location 1, despite having the highest non-work zone speed limit of 70 miles per hour.

The mean speed of large trucks followed the same profile. Large trucks were traveling 0.8 miles per hour *faster* than passenger cars at Location 3. However, large trucks were traveling up to 3.7 miles per hour *slower* than passenger cars at the other four locations.

The mean speeds of both passenger vehicles and large trucks at Locations 1, 3, and 5 were under the respective speed limits. Even the 85th percentile speeds were under the speed limits at Locations 1 and 3. Only 7 percent of the motorists at Locations 1 and 3 were over the speed limit. Among the work zones studied, this work zone had the lowest proportion of speeders in the middle of the work zone (Location 3) (Table 5).

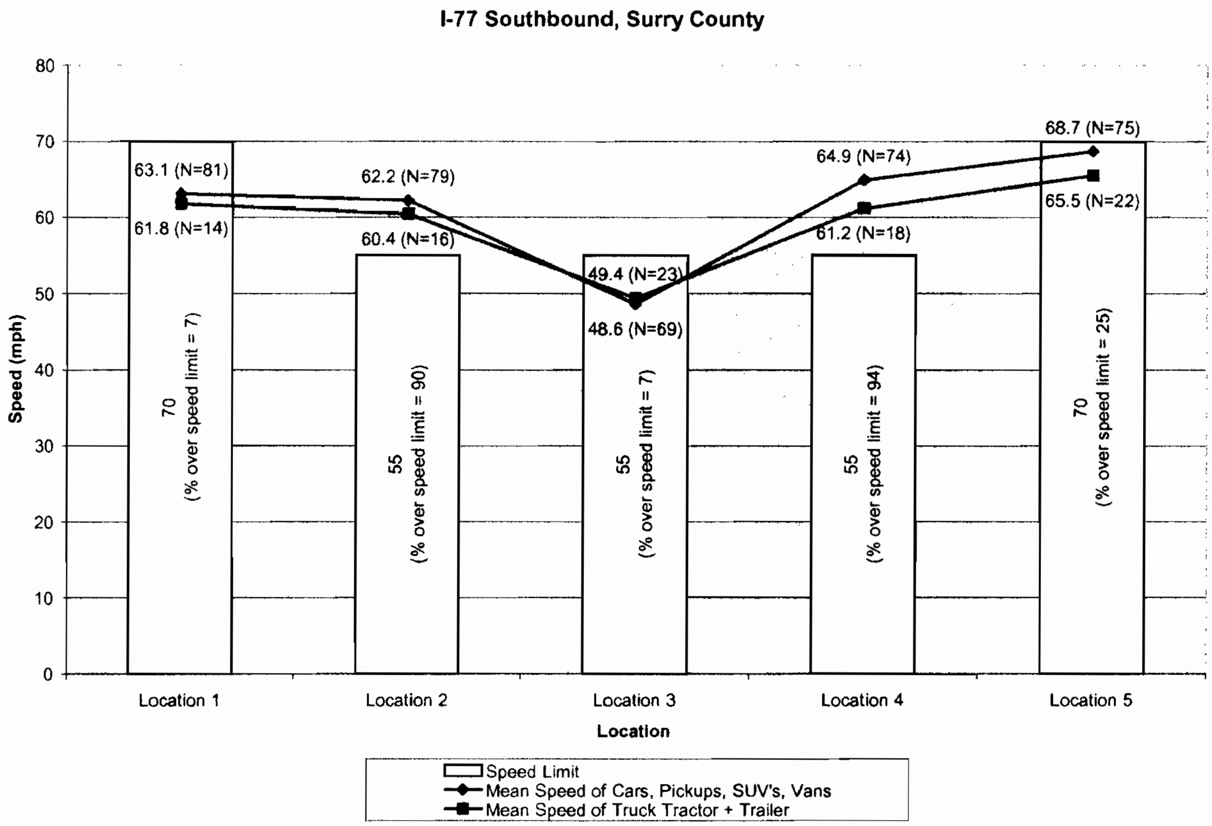


Figure 21. I-77 southbound, Surry County.

I-85, Rowan County

I-85 is a four-lane divided highway with a grass median. The highway was being widened from two to four lanes in each direction. Some bridge work was also being done. New pavement was being laid both to the right of the travel lanes and in the median. All lanes remained open to traffic, but the lanes in both directions shifted to accommodate the work areas in the median (Figures 22 and 23). Barrels and concrete median barriers were used to separate the travel lanes from the work areas. The speed limit of 65 miles per hour outside the work zone was reduced to 55 miles per hour in the work zone.

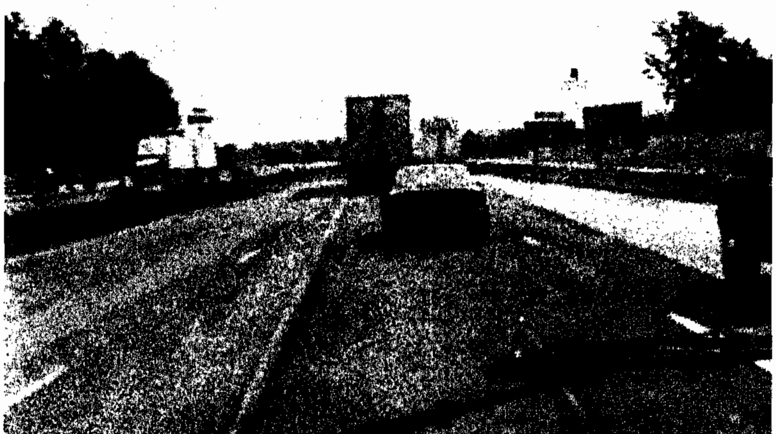


Figure 22. I-85, Rowan County, showing the lane shift.

