FINAL REPORT

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NCDOT RESEARCH PROJECT 2004-17

REASONABLE SPEEDS ON IMPROVED CURB AND GUTTER FACILITIES

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16. Abstract
When some two-lane roads with 55 mph speed limits are widened to four through lanes, curb and gutter is installed to address issues such as access control, difficult terrain, and limited right-of-way. Posted speed limits along such highway segments are typically decreased to 45 mph in North Carolina because of guidance in the AASHTO "Green Book" and elsewhere that vertical curbs should not be placed next to high-speed lanes. In spite of those expensive improvements, the results may be viewed negatively by the public, design professionals, and law enforcement personnel. Drivers may suffer from getting tickets or driving slower, designers may be blamed by the public, and the police may face an increased enforcement burden.

To help resolve this dilemma, in this research the team collected relevant data such as speeds and collisions on four-lane road sections with curbs which have 45 or 55 mph speed limits and non-traversable medians or two-way left turn lanes. The team found that the speed limit does not seem to make an important difference in the collision rates or severities for the roads the team examined. The higher speed limit also made relatively small differences in the mean speeds and speed variances observed. Considering all of the results, the researchers recommended that the NCDOT continue its current policy of allowing 55 mph speed limits on four-lane roads with curbs on a selective, case-by-case basis. The team suggested a list of things to consider when making decisions about posted speed limits in such cases.

17. Key Word
Curb, four-lane, speed limit, non-traversable median, two-way left turn lane, collision rate, severity, access point density

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EXECUTIVE SUMMARY

Posted speed limits along suburban highway segments widened from two lanes to four through lanes with curb and gutter are typically decreased from statutory 55 mph to regulatory 45 mph in North Carolina because of guidance in the AASHTO "Green Book" and elsewhere that vertical curbs should not be placed next to high-speed lanes. In spite of those expensive improvements, drivers may suffer from getting tickets or driving slower, designers may be blamed by the public, and the police may be faced with an increased enforcement burden.

The primary purpose of these studies was to answer the question, "Does a 45 mph speed limit on a four-lane road with a 2'-6" curb and gutter really cause motorists to drive differently, thus increasing or decreasing the frequency and severity of collisions in comparison to a 55 mph speed limit?" For this, the team collected relevant data such as speeds and collisions on four-lane road sections with curbs which have 45 or 55 mph speed limits and non-traversable medians or two-way left turn lanes. We also note that, even though we did not study sections posted at 50 mph, we believe that the findings we document for sections posted at 55 mph most likely apply to those posted at 50 mph as well.

The research team found that, for a random sample of suburban four-lane highways with curbs in North Carolina, relative to segments posted at 45 mph, segments posted at 55 mph had a:

- Significantly higher mean speed and 85th percentile speed, by 6-7 mph,
- Significantly higher variance about the mean speed,

- Lower mean overall collision rate, by about 0.27 collisions per million vehicle miles of travel (MVMT),
- Higher mean curb-involved collision rate, by about 0.02 collisions per MVMT,
- Significantly lower variance about the mean for overall and curb-involved collision rates,
- Lower mean equivalent property damage only (EPDO) collision rate for total collisions, by about 1.1 EPDO collisions per MVMT, and
- Higher mean EPDO collision rate for curb-involved collisions, by about 0.4 EPDO collisions per MVMT.

Overall, speed limit does not seem to make an important difference in the collision rates or severities for the roads the team examined. When there was a difference in collision rate or severity, it was usually the 55 mph segments that had the lower rates. The higher speed limit made a difference in the mean speeds and speed variances observed, but the differences were not that large. The mean speed for segments posted at 55 mph was still right around 55 mph.

Considering all of the findings, the researchers recommended that the North Carolina Department of Transportation (NCDOT) continue to exercise sound engineering judgment in determining speed limits on four-lane roadways with curbs on a selective, case-by-case basis. Corridors with curbs and higher posted speeds in North Carolina had some common features such as location in a suburban or rural area, low access point densities, and limited right-of-way restrictions. If curb and gutter is installed in locations where the characteristics for safe higher speed operation are not present, NCDOT should continue its practice of lowering its posted speed limits to no more than 45 mph.

To help determine a proper speed limit for a new or existing road section with curbs where higher speeds may be justified, the team suggests a list of things to consider based on Federal Highway Administration (FHWA)'s Manual on Uniform Traffic Control Devices (MUTCD) 2003 edition (*FHWA, 2003*) and North Carolina's "Guidelines for the Establishment of Restrictive Speed Limits" (May 15, 1995):

1) The 85th percentile speed of prevailing and free-flowing traffic in the area under study
2) Overall design speed, and nature of any violations of the design speed by specific roadway elements
3) Classification and strategic purpose of facility
4) Conditions and type of roadway surface
5) Roadway type, width, and number of traffic lanes
6) Shoulder width, condition, and type
7) Horizontal and vertical alignment and sight distance of the roadway
8) Roadside development: amount, type, and proximity to the travel way
9) Parking practices and pedestrian activity
10) Composition of the traffic using the roadway
11) Numbers and types of intersections, including interchanges and private driveways and roads
12) Crash experience, including frequency, severity, and rate for at least a 36-month period if available
13) Statutory limits for the area under study
14) Section length and speed limits on adjacent links

15) Lane density, level of service, and ADT

16) Directional peak hour volume

17) Peak hour factor

18) Seasonal traffic and condition variations

19) Presence of or lack of median barrier and median type and width

20) Clear zone, roadside recovery area, and lateral clearances

21) Acceleration and deceleration lane lengths

22) Pending development or highway construction

Note that items 1, 4, and 12 are not applicable to a new road section.

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1. INTRODUCTION

1.1 Problem Definition

As a city grows, the fringe area around the city is getting developed and urbanized, which generates more traffic than before. When some narrow two-lane roads in such fringe areas with 55 mph statutory speed limits are upgraded to four through lanes, curb and gutter is often installed to address issues such as access control, difficult terrain, and limited right-of-way. Posted speed limits along such highway segments are typically decreased to 45 mph by regulation when using 2’-6” curb and gutter in North Carolina because of guidance in the American Association of State Highway and Transportation Officials (AASHTO) “Green Book” (*AASHTO*, *2004*) and elsewhere that vertical curbs should not be placed next to high-speed lanes.

This lower speed limit creates a behavioral and compliance issue, as many drivers do not perceive danger from the curbs and try to travel at least as fast as they did before the road was improved. Although the North Carolina Department of Transportation (NCDOT) invests millions to improve such roadways, the results may appear to be negative to many of the participants: many drivers suffer from getting tickets or perceive a loss of mobility, NCDOT personnel may be blamed by the public, and the police face an increased enforcement burden. In trying to solve this problem, it is essential to find an answer for the following question:

> “Does a 45 mph speed limit on a four-lane road with a 2’-6” curb and gutter really reduce the frequency and severity of collisions in comparison to a 55 mph speed limit?”

1.2 Research Objectives

The purpose of this research was to collect relevant speed, operational, and safety data on appropriate sample sites and analyze those data to answer the question given above for North Carolina roadways. With the answer to the question, the NCDOT can avoid the unhappy scenario described above.