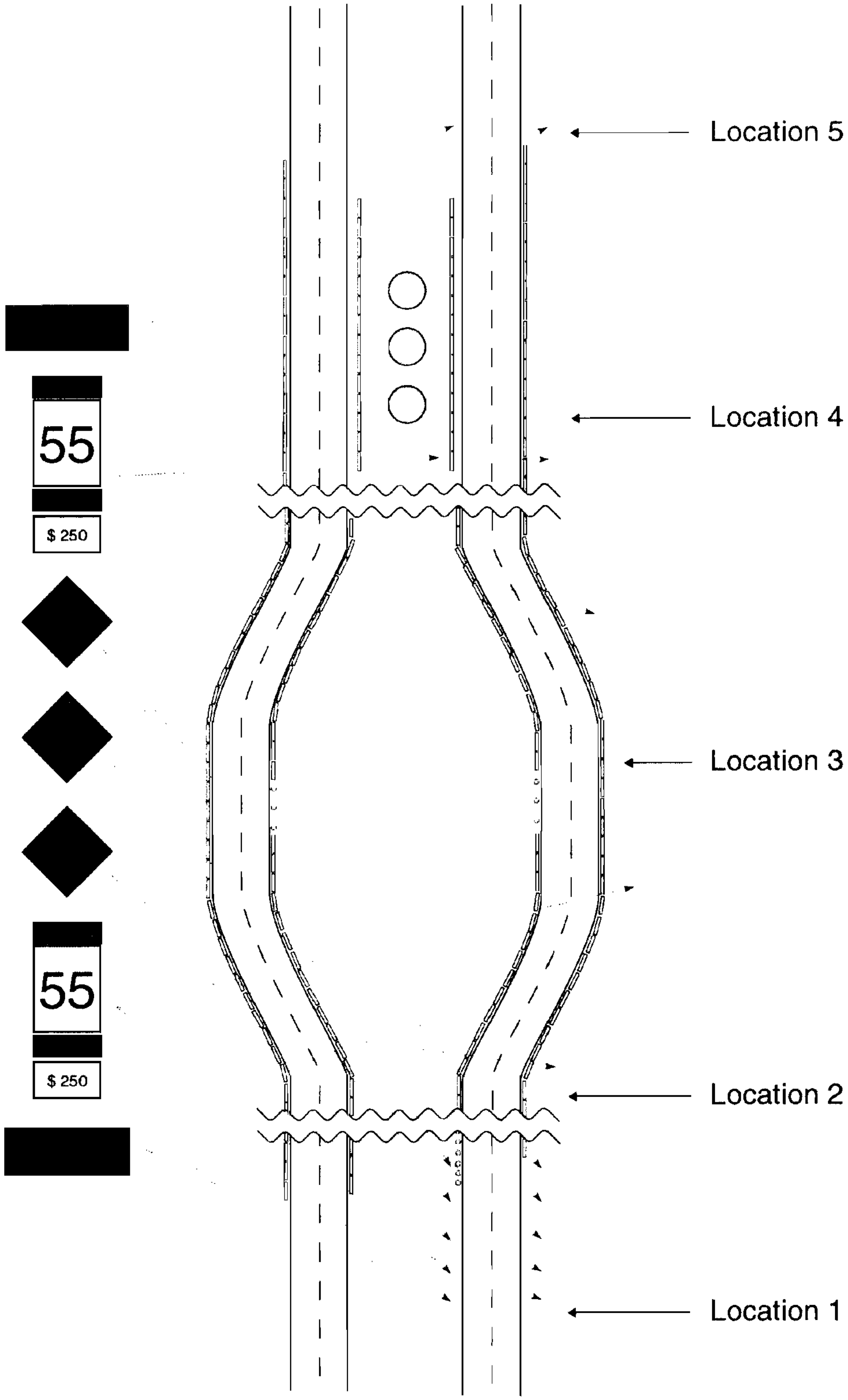


Figure 23. I-85, Rowan County.

The speed profiles for passenger vehicles and large trucks were comparable to those for US 421 in Lee County (Figure 15). Mean passenger vehicle speeds fell from 67.6 miles per hour (Location 1) to 62.6 miles per hour (Location 3) (Figure 24). At all five locations, large trucks were *slower* than passenger vehicles. The difference ranged from 1.5 to 2.6 miles per hour. Among all work zones, this work zone tied with US 421 in Sanford County for having the second highest percentage of speeders (95 percent) in the middle of the work zone (Location 3) (Table 5).

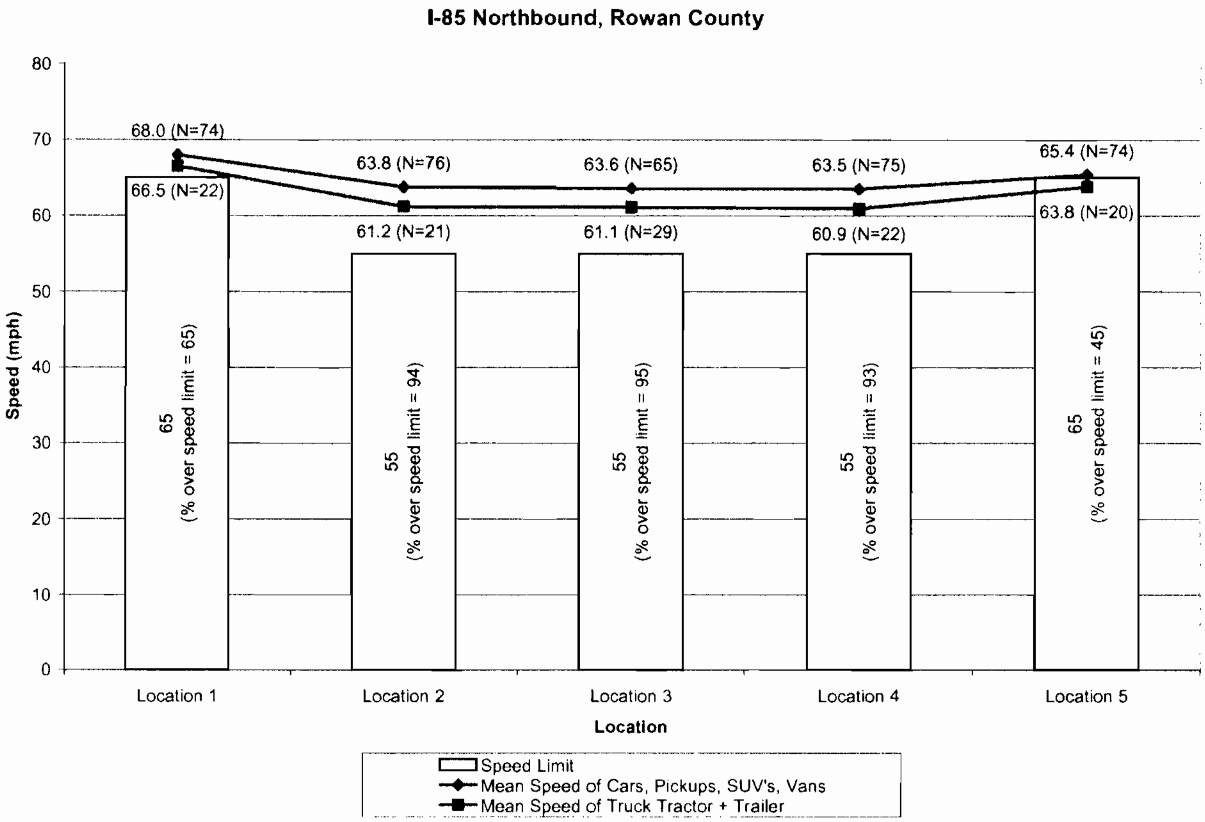


Figure 24. I-85 northbound, Rowan County.

Summary

Mean speeds were reduced by 10 miles per hour or more between Locations 1 and 3 in five work zones (Johnston northbound, Robeson northbound, Durham, McDowell / Burke, and Surry). Smaller reductions of 5 to 6 miles per hour were observed in two work zones (Lee and Rowan). Speeds remained constant when travel lanes remained open (Johnston southbound and Robeson southbound).

The analysis examined whether large trucks traveled at faster speeds than passenger vehicles. In the middle of most work zones (Location 3), large trucks were up to 3.1 miles per hour *slower* than passenger vehicles. The exceptions were McDowell / Burke and Surry, and these differences were small. Also, large trucks were usually *slower* than passenger vehicles at the other four locations. In fact, when large trucks were faster than passenger vehicles at any of the five locations, the greatest speed differential was 1.5 miles per hour (Location 3, I-40 in McDowell / Burke). When large trucks were slower than passenger vehicles, the greatest speed differential was 4.5 miles per hour (Location 2, I-40 in McDowell / Burke).

Outside the work zone (Locations 1 and 5), motorists were often traveling faster than the speed limit (Table 5). Although motorists started slowing down between Locations 1 and 2, the speed limit was usually lower at Location 2 than at Location 1. Thus, the majority of motorists at Location 2 were traveling over the speed limit. In five work zones, motorists were least likely to be speeding at Location 3, compared to the other locations. In three other work zones, motorists slowed down but the majority still exceeded the speed limit. Motorists started accelerating as the lanes shifted back to their original configuration (Location 4), even when work zone speed limits were still in effect, so the majority were exceeding the speed limit at Location 4.

Table 5. Percent of vehicles that exceeded the speed limit.

	Location 1	Location 2	Location 3	Location 4	Location 5
I-95 / US 70 N - Johnston County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	39	68	31	73	45
I-95 / US 70 S - Johnston County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	78	100	100	100	80
I-95 N - Robeson County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	39	73	32	73	45
I-95 S - Robeson County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	78	99	100	100	80
NC 147 N - Durham County					
– Speed Limit (mi/hr)	55	55	55	55	55
– Percent Over	100	98	60	91	100
US 421 N - Lee County					
– Speed Limit (mi/hr)	55	45	45	45	55
– Percent Over	93	99	95	96	88
I-40 E - McDowell County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	59	91	38	85	51
I-77 S - Surry County					
– Speed Limit (mi/hr)	70	55	55	55	70
– Percent Over	7	90	7	94	25
I-85 N - Rowan County					
– Speed Limit (mi/hr)	65	55	55	55	65
– Percent Over	65	94	95	93	45

Vehicle Types Observed in the Work Zones

At each location, speeds were measured for 100 vehicles. Each work zone had five locations, for a total of 500 vehicles. The one exception is NC 147, where one of the speed values could not be used. Hence, speeds were measured for a total of 499 vehicles in that work zone. Table 6 shows that passenger cars were the most common vehicle type, accounting for 43.0 percent of all vehicles for which speeds were measured. The second most common vehicle type was truck tractor / trailer (20.7 percent). Another 30.9 percent were pickup trucks, sport utility vehicles, and vans. Therefore, 73.9 percent of all observed vehicles were considered to be passenger vehicles and 20.7 percent were considered to be large trucks. Straight trucks, buses, school buses, motorcycles, and campers were classified as "other" vehicles and were not included in the comparisons of passenger vehicle and large truck speeds.

Table 6. Number of vehicles by type in each work zone.

WORK ZONE	Passenger Car	Pickup Truck	SUV	Van	Truck Tractor + Trailer	Other
I-95 N Johnston	202	41	35	43	145	34
I-95 S Johnston	221	64	60	43	89	23
I-95 N Robeson	202	41	35	43	145	34
I-95 S Robeson	221	64	60	43	89	23
NC 147 N Durham	276	57	47	67	28	24
US 421 N Lee	185	87	30	45	125	28
I-40 E McDowell	201	80	48	44	102	25
I-77 S Surry	220	52	49	57	93	29
I-85 N Rowan	205	53	54	52	114	22
TOTAL	1,933 (43.0%)	539 (12.0%)	418 (9.3%)	437 (9.7%)	930 (20.7%)	242 (5.4%)

Analysis of Work Zone Crashes in which Speeding Was Involved

Objectives of the Crash Analysis

The crash analysis involved special coding and was performed to answer two questions:

1. What are the characteristics of construction-related crashes?
2. How do the characteristics differ by crash severity?

The crash analysis was totally independent from the speed data reported in the preceding text. The crash analysis was not limited to the work zones for which speed data were collected.

Selection of Crashes to Be Coded

For the data used in this study, the North Carolina crash report form allowed the officer to indicate road defects but not work zones. The project team used computerized crash files from 1996 through 1998 and identified those crashes for which two criteria were met: (1) road defect was coded as "Under construction with defects" or "Under construction, no defects" and (2) contributing circumstance was coded as "Exceeding speed limit," "Exceeding safe speed," or "Failure to reduce speed." The road classes of interest were Interstate, US Routes, NC Routes, and secondary routes.

A total of 7,169 crashes met the criteria and were considered to be candidate work zone crashes in which speeding was involved. Crash severity was defined as the most severe injury that anyone involved in the crash suffered and was distributed as follows:

Fatal (K)	65 crashes	(0.9 %)
A injury	242 crashes	(3.4 %)
B injury	793 crashes	(11.1 %)
C injury	2,165 crashes	(30.2 %)
No injury (O)	3,904 crashes	(54.5 %)

Hard copy police crash reports were obtained for all of the K and A crashes (307 crashes total). For the B, C, and O crashes, a five percent random sample was drawn. The resulting sample contained 343 crashes. Hard copy police crash reports were obtained for these 343 B, C, and O crashes. Thus, hard copy crash reports were obtained for a total of 650 crashes.

The code "under construction" could refer to a variety of construction projects, such as pothole repair, utility work, new roadway construction, and others. Not all of these construction types were of interest in this study. The work zones of interest were major projects such as construction or addition of new lanes and bridges, as well as resurfacing. On each crash report, the officer's narrative and site diagram were examined. A crash was considered to be of interest if the narrative and/or the site diagram contained words such as "construction" or "barrels," or if the diagram showed barrels or other evidence of major construction activity.

Out of the 650 crashes, 257 crashes were deemed to be of interest (*i.e.*, these were eligible crashes). Among the eligible crashes, 131 crashes were K or A (51.0 percent), and the remaining 126 crashes were B, C, or O (49.0 percent).

The Coding Form

The narrative and site diagram were used to identify variables of interest that may not be on the NC crash report form. Examples of these variables are effect of construction on road and how did construction contribute to the crash. A form was developed for coding purposes (Appendix A).

The coding form consisted of 23 questions, divided into roadway, crash, and vehicle variables. The vehicle questions were coded only for the "culprit" vehicle, defined as the vehicle that "caused" the crash. Questions were coded primarily according to the information given in the officer's narrative and crash diagram on each hard-copy crash report. If the desired information was not stated, then the question was coded as "Unknown." It should be noted that the completeness of the crash reports varies. For example, some officers may not show or mention that a lane is closed, whereas other officers will. A lane closure could have taken place even if it was not shown or mentioned. Therefore, the omission of a lane closure does not necessarily imply the absence of a lane closure. It is very likely that underreporting is present in the results.

The form included both closed-ended (1, 3, 5-7, 9, 10, 13, 16, 18-21, and 23) and open-ended (2, 4, 8, 11, 12, 14, 15, 17, and 22) questions. Most of the open-ended questions were preceded by a closed-ended question and allowed the coder to more fully explain the choice of "Other" in the closed-ended question. For example, Question 1 asked for the effect of construction on the road. If the effect was not one of the first five choices given, this question would be coded as "Other" and the coder would specify the effect in Question 2.