1.3 Scope

The research focused specifically on four-lane roads with 45 or 55 mph posted speed limits in developing fringe areas in North Carolina. Most often, for the sections we studied with 55 mph posted speed limits these limits were statutory rather than speed zones. We also note that, even though we did not study sections posted at 50 mph, we believe that the findings we document for sections posted at 55 mph most likely apply to those posted at 50 mph as well. In more settled urban and suburban areas, curbs with lower speed limits are obviously appropriate. In rural areas, shoulders are usually a better design choice than curbs. The problem described above is typically an interim difficulty for a few years after a new road section is opened but before the roadside develops. The research examined both four-lane roads with non-traversable medians (NTM) and with two-way left turn lanes (TWLTL). The emphasis on four-lane cross-sections is appropriate because the NCDOT rarely rebuilds old two-lane roads in fringe areas into two-lane with curb cross-sections or into six-lane cross-sections. The research analyzed the collision data for three years from 2001 to 2003.

1.4 Definitions

There is some terminology which may cause confusion in this report. In this section, a list of definitions that will be referred to throughout the rest of this report is presented in order to promote reader comprehension.

Vertical curb – one of the AASHTO type A curbs presented in the 2004 AASHTO Green Book.

Barrier curb – this term means the same thing as “vertical curb”. In the 2001 AASHTO Green Book, this term was replaced with “vertical curb.”

Sloping curb – one of the AASHTO type B to G curbs introduced in the 2004 AASHTO Green Book.

Mountable curb – this term means the same thing as “sloping curb”. In the 2001 AASHTO Green Book, this term was replaced with “sloping curb.”

Valley curb and gutter – this term refers to one of the lower, less steep types of sloping curb, which together with a gutter, is typically used on the edges of medians.

Non-traversable median – This term is intended, in this research, to designate medians designed to separate opposing traffic and to discourage vehicles from traversing the median, such as a raised or depressed grass median, in contrast with two-way left turn lane.

2. LITERATURE REVIEW

We conducted a review of the pertinent literature to identify issues and results regarding the safety and speed effect of curbed roadways under consideration in this study. Topics of interest in the literature were: safety of curbs, control of speeds, and prior responses to the problem of speed on curbed roadways.

2.1 Safety of Curbs

The American Association of State Highway and Transportation Officials book, *"A Policy on Geometric Design of Highways and Streets"*, also called the "Green Book", provides general guidelines for configurations and placement of curbs (*AASHTO, 2004*). Curbs are one of the cross section elements of roads and are used for the purposes of drainage control, roadway edge delineation, right-of-way reduction, aesthetics, delineation of pedestrian walkways, reduction of maintenance operations, and assistance in orderly roadside development. Driver behavior, safety, and the utility of highways are affected by the type and location of curbs. Typical highway curbs consist of "vertical" and "sloping" curbs (AASHTO definition). Figure 1 illustrates general configurations of AASHTO type A (vertical) and type B (sloping) curbs. Vertical curbs have a vertical or nearly vertical curb face and range from 150 to 200 mm (6 to 8 in) in height. Sloping curbs have a flat sloping curb face 150 mm (6 in) or less in height. Vertical curbs may be used in order to discourage vehicles from leaving the roadway, while sloping curbs are intended to have vehicles cross them easily in case of need. AASHTO acknowledges that driver behavior as manifested by the lateral placement of moving vehicles might be affected by curbs located at the edge of the traveled way according to the configuration and appearance of curbs (*AASHTO, 2004*).

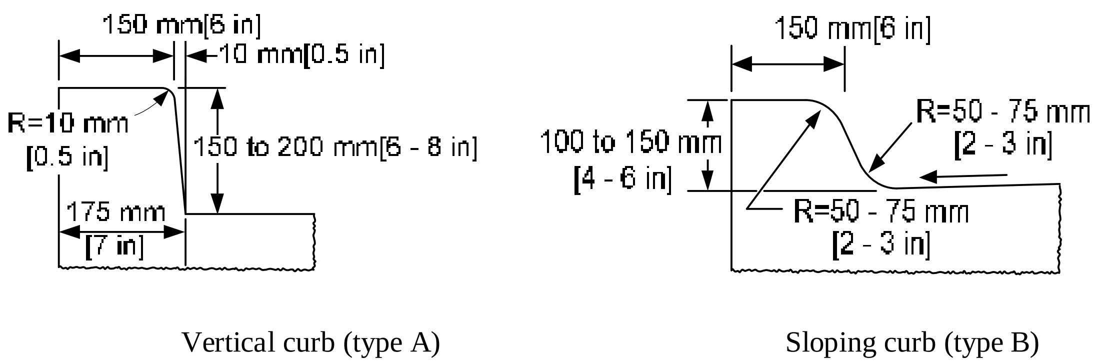


Figure 1. AASHTO type A and B curb (*AASHTO, 2004*)

The AASHTO "Roadside Design Guide" states that after an errant vehicle strikes a curb with its wheel as it leaves the roadway, the curb may cause it to trip and overturn, or become airborne, which may cause the vehicle to be out of control (*AASHTO, 2002*). It also mentioned that the trajectory of a vehicle after striking a curb depends on several factors: the characteristics of the vehicle's size and suspension, impact speed and angle of the vehicle, and the height and shape of the curb (*AASHTO, 2002*).

The two AASHTO references also provide guidelines for using the combination of a curb and traffic barrier. They recommend that if the combination of a curb and a traffic barrier is used, a vertical curb should be limited to 100 mm (4 in) in height or a sloping type curb should be used and curbs should be located flush with or behind the face of the barrier. In addition, if the height of a curb is 150 mm (6 in) or more, the barrier's deflection should be reduced by stiffening the barrier so as to prevent a vehicle from vaulting the barrier. They also state that use of a curb and concrete median barrier combination, particularly if the curb is in front of a sloping-faced concrete barrier, is not desirable because such a combination may cause unsatisfactory barrier performance (*AASHTO, 2004 and AASHTO, 2002*).

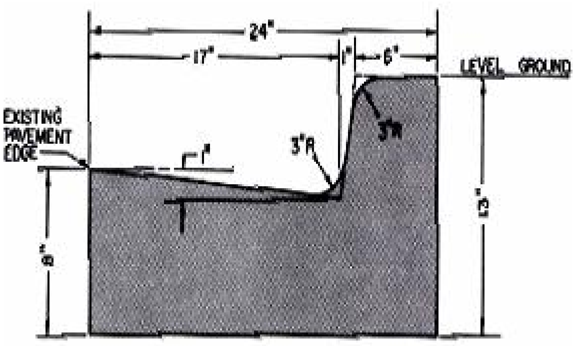
The *Roadway Design Guide*, published by the Texas DOT, deals with a new type of roadway class referred to as a "suburban roadway" (*Roadway Design Manual, 2005*). Suburban roadways are typically 1 to 3 miles in length and have light to moderate driveway densities (approximately 10 to 30 driveways per mile) and are high-speed roadways that serve as transitions between low-speed urban streets and high-speed rural highways. Since suburban roadways typically fall between those for rural highways and urban streets, the guideline advised that the desirable design speed for a suburban roadway is 60 mph with a 2-foot offset from the face of the curb to the traveled path. The minimum design speed to meet their suburban roadway criteria is 50 mph with a 1-foot offset from the travel way to the face of the curb. Like the AASHTO policy, the guideline recommended an offset between the face of curbs and the traveled path (*Roadway Design Manual, 2005*).

In addition to these guidelines, the *Highway Capacity Manual* also addressed driver behavior near curbs. In chapter 12, on multilane highways, it states that drivers have a tendency to drive further away from a raised curb in the median (*Highway Capacity Manual, 2000*).

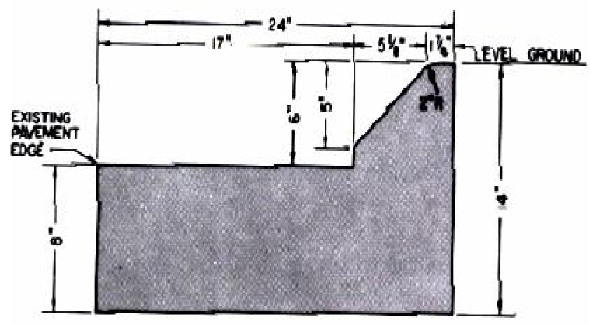
Other studies regarding the effectiveness or performance of curbs assert that it was unwise to use curbs, especially vertical curbs, along freeways or other high-speed roadways. While some early studies evaluated the performance of curbs through mathematical analysis and a few studies examined collision data, most studies performed crash tests on various types of curbs through full-scale tests or computer simulation methods. The research studies generally included testing on a vehicle's behavior such as its trajectory, angular displacements, and vaulting potential during and after curb impacts in a tracking and non-tracking condition. The following is a summary of major research studies with respect to curb performance.

The first study to employ full-scale tests or computer simulation to estimate the performance of curbs was conducted in the California Division of Highways by Beaton et al. in 1953. The study involved 149 full-scale impact tests on eleven different barrier curb cross-sections. Two 12 in. high curbs, eight 9 in. high curbs, and one 6 in. high curb were tested at various impact speeds ranged from 5 to 50 mph and angles between 5 and 30 degrees. The results of the study showed that a steeper curb face discouraged mounting and enhanced redirection for impact angles above 15 degrees. It also stated that at lower angles, the vertical curb face enhanced mounting (*Beaton and Peterson, 1953*).

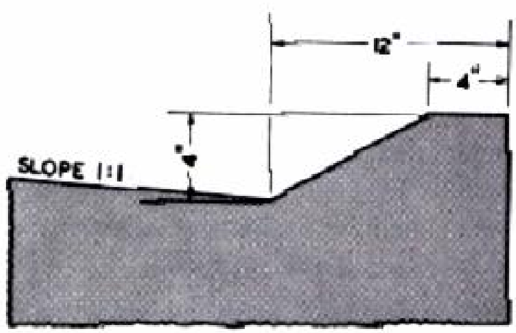
A study by Olson et al. used full-scale testing and the "Highway-Vehicle-Object-Simulation (HVOSM)" computer simulation to investigate the effect of curb geometry and location on vehicle behavior. Three curbs (1965 AASHTO Types C, E, and H) were evaluated. As can be shown in Figure 2, types C and E were 6 in. high curbs and Type H was a 4 in. high curb. These were studied because they were the most widely-used in the U.S at that time. The study showed that curbs 6 in. high or less with configurations similar to those of AASHTO Types C, E, or H will not redirect vehicles at speeds above 45 mph and encroachment angles greater than approximately 5 degrees. Therefore, curb Types C, E, and H were found to be not satisfactory for installations where redirection is the primary design intent. It also estimated that under certain speed and angle impact conditions, curb impacts produced vaulting or under-riding of 27 in. high guardrails located behind the curb. The researchers concluded that omission of curbs along high-speed roadways will promote safety and that if a vertical curb is needed, a full height vertical curb should be selected (*Olson, et al., 1974*).



TYPE C CURB



TYPE E CURB



TYPE H CURB

Figure 2. AASHTO (1965) type C, E, and H curb (*Olson, et al.*)

The main concern of a later study was to determine if the potential existed for a vehicle to vault over a barrier placed behind a curb, or a barrier placed in a sloped median. The study also used HVOSM and concluded that traffic barriers should not be placed near curbs because curbs may cause a vehicle to vault a roadside barrier or to impact it at a lower than normal position which can cause snagging problems. It also stated that problems with barriers on raised curb-median or curb-roadside configurations could be reduced in certain conditions by sloping the median or roadside up to the barrier (*Dunlap*, 1973).

Ross et al. (1989) conducted a similar study on other curbs such as AASHTO (1984) Type B (mountable curb) as Figure 3 shows. This study estimated the performance of the curbs using both a series of full-scale vehicular tests with minicars and the HVOSM computer simulation program. This research revealed that the Type B curb posed no major hazards to occupants of a minicar for the evaluated conditions. Those conditions were tracking (non-skidding) impacts with the curb at various encroachment angles and speeds up to 60 mph. An additional finding was that 6 in. high curbs can easily be traversed by a 1,250 lb car if it impacts the curb in a tracking (non-skidding) condition. Further, it was concluded that the Type B curbs could destabilize a vehicle, especially minicars, when impacted in a non-tracking (skidding) condition and recommended that the face of the curb should be sloped as flat as possible such as AASHTO curb Type C, E, and G (refer to Figure 3) (*Ross, Perera, Sicking, and Bligh, 1989*).