Questions 5 - 7 allowed the coder to specify up to three types of construction objects or persons that were present. These include barrels, workers, and other objects or persons that were depicted in the crash diagram or mentioned in the officer's narrative. The objects and persons may or may not have been actually struck by the culprit vehicle. If only one type of object or person was present, then Questions 6 and 7 were left blank. If only two types were present, then Question 7 was left blank.

Questions 19 - 21 allowed the coder to specify up to three types of construction objects or persons that were hit by the culprit vehicle. Questions 20 and 21 were coded as necessary.

Noteworthy crash circumstances, such as ice or snow on the roadway, drunk driving, and police pursuit, were specified in Question 12. Pedestrian, bicycle, and motorcycle involvement were noted in Question 15.

The crash reports for the 257 eligible crashes were read and the questions were coded. To maintain consistency in coding, the same person coded all 257 crashes. The coding forms were then keyed into a Microsoft Excel spreadsheet.

Results of Coding Analysis

The 257 crashes were divided into two groups according to injury level: (1) K and A, and (2) B, C, and O. Frequency distributions by severity were generated for several characteristics. These are described in the following paragraphs and are shown in Figures 25 - 32. Observations with a value of "unknown" are included in the descriptions and figures.

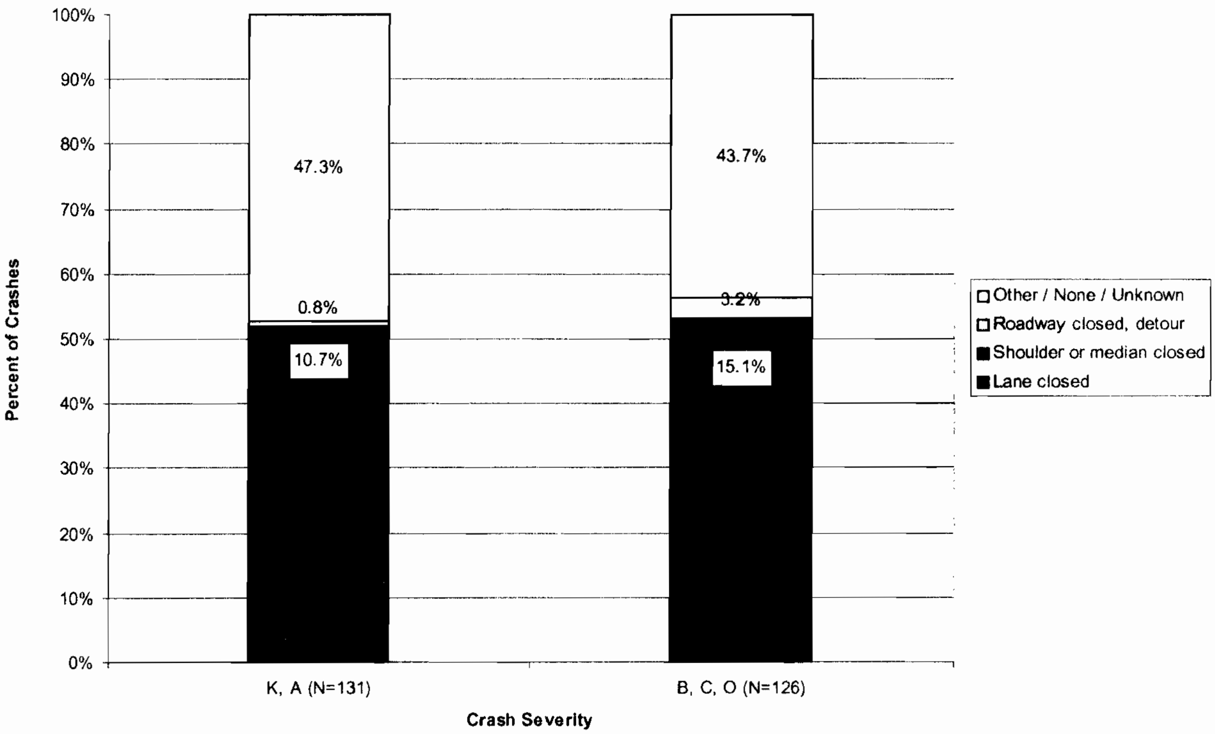
The chi-square statistic was used to determine whether the distributions for each characteristic were significantly different by severity (K-A vs. B-C-O). A significance level of 0.05 was used. Observations with a value of "unknown" were not included in the calculation of the chi-square statistic, and thus, not used in determining significance.

Effect of Construction on Road

Work zones often require lane or shoulder closures. There was a lane closure for around 40 percent of K-A and B-C-O crashes (Figure 25). Shoulder or median closure was more common for B-C-O crashes (15.1 percent) than for K-A crashes (10.7 percent). Overall, the effects of construction were not different between the K-A and the B-C-O crashes. For over 40 percent of the crashes, the police report did not indicate the effect, if any, of construction on the road.

The chi-square statistic was calculated for lane closures and shoulder / median closures. The p-value of 0.2936 indicates that there was not a significant association between crash severity and whether a lane closure or shoulder / median closure was present.

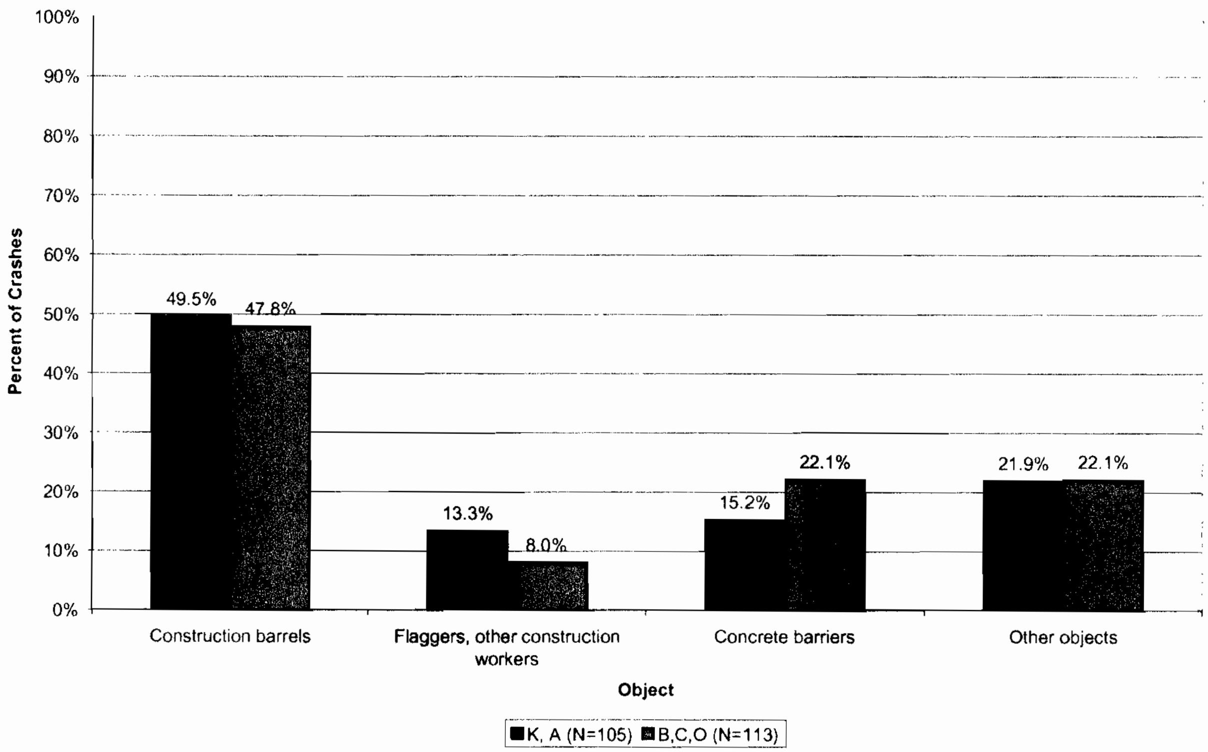
Figure 25. Effect of Construction on Road