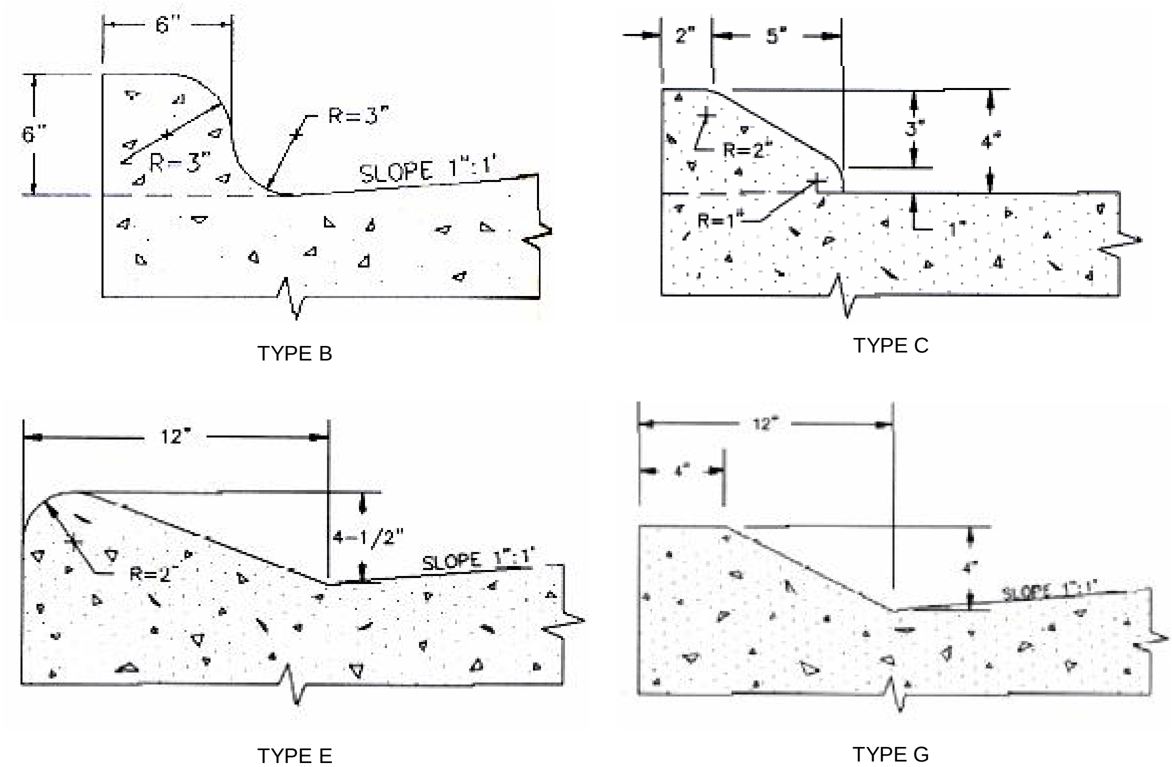


Figure 3. AASHTO (1984) type B, C, E, and G curb (*Ross, Perera, Sicking, and Bligh, 1989*)

A study in Nebraska by Holloway et al. evaluated the effectiveness of three common-used standard mountable curbs on relative safety through a combination of full-scale testing and the HVOSM computer simulation. The curbs investigated in the study were one 4 in. mountable curb and two 6 in. mountable curbs. The study assessed these using 23 full-scale tests conducted with 1800 and 4500 lb test vehicles at impact speeds of 45, 50, and 55 mph and impact angles of 5, 12.5, and 20 degrees. The results of the study showed that the mountable curbs didn't have a potential for causing loss of vehicle control or vehicle destabilization in case of a tracking impact. Also, it was revealed that W-beam guardrail could be adversely affected when used in conjunction with roadside curbs. Furthermore, through a limited simulation effort of non-tracking impacts, it was concluded that these curb types may be traversable over a wide range of vehicle orientations and may not be a significant cause of vehicle rollovers (*Holloway, et al., 1994*).

Several studies examined the performance of curbs through collision data. One study, conducted recently by Bligh and Mak, evaluated the safety performance of roadside features on rollover for 1990 to 1996 collision model passenger cars and light trucks. The study approach included comparing collision frequency, collision severity, and the occurrence of rollover involving single-vehicle crashes striking roadside objects. The crash data, from 1991 to 1995, were acquired from the Fatal Accident Report System, the General Estimates System, and the Highway Safety Information System. As Tables 1, 2, and 3 show, the data indicate that rollover rates for collisions with non-rigid or low-profile fixed objects, such as curbs, are considerably higher than those with rigid fixed objects such as bridge piers and abutments. It also stated that light trucks are more likely to roll over than passenger cars in collisions with most roadside features, including curbs (*Bligh and Mak, 1999*).

Table 1. Percent Rollover by Vehicle Type and Object Struck, FARS Data (*Bligh and Mak, 1999*)

Object Struck	Passenger Car		Light Trucks		Combined	
	No.	% Rollover	No.	% Rollover	No.	% Rollover
Bridge Rail	88	37.5	55	60.0	143	46.2
Concrete Barrier	123	36.6	49	55.1	172	41.9
Guardrail	665	50.5	387	66.1	1,052	56.3
Culvert	358	56.7	198	67.2	556	60.4
Ditches	481	69.9	299	68.6	780	69.4
Embankment	703	70.6	420	68.8	1,123	69.9
Curb	446	41.7	121	53.7	567	44.3
Sign	229	51.1	146	57.5	375	53.6
Utility Pole	882	22.0	259	37.1	1,142	25.4
Bridge Pier/Abutment	115	13.0	52	21.2	167	15.6
Total	4,090	47.1	1,986	60.7	6,077	51.6

Table 2. Percent Rollover and Injury by Vehicle Type and Object Struck, NASS GES Data (*Bligh and Mak, 1999*)

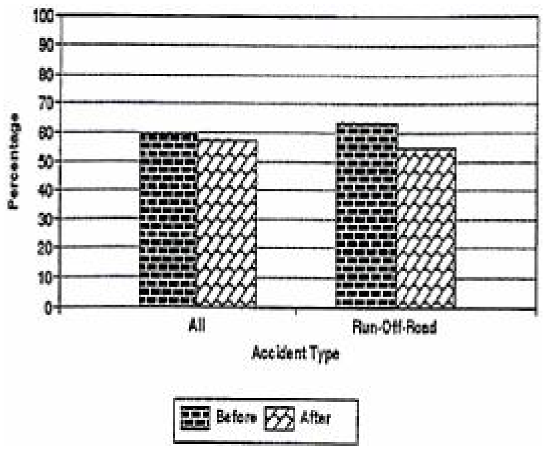
Object Struck	Passenger Cars			Light Trucks			Combined		
	% Rollover	% Total Injury	% (A+K) Injury	% Rollover	% Total Injury	% (A+K) Injury	% Rollover	% Total Injury	% (A+K) Injury
Impact Attenuator	0.0	23.1	4.6	0.0	38.0	0.0	0.0	24.7	4.1
Bridge Structure	3.8	40.4	6.9	4.3	37.8	3.3	4.0	39.6	5.9
Guardrail	4.7	31.5	5.3	11.2	39.1	11.4	6.2	33.3	6.7
Concrete/Other Barrier	6.5	41.3	4.3	10.2	44.4	3.8	7.1	41.8	4.2
Post, Pole or Support	4.0	42.3	6.5	6.0	33.8	5.8	4.6	39.8	6.3
Curb	6.3	28.4	4.3	19.8	38.7	6.8	8.9	30.3	4.7
Culvert or Ditch	23.2	39.4	9.9	32.8	45.2	12.0	26.0	41.1	10.5
Embankment	24.2	50.5	10.8	44.3	44.8	14.8	29.8	49.0	11.9
Total	10.2	38.6	6.9	18.2	39.4	8.9	12.3	38.8	7.4

* A+K Injury: Incapacitating and fatal injury

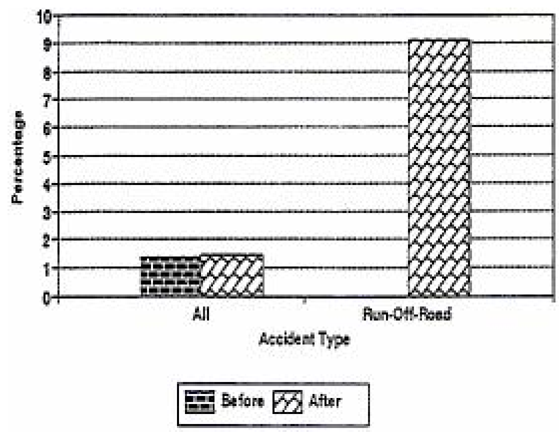
Table 3. Percent Rollover by Vehicle Type and Object Struck, Illinois Data (*Bligh and Mak, 1999*)

Object Struck	Passenger Car		Light Truck		Total	
	No.	% Rollover	No.	% Rollover	No.	% Rollover
Guardrail	1,254	4.7	374	6.4	1,628	5.1
Conc. Median Barrier	223	5.8	40	2.5	263	5.3
Median Fence	22	9.1	3	-	25	12.0
Bridge Rail	171	4.1	99	9.1	270	5.9
Impact Attenuator	33	0.0	6	-	39	0.0
Highway Sign	515	3.7	203	7.4	718	4.7
Traffic Signal	183	0.0	69	1.4	252	0.4
Light Standard	332	3.0	87	2.3	419	2.9
Tree	544	5.3	214	5.1	758	5.3
Utility Pole	461	2.4	164	3.7	625	2.7
Mail Box	77	6.5	48	18.8	125	11.2
Delineator Post	83	12.5	31	32.3	114	19.3
Curb/Island	44	9.1	10	-	54	11.1
Bridge Structure	60	0.0	18	-	78	0.0
Culvert Headwall	3	-	4	-	7	-
Ditch/Embankment	100	42.0	66	57.6	166	48.2
Total	4,105	5.2	1,409	8.7	5,541	6.2

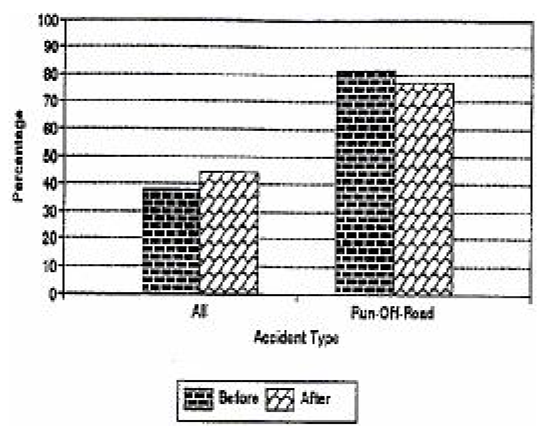
A study carried out by Fambro, et al. in Texas developed design guidelines for suburban, high-speed, curb and gutter roadways. Part of the study evaluated the safety effects of high speed curb and gutter roadway on collision rates, severities, and frequencies. The study used a statistical comparison of the three safety measures before and after installing a curb and gutter cross section in 10 sites. Collision data were collected for at least three years including 'before' and 'after' periods. The results of the study showed that curbs appear to have a negative effect on the safety of high-speed roadways depending on the driveway density and average daily traffic (ADT). While the collision rate in high driveway density where drivers tend to decrease speeds by being aware of roadside interactions did not increase with increasing ADT, the rate in low density driveway increased with increasing ADT. As Figure 4 shows, collision percentages for all collisions increased after installing the curb and gutter facilities under different conditions and the severity of run-off-road accidents might be worse on a high-speed road with the curbs. The researchers also stated that the facilities of interest have safety problems under storm water ponding. They recommended that curb and gutter without paved shoulders in high-speed roadway would be a less safe driving environment (*Fambro, et al. 1995*).



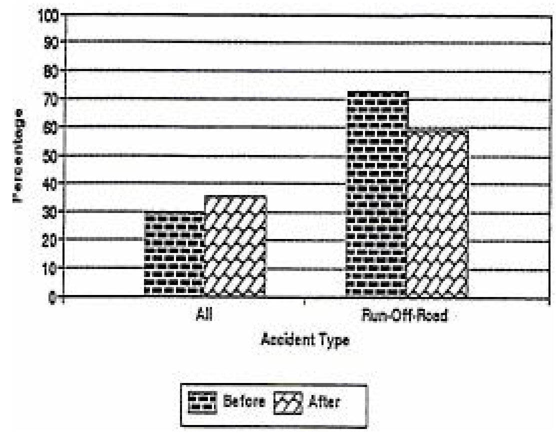
Percentage of Accidents with No Injuries



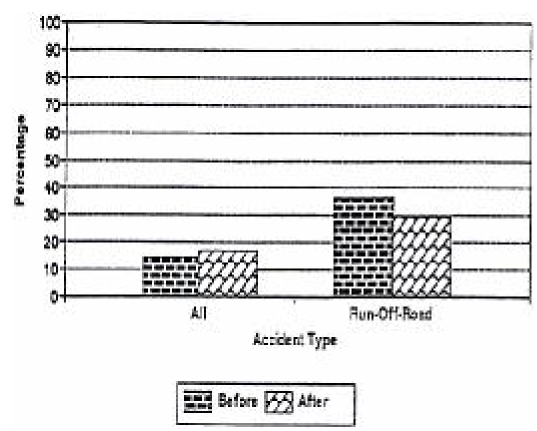
Percentage of Accidents with Fatalities



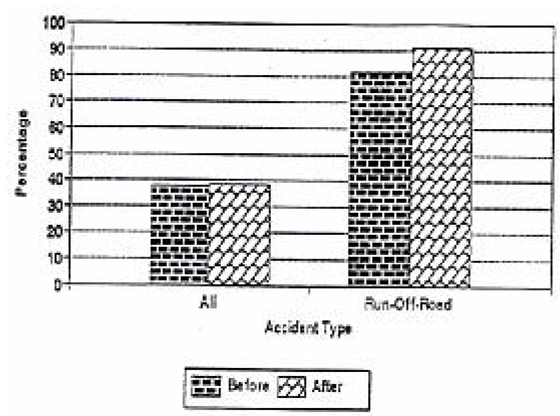
Percentage of Accidents with Impaired Visibility



Percentage of Accidents During Nighttime



Percentage of Accidents on Wet Road Surfaces



Percentage of Accidents Intersection Related

Figure 4. Percentage of Accidents by Accident Severities and Road Conditions (*Fambro, et al., 1995*)

Lienau conducted an earlier, very similar, study on other sites in Texas and Illinois. The study estimated the safety effects of barrier curbs on high-speed suburban multi-lane highways. The study employed four statistical methods to quantify the safety effect: the *t*-test, analysis of variance, regression, and log-linear modeling. The study selected 10 sites before and after curb installation in Texas and 9 matched pair (non-curbed and curbed) sites in Illinois and gathered the collision data from those sites. Three measures of effectiveness - collision rate, collision characteristic frequency, and collision severity - were examined to determine whether these were differences from one population to another. The results of the study were (*Lienau, 1996*):

- Driveway density seemed to affect the safety of high speed road sections with curb and gutter. That is, at a condition of low density, curb and gutter appeared to decrease the safety of the road because drivers were not expecting a curb, but a shoulder.
- As traffic volume goes up, curb and gutter caused more collisions.
- The mean collision rates involving impaired visibility were much higher for sites with curb and gutter than without curb and gutter.
- The rates of run-off-the-road collisions for sites with curb and gutter were higher than those for sites without curb and gutter.