Construction Objects Present

The coding form allowed up to three construction objects to be coded. The police reports usually indicated only one, or sometimes two, objects. In 70 crashes, the police report did not indicate what construction objects, if any, were present. A total of 218 objects were coded among the remaining 187 crashes. Construction (orange) barrels were the most common construction object. The barrels were present in 49.5 percent of the K-A and 53.1 percent of the B-C-O crashes (Figure 26). Concrete barriers were more likely to be present in B-C-O crashes (22.1 percent) than in K-A crashes (15.2 percent). On the other hand, flaggers and other construction workers were present in 13.3 percent of K-A crashes. This compares with 8.0 percent of B-C-O crashes. The differences in the construction objects present were not significant (p-value = 0.4083).

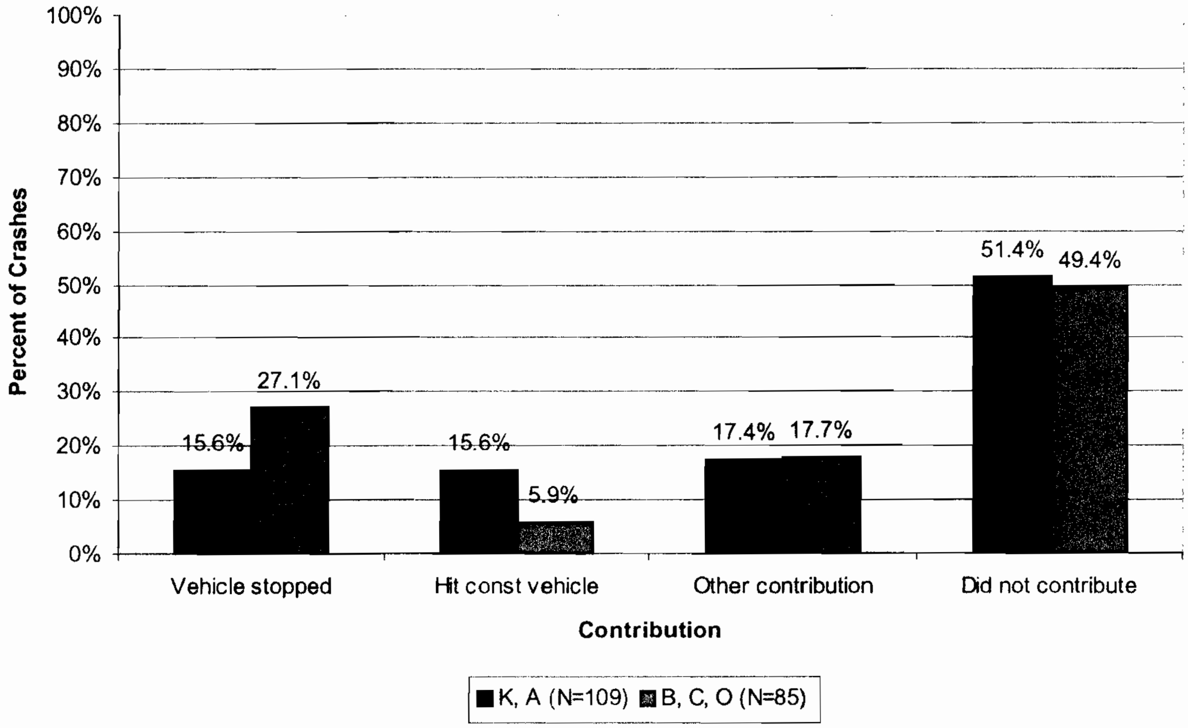
Figure 26. Construction Objects Present



How Did Construction Contribute to the Crash?

Construction can contribute to crashes in a variety of ways. For example, a car that is stopped in traffic may be rear-ended. A motorist may crash into a construction vehicle. Active construction may raise clouds of dust and obscure drivers' vision. How construction contributed was coded for 194 crashes. In 15.6 percent of K-A and 27.1 percent of B-C-O crashes, the motorist rear-ended a stopped vehicle (Figure 27). In another 15.6 percent of K-A but only 5.9 percent of B-C-O crashes, the motorist hit a construction vehicle. Construction did not contribute to 51.4 percent of K-A and 43.8 percent of B-C-O crashes. These differences between the K-A and the B-C-O crashes, with regard to how construction contributed to the crash, were marginally significant (p-value = 0.0702).

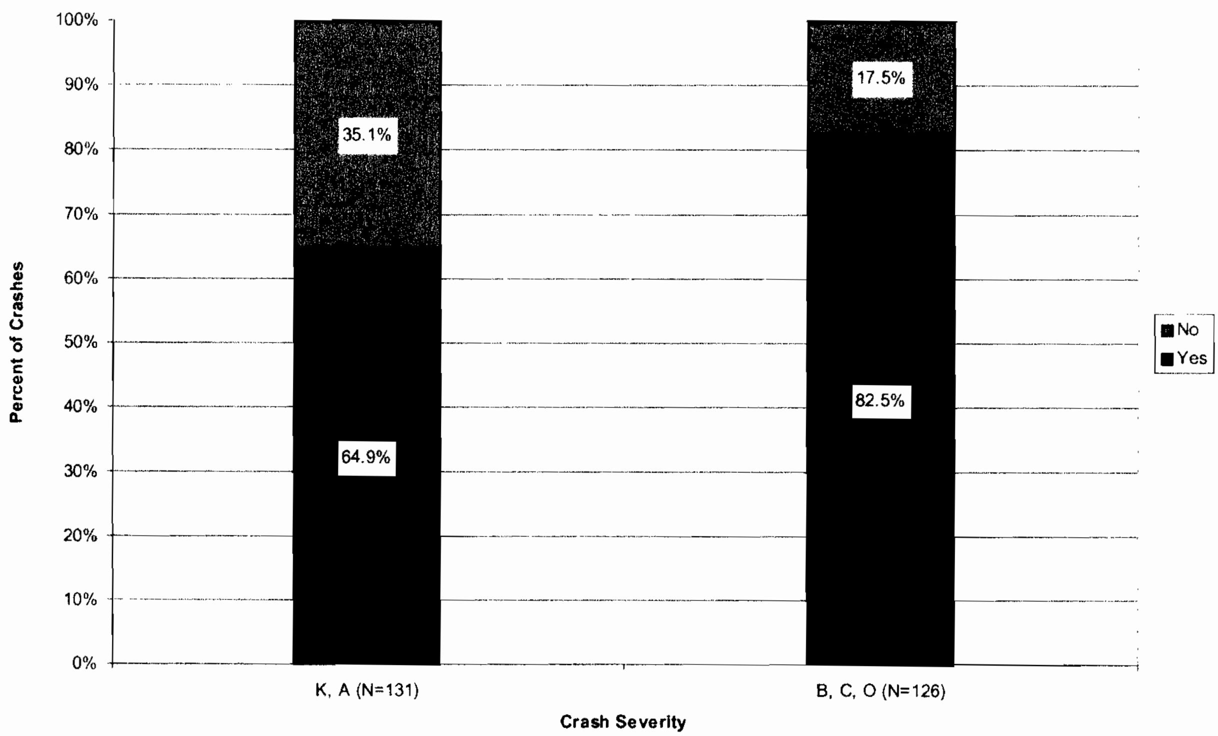
Figure 27. How Did Construction Contribute to the Crash?



Was More Than One Vehicle Involved?

Two or more motor vehicles were involved in 64.9 percent of the K-A crashes but 82.5 percent of the B-C-O crashes (Figure 28). This difference was significant (p-value = 0.0013).

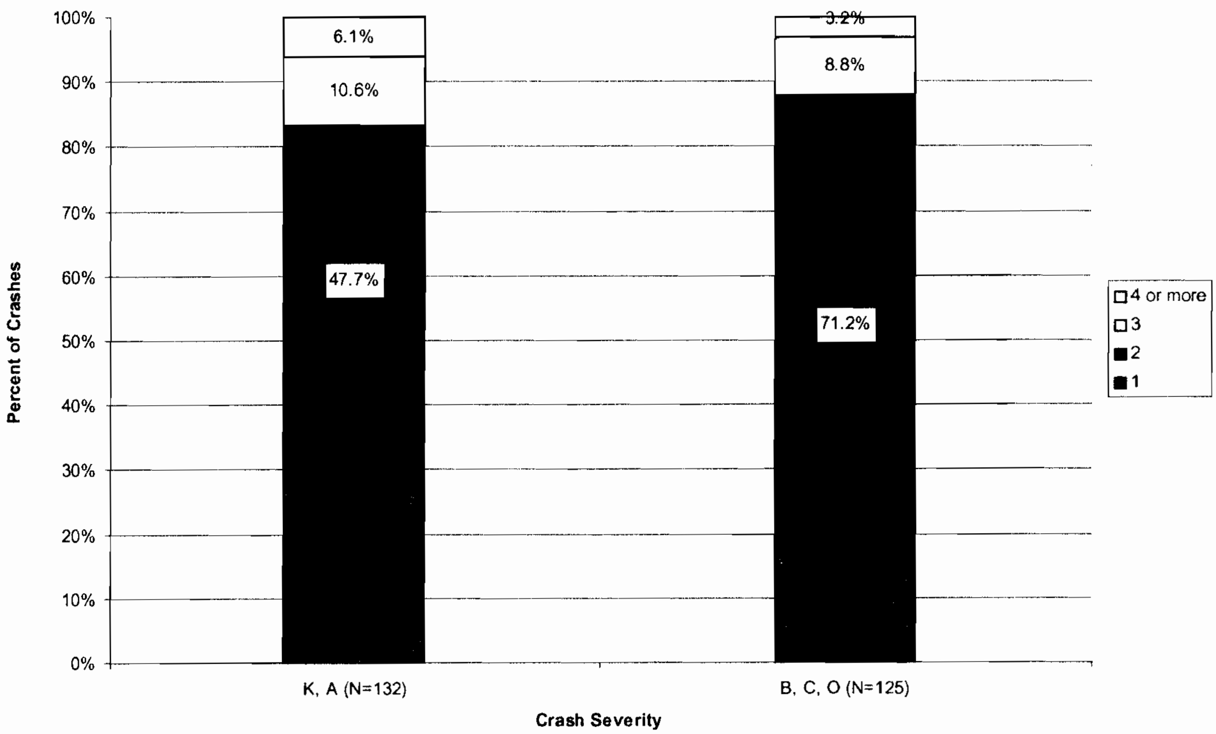
Figure 28. Was More Than One Vehicle Involved?



Number of Vehicles Involved

As shown in Figure 29, crashes were most likely to involve exactly two motor vehicles (47.7 percent of K-A and 71.2 percent of B-C-O). K-A crashes were twice as likely to involve only one motor vehicle, compared to B-C-O crashes (35.6 percent of K-A and 16.8 percent of B-C-O). The difference in the number of motor vehicles involved was significant (p-value = 0.0023).

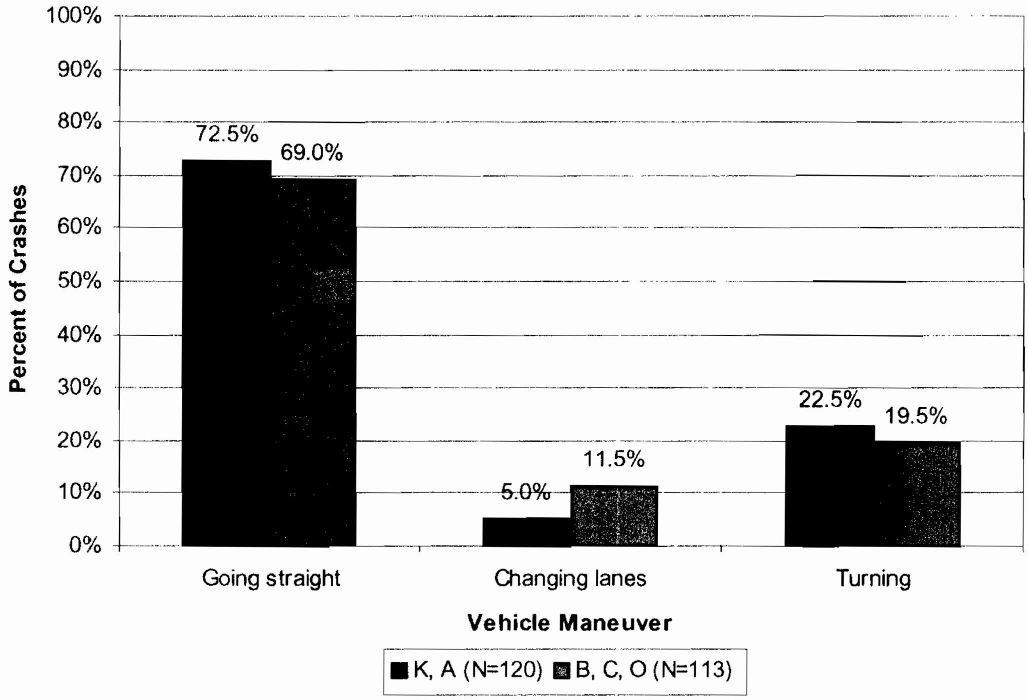
Figure 29. Number of Vehicles Involved



Vehicle Maneuver Prior to Crash

This and the two crash characteristics described below are vehicle variables. The vehicle variables were coded for the "culprit" (*i.e.*, at-fault) vehicle. A total of 233 vehicles executed one of three maneuvers: going straight, changing lanes, or turning. For both K-A and B-C-O crashes, over two-thirds of the "culprit" vehicles were going straight prior to the crash (Figure 30). The second most common maneuver was turning (left or right into or out of the work zone, or U-turns). About 20 percent of the vehicles in both K-A and B-C-O crashes were turning. Vehicles were more than twice as likely to be changing lanes in B-C-O crashes as they were in K-A crashes (11.5 percent vs. 5.0 percent). When these three maneuvers are taken together, the K-A crashes did not differ from the B-C-O crashes ($p = 0.1852$).