A study by Council et al. identified collision types and circumstances where small vehicles (≤ 2204 lb) were overrepresented. Part of the study examined the effect of roadside characteristics on the rollover propensity of small vehicles. The study analyzed collision and roadway data from the States of Washington, Texas, and North Carolina, and computer simulation runs related to vehicle dynamics. It showed that while there are no frequency differences in terms of small vehicles over-involvement for curbs in North Carolina, in the other states it appears that small vehicles are overrepresented in single-vehicle collisions related to curbs (*Council, et al., 1987*).

In addition to estimating the performance of curbs, a study by Dunlap developed a method of defining the redirective effectiveness of a given curb at any particular installation site. In this research, the measure to determine the efficiency of a barrier curb as a redirective device was the percentage of the total errant vehicle population that could be expected to be redirected by a given barrier curb. From the results, the researchers concluded that a carefully designed barrier curb can be an effective redirection device (*Dunlap, 1973*).

2.2 Control of Speeds

The imposition of speed limits is one of the oldest strategies for controlling driving speeds. After the first speed limit was imposed in Connecticut in 1901, state and local governments have had primary responsibility for setting speed limits. Currently, legislated speed limits are determined by state legislatures, city councils, or Congress on the basis of considerations for public safety, community concerns, and travel efficiency. Generally, methods of setting speed limits are based on engineering study and on such factors as operating speeds of free-flowing vehicles, crash experience, roadside development, roadway geometry (design speed), parking, and pedestrian levels. In many speed zones, the 85th percentile speed is commonly used in setting speed limits. In general practice, the imposed speed limit sets the maximum speed limit for a roadway where the operating speed may be above the design speed for a particular location of the roadway (*Agent, Pigman, and Weber, 1998; TRB, 1998*).

The essential purpose of imposing speed limits is to reduce the risks of collisions caused by inappropriate speed distributions or by speed itself. Many studies have been performed to find the effectiveness of speed limits. While some studies showed that there was a positive effect of changing posted speed limits on highway safety, other studies showed a negative effect or no significant difference in highway safety before and after changing the posted speed limits.

Parker evaluated the effects of raising and lowering posted speed limits on driver behavior in urban and rural non-limited access highways in 22 states. The study used a simple ‘before’ and ‘after’ comparison with statistical testing. The speeds of free-flow vehicles and collision data were collected at 100 treatment sites where speed limits were either raised or lowered and at 83 comparison sites with no changes in speed limits from October 1985 to September 1992. The results showed that there were practically no significant changes in speeds at the treatment sites, with average changes less than 1 mph (1.6 km/h) regardless of whether speed limits were raised or lowered (Figure 5). The results also indicated that, although the changes in vehicles speeds were not practically significant, driver violations of the posted speed limits increased when the speed limits were lowered and, conversely, driver violations decreased when speed limits were raised. Further, it showed that there are no significant differences in collision changes when speed limits were either lowed or raised (*Parker, 1997*).

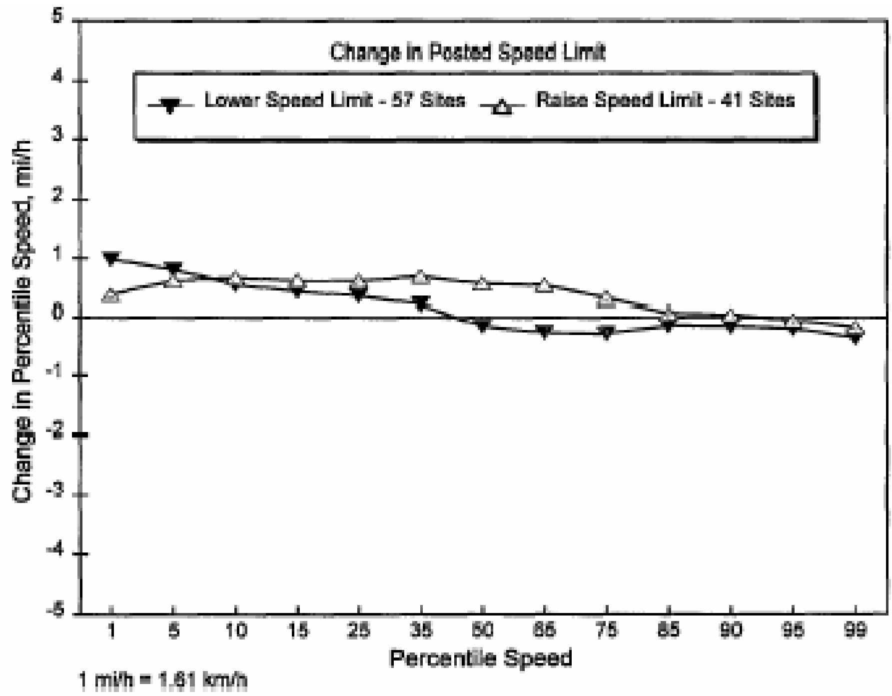


Figure 5. Mean Changes in Percentile Speeds After Lowering and Raising Speed Limit (*Parker, 1997*)

A very similar study regarding the effects of increasing the speed limit from 104.6 to 112.6 km/h (65 to 70 mph) on certain sections of freeway was conducted by Binkowski, et al. in Michigan. The study employed simple comparisons with speed data collected on the test sites where speed limits were raised and control sites where speed limits were not raised. Speed data were collected through permanent and portable traffic recorders over 7 days for 'before' periods and three months for 'after' periods. The results revealed that there was no meaningful effect of increasing the speed limits on the change in recorded speed and capacity on both test sections where the speed limits were raised and control sections where the speed limits were not raised (*Binkowski, Maleck, Taylor, and Czewski, 1998*).

Agent, et al. examined the criteria and procedures used to set speed limits in Kentucky. The study was done by comparing speed data and collision data collected before and after speed limit changes on rural and urban interstate, non-interstate freeway, parkway, and two-lane roadways with and without full-width shoulders. The study showed that at locations where speed limits were changed by 10 mph there were only slight differences in recorded speeds and no significant difference in the total, injury, or fatal collision rates. It also recommended that the 85^{th} percentile speed is preferable for setting speed limits and that different speed limits for cars and trucks are desirable for some highways (*Agent, Pigman, and Weber, 1998*).

Unlike the studies cited above, the following studies showed that changing speed limits has some effect on highway safety. A study by Raju, et al. evaluated the impact of 65 mph speed limit on Iowa's rural interstate highways. The study was done to estimate the impact of the increased speed limit with an integrated Bayesian forecasting and dynamic modeling approach. The following data sets were collected: VMT and fatal collisions in Iowa from 1980 to 1993; VMT and fatal collisions in Iowa from 1976 to 1995; and VMT and fatal collisions in New Jersey (a state that did not increase its speed limit) from 1976 to 1995. They concluded that speed limits increased from 55 mph clearly had serious safety implications. A comparison of Iowa's experience with New Jersey's for the same time period of 1976 to 1987 confirmed this conclusion because Iowa's fatal collision rates rose as the speed limits were increased, while New Jersey's fatality rates did not increase (*Raju, Souleyrette, and Maze, 1998*).