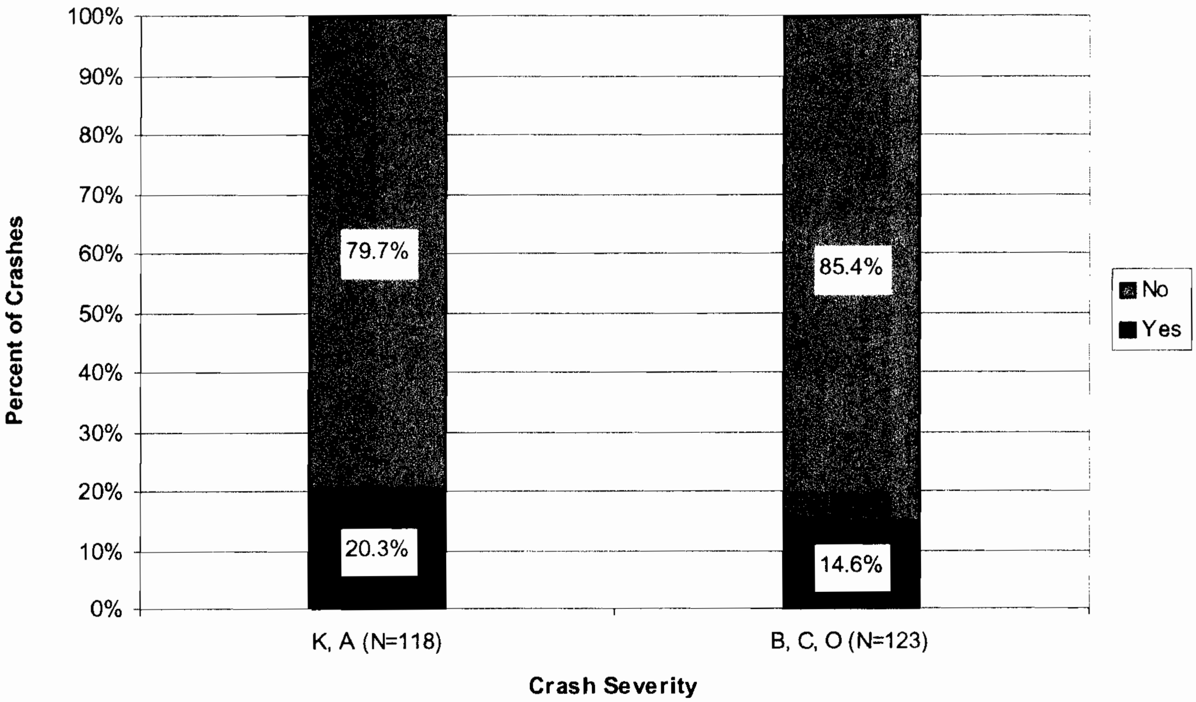
Figure 30. Vehicle Maneuver Prior to Crash



Did the Vehicle Enter the Actual Work Area?

A vehicle may enter the actual work area if the motorist loses control and veers off the traveled roadway, or the motorist may mistake the work area for part of the traveled way. The result may be a collision with a construction worker or with construction equipment. Whether the "culprit" vehicle entered the actual work area was coded in 241 crashes. The "culprit" vehicle was more likely to have entered the actual work area in K-A crashes than in B-C-O crashes (20.3 percent vs. 14.6 percent) (Figure 31). This difference was not significant (p-value = 0.2432).

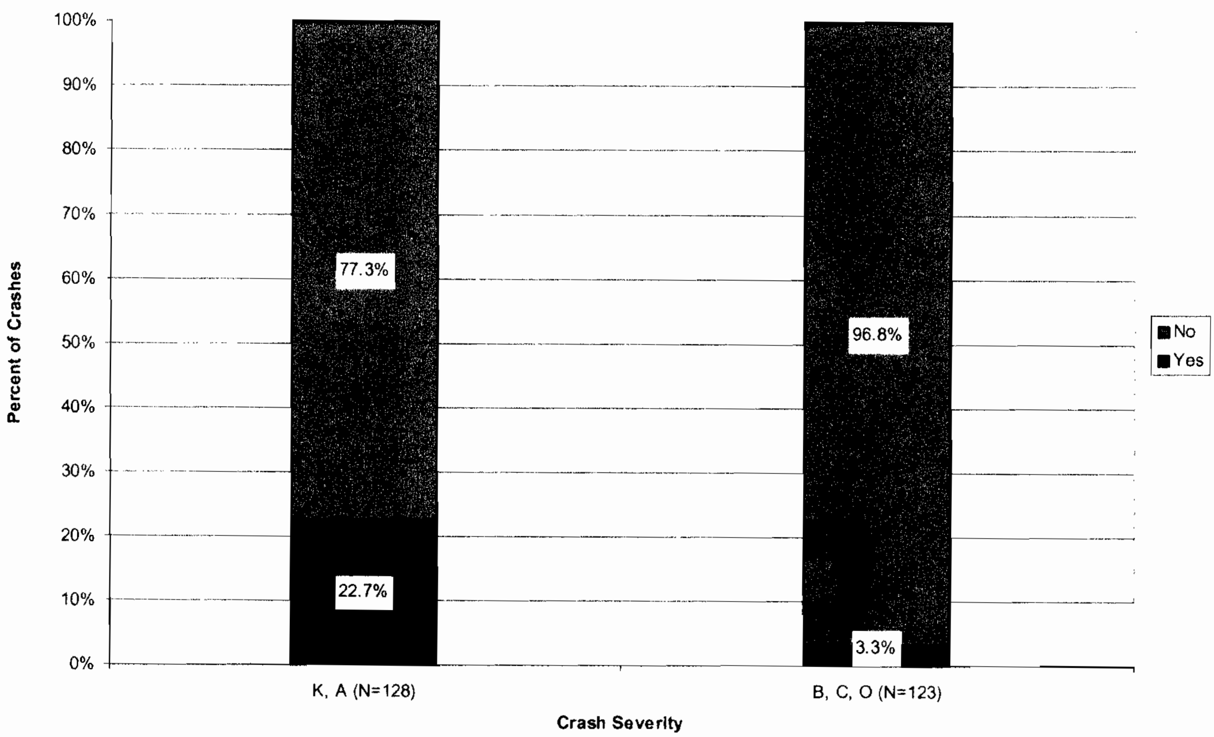
Figure 31. Did the Vehicle Enter the Actual Work Area?



Did the Vehicle Enter the Opposing Travel Lanes?

A driver may lose control or become confused and unintentionally enter the opposing travel lanes. The driver is then at risk of a head-on collision, possibly resulting in a fatality or "A" injury. Also, higher speeds are associated with a higher likelihood of losing control and with a higher likelihood of a fatality or "A" injury. "Entering the opposing travel lanes" was coded for 251 crashes. Figure 32 shows that "culprit" vehicles were seven times more likely to have entered the opposing travel lanes in K-A crashes than in B-C-O crashes (22.7 percent vs. 3.3 percent). This difference was significant (p-value < 0.0001).

Figure 32. Did the Vehicle Enter the Opposing Travel Lanes?



Summary of Crash Analysis

The analysis of coded work zone crashes compared K-A crashes with B-C-O crashes. For four crash characteristics, the differences between K-A crashes and B-C-O crashes were found to be significant.

1. How did construction contribute to the crash?
   A construction vehicle was more likely to be hit in K-A crashes (15.6 percent) than in B-C-O crashes (5.9 percent). A stopped vehicle was more likely to be rear-ended in B-C-O crashes (27.1 percent) than in K-A crashes (15.6 percent).
2. Was more than one vehicle involved?
   K-A crashes were less likely to involve more than one vehicle (64.9 percent vs. 82.5 percent of B-C-O crashes).
3. Number of vehicles involved
   K-A crashes were twice as likely to involve only one motor vehicle, compared to B-C-O crashes (35.6 percent of K-A and 16.8 percent of B-C-O). K-A crashes were also more likely to involve three or more vehicles (16.7 percent of K-A and 12.0 percent of B-C-O).
4. Did the vehicle enter the opposing travel lanes?
   The "culprit" vehicle was seven times more likely to enter the opposing travel lanes in K-A crashes (22.7 percent) than in B-C-O crashes (3.3 percent).

ACKNOWLEDGMENTS

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APPENDIX A
CODING FORM

WORK ZONE CODING FORM

Roadway Variables

1. Effect of construction on road
   1. Lane closed
   2. Shoulder or median closed
   3. Roadway closed, detour onto opposing side
   4. Lanes become narrow
   5. Lanes shift but same number of lanes
   6. Other (specify in Question #2)
   7. Unknown
   8. None

2. Other effects of construction on road __________ (50 characters)

3. Type of work being done
   1. Widening
   2. Repaving / resurfacing
   3. Restriping
   4. Shoulder / median work
   5. Bridge work
   6. New roadway
   7. Other (specify in Question #4)
   8. Unknown

4. Other type of work being done __________ (50 characters)

5. First construction object / person present
   1. Construction (orange) barrels
   2. "Road Closed" / barricades in roadway
   3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
   4. Flagger
   5. Construction workers (not in vehicles; otherwise code as #7 or #8)
   6. Construction vehicles - parked and unattended
   7. Construction vehicles - working in work zone
   8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
   9. Other construction-related object (specify in Question #8)
   10. Concrete barrier (may or may not be construction-related)
   11. Unknown

6. Second construction object / person present
    1. Construction (orange) barrels
    2. "Road Closed" / barricades in roadway
    3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
    4. Flagger
    5. Construction workers (not in vehicles; otherwise code as #7 or #8)
    6. Construction vehicles - parked and unattended
    7. Construction vehicles - working in work zone
    8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
    9. Other construction-related object (specify in Question #8)
    10. Concrete barrier (may or may not be construction-related)
    11. Unknown

7. Third construction object / person present
    1. Construction (orange) barrels
    2. "Road Closed" / barricades in roadway
    3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
    4. Flagger
    5. Construction workers (not in vehicles; otherwise code as #7 or #8)
    6. Construction vehicles - parked and unattended
    7. Construction vehicles - working in work zone
    8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
    9. Other construction-related object (specify in Question #8)
    10. Concrete barrier (may or may not be construction-related)
    11. Unknown

8. Other construction object / person present __________ (50 characters)

9. Was there actual construction activity going on when the crash occurred?
    1. Yes
    2. No
    3. Unknown

Crash Variables

10. How did construction contribute to the crash?
    Drunk driving, police pursuit, drag racing, etc. – code as #8 (did not contribute)
    1. Non-construction vehicle in front stopped for a construction-related reason and was rear-ended (flagger, letting a car merge into lane, traffic was backed up, etc.)
    2. Vehicle was trying to merge into another lane and was struck
    3. Lost control when lanes shifted
    4. Lost control when swerved to avoid hitting a flagger, barrels, or other construction-related objects
    5. Vehicle hit construction-related vehicles, workers, barrels, etc.
    6. Driver's vision was obstructed
    7. Other (specify in Question #11)
    8. Construction did not contribute to crash
    9. Unknown whether construction contributed to the crash

11. Other way that construction contributed to the crash __________ (50 characters)

12. Comments about crash __________ (50 characters)
    Include anything unusual, such as hit-and-run, drunk driving, ice or snow on road, etc.

13. Was there more than one motor vehicle involved in the crash?
    1. Yes (specify in Question #14)
    2. No
    3. Unknown

14. How many motor vehicles were involved in the crash? ____ (2 characters)

15. Comments about crash involvement __________ (50 characters)
    Pedestrian, bicycle, motorcycle, etc.

Vehicle Variables (for the culprit vehicle)

16. Vehicle maneuver prior to crash
    1. Going straight
    2. Changing from one lane to an adjacent lane
    3. Turning
    4. Other / unusual maneuver (specify in Question #17)
    5. Unknown

17. Other / unusual vehicle maneuver __________ (50 characters)

18. Did the vehicle enter the actual work area (the area closed to thru traffic)?
    1. Yes
    2. No
    3. Unknown

19. First construction object, worker, or vehicle hit
    1. Construction (orange) barrels
    2. "Road Closed" / barricades in roadway
    3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
    4. Flagger
    5. Construction workers (not in vehicles; otherwise code as #7 or #8)
    6. Construction vehicles - parked and unattended
    7. Construction vehicles - working in work zone
    8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
    9. Other construction-related object (specify in Question #22)
    10. Concrete barrier (may or may not be construction-related)
    11. Unknown
    12. None / Not applicable

20. Second construction object, worker, or vehicle hit
    1. Construction (orange) barrels
    2. "Road Closed" / barricades in roadway
    3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
    4. Flagger
    5. Construction workers (not in vehicles; otherwise code as #7 or #8)
    6. Construction vehicles - parked and unattended
    7. Construction vehicles - working in work zone
    8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
    9. Other construction-related object (specify in Question #22)
    10. Concrete barrier (may or may not be construction-related)
    11. Unknown

21. Third construction worker, object, or vehicle hit
    1. Construction (orange) barrels
    2. "Road Closed" / barricades in roadway
    3. Side-mounted temporary signs (such as Begin / End Work Zone, speed limit, etc.)
    4. Flagger
    5. Construction workers (not in vehicles; otherwise code as #7 or #8)
    6. Construction vehicles - parked and unattended
    7. Construction vehicles - working in work zone
    8. Construction vehicles putting down or taking up barrels, signs, arrow boards, etc.
    9. Other construction-related object (specify in Question #22)
    10. Concrete barrier (may or may not be construction-related)
    11. Unknown

22. Other construction-related object hit __________ (50 characters)

23. Did the vehicle enter the opposing travel lane(s) unintentionally?
    1. Yes
    2. No or no opposing travel lane
    3. Unknown