Another study, conducted by Renski, et al. in North Carolina, evaluated the effect of speed limit increases (based on engineering studies) on collision injury severity on

North Carolina interstate highways through a paired comparison analysis and an ordered probit model. This study estimated that increasing speed limits from 88.5 to 96.6 km/h (55 to 60 mph) and from 88.5 to 104.6 km/h (55 to 65 mph) increased the probability of sustaining minor and nonincapacitating injuries as Figure 6 shows, but increasing speed limits from 104.6 km/h to 112.7 km/h (65 to 70 mph) did not have a significant effect on collision severity (*Renski, Khattak, and Council, 1999*).

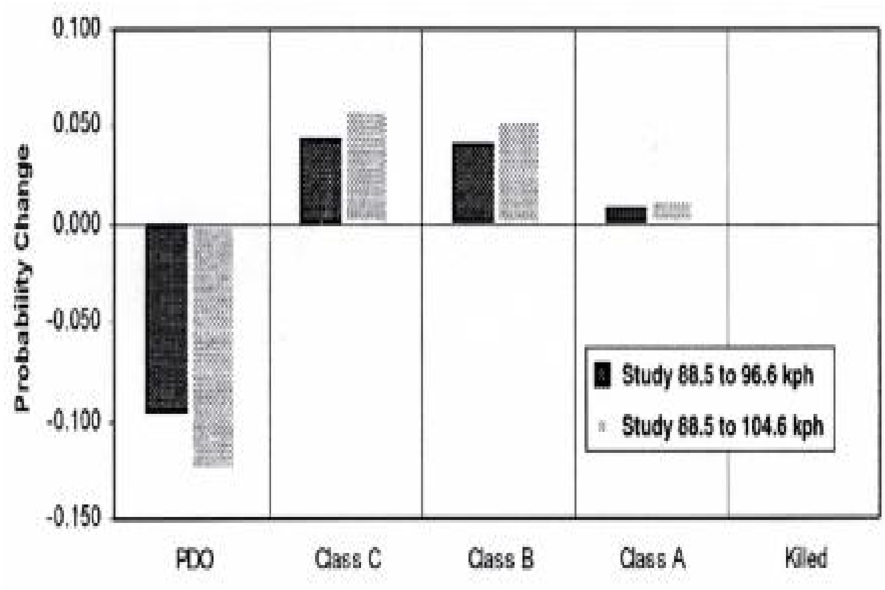


Figure 6. Marginal Effects of Speed Limit Changes on Crash Severity (*Renski, Khattak, and Council, 1999*)

In addition to estimating the safety effectiveness of changing in speed limits, Fitzpatrick, et al. reevaluated how design speed and operating speed are adopted in current design policies and guidelines. The study was conducted by reviewing relevant literature and using mail-out surveys. They pointed out some issues such as the role of functional classification in setting speed limits. They also showed that between 23 and 52 percent of the free-flow vehicles on suburban/urban roadways were at or below the posted speed limit and that the percentage of vehicles that exceeded the speed limit on suburban/urban non-freeway roadways was much larger than that on rural non-freeway roadways (*Fitzpatrick, et al., 2003*).

2.3 Prior Responses to the Problem of Speed on Curbed Roadways

For the purposes of this project, the most relevant past research is by other agencies responding to the problem of speeds on curbed roadways in developing fringe areas. A search of the on-line databases revealed three agencies that responded to the problem in three different ways.

One of the three agencies is the Texas DOT. They had conducted diverse safety studies, operational studies, and clear zone studies of various sites in Texas. The safety study looked at collision rates, severities, and characteristics and concluded that the safety of high-speed curb and gutter sections appeared to be affected by driveway density and ADT as we mentioned previously. The operations and clear zone study stated shoulder requirements. The results from these studies were incorporated into the *Texas Roadway Design Guide*, where they defined a new type of roadway class referred to as a “suburban roadway” (*Fambro et al., 1995; Lienau,1996; and Texas Department of Transportation, 2002*).

The City of Sacramento responded to the same problem in a different way. They engaged the public to help them balance the needs of the different roadway users to develop a design that provided more livable streets. The community-based approach allowed the residents to debate the different issues and gave them a better appreciation of the duties of the roadway agency. The final design incorporated minimum street widths needed for function and safety, rolled curbs with planter boxes and specific standards for specific applications (*Owens, 1999*).

The Idaho DOT took another approach as they expanded rural, two-lane roadways with 15,000 to 28,000 vehicles per day to four-lane or five-lane facilities. They have completely avoided the curb issue with a new design that provides a rural cross section without curbs, gutters, or sidewalks. The speed limit of the facility is 55 mph. They have also developed a five-stage graduated plan to manage access along the corridors that will minimize the expenditure of public funds for right-of-way acquisitions (*Carter and Szplett, 1999*).

2.4 Summary

This chapter reviewed the literature with respect to the effectiveness or performance of various types of curbs through crash tests, computer simulations, and collision data analyses. These studies showed that vertical curbs placed at the edge of higher speed roads may cause some errant vehicles to become airborne, rollover, or be redirected back into travel lanes. It was also recommended that we should pay scrupulous attention to using the combination of a curb and a traffic barrier not to cause an undesirable result. Some research results revealed that collision rates for roads with curb and gutter were higher than those for similar roads without curb and gutter.

In addition, the chapter looked at the literature pertaining to establishing and enforcing speed limits and the effectiveness of speed limits. The studies, however, did not show consistent conclusions. The question still remains regarding the effect an imposed speed limit has on operating speeds. Even though the primary aim of speed limits is to improve safety, it is difficult to guarantee that just imposing a speed limit can reduce collisions or collision severity. There is general consensus that an engineering study is needed to establish or to change the speed limits for any specific section of roadways such as high-speed highways with curbs.

3. NCDOT CURRENT POLICIES AND PROCEDURES

This chapter discusses current policy in an attempt to understand the existing decision making processes within the Department as they relate to the use of curb and gutter on high speed roadways. Designing roadways using curb and gutter has become problematic in instances where corridors warrant posted speeds in excess of 45 mph (such as where the statutory speed is 55 mph). The chapter first presents current AASHTO and NCDOT guidelines. Next, the chapter discusses the design process as it relates to the selection of road edge treatment. Last, case studies across the State help provide an understanding of the relevant decision-making processes as they pertain to varying roadway facility types and conditions; this is especially helpful when those decisions varied from current standards and policies.

3.1 Current Policy Regarding the Use of Curb and Gutter

3.1.1 AASHTO Guidance and Policy

The 2002 AASHTO Roadway Design Guide (*AASHTO, 2002*) and 2004 AASHTO Policy on Geometric Design of Highways and Streets (*AASHTO, 2004*) contain several suggestions on the use of curb and gutter. However, these suggestions are vague in reference to the use of curb and gutter on higher speed facilities with posted speeds in excess of 45 mph. The literature review in the previous chapter outlined some of the material from these references. To help illustrate the problem and summarize guidelines, a review of some of the key points in each of the books as it relates to assistance with the use of curbs along high speed facilities (posted 50 mph and up) is provided below.

- 2002 AASHTO Roadway Design Guide
  - *Section 3.4.1*
    - "In general, curbs are not desirable along high-speed roadways. If a vehicle is spinning or slipping sideways as it leaves the roadway, wheel contact with a curb could cause it to trip and overturn. Under other impact conditions, a vehicle may become airborne, which may result in loss of control by the motorist. The distance over which a vehicle may be airborne and the height above (or below) normal bumper height attained after striking a curb may become critical if secondary crashes occur with traffic barriers or other roadside appurtenances."
  - *Section 5.6.2.1*
    - "Crash tests have shown that use of any guardrail/curb combination where high-speed, high–angle impacts are likely should be discouraged. Where there are no feasible alternatives, the designer should consider using a curb no higher than 100 mm [4 in.] and consider stiffening the guardrail to reduce potential deflection. ….. A case-by-case analysis of each situation considering anticipated speeds and consequences of vehicular penetration should be used."
  - *Section 10.7*
    - "Curbed sections are generally restricted to design speeds of 70 km/h [45 mph] or less on roadways in urban or highly developed areas. Items that need to be considered are: delineation of the pavement edge, delineation of pedestrian walkways, control of access points, retention of water on the roadway, and vaulting or destabilization of vehicles……Crash tests have shown that the use of guardrail with 150 mm [6 in.] curb should not be considered where high-speed, high-

angle impacts are likely to occur. Where curb is needed for drainage, the use of a curb no higher than 100 mm [4 in.] is satisfactory."

- 2004 AASHTO Policy on Geometric Design of Highways and Streets
  - CHAPTER 4: CROSS SECTION ELEMENTS – CURBS (*General Considerations*)
    - "Curbs are used extensively on all types of low-speed urban highways, **….** In the interest of safety, caution should be exercised in the use of curbs on high-speed rural highways. Where curbs are needed along high-speed rural highways due to drainage considerations, the need for access control, restricted right-of way, or other reasons, they should always be located at the outside edge of the shoulder."
  - CHAPTER 4: CROSS SECTION ELEMENTS – CURBS (*Curb Configurations*)
    - "Vertical curbs should not be used along freeways or other high-speed roadways because an out-of-control vehicle may overturn or become airborne as a result of an impact with such a curb. Since curbs are not adequate to prevent a vehicle from leaving the roadway, a suitable traffic barrier should be provided where redirection of vehicles is needed."

In summary, AASHTO guidelines seem to indicate that the use of curbs and gutters along urban and rural "high-speed roadways" with posted speed limits of higher than 45 mph could be hazardous to motorists striking them at high angles and velocities. However, in both major AASHTO references the relevant passages are vague, qualitative, and offer little support or evidence. For example, the Roadside Design Guide does not mention where curbs might be placed while the Green Book is silent on curb and guardrail combinations.

3.1.2 NCDOT Guidance and Policy

Based on AASHTO guidelines, NCDOT has developed standard drawings in 2002 depicting various types of curb and gutter combinations to be used in North Carolina (*Roadway Standard Drawings, 2002*). This review focuses on the most commonly used combinations: 2’-6” curb and gutter, 1’-6” curb and gutter, expressway curb and gutter, and 8” by 12” or 18” concrete curb with no gutter. The standards provide primary objectives and limitations for each as discussed below.

Standard 2’ 6” curb and gutter is synonymous with the AASHTO Type B sloping curb. It has a nearly vertical face, is six inches (150 mm) in height, has a two-foot gutter width, and has little vertical deflection (Figure 7). NCDOT typically uses this curb and gutter type on the outer edge of pavement for drainage control, edge of pavement delineation and support, and right-of-way reduction. It is not typically used on high-speed roadways with posted speeds in excess of 45 mph (*Bennett, 2005*). This curb and gutter treatment is used with various median treatments such as the standard 1’-6” curb and gutter as well as along undivided facilities.

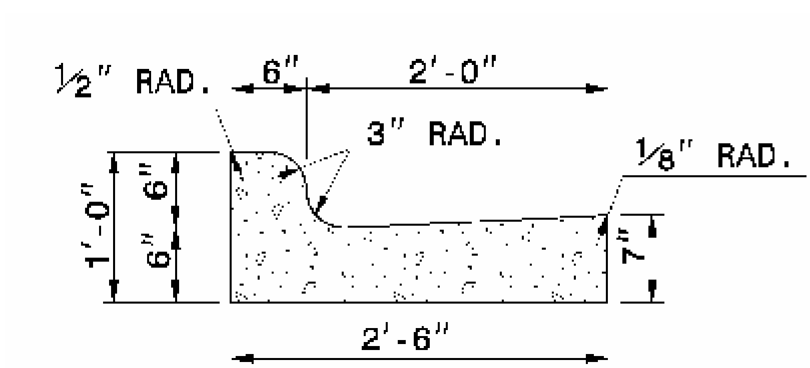


Figure 7. 2'-6" Curb and Gutter (*Roadway Standard Drawings, 2002*)

The 1’-6” curb and gutter is a cross between the AASHTO Types B and C sloping curbs. Its five-inch (126 mm) curb face contains a two-inch vertical lip followed with a sloping 3:1 offset for easier traversal, and has a nine-inch gutter width (Figure 8). NCDOT primarily uses this curb and gutter as a median treatment (with grass or concrete) on divided facilities in urban and suburban areas with posted speeds not exceeding 45 mph. The purposes of this median are typically to separate opposing directions of travel and to provide space for turning lanes. This curb and gutter type on the median is primarily used with paved shoulders or with curb treatments such as the 2’-6” curb and gutter mentioned above on the outside roadway edge.

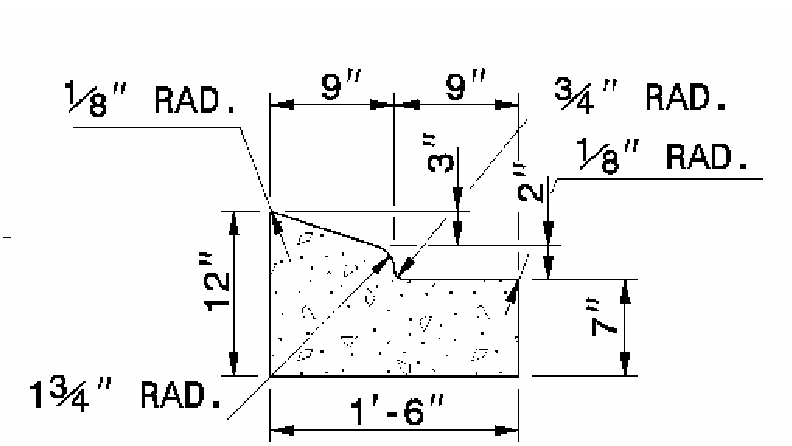


Figure 8. 1'-6" Curb and Gutter (*Roadway Standard Drawings, 2002*)

Figure 9 shows a typical cross-section view of a divided facility using 2’-6” and 1’-6” curb and gutter treatments in combination. Figure 10 shows a cross-section view of a divided facility with paved shoulders and a 1’-6” curb and gutter median treatment.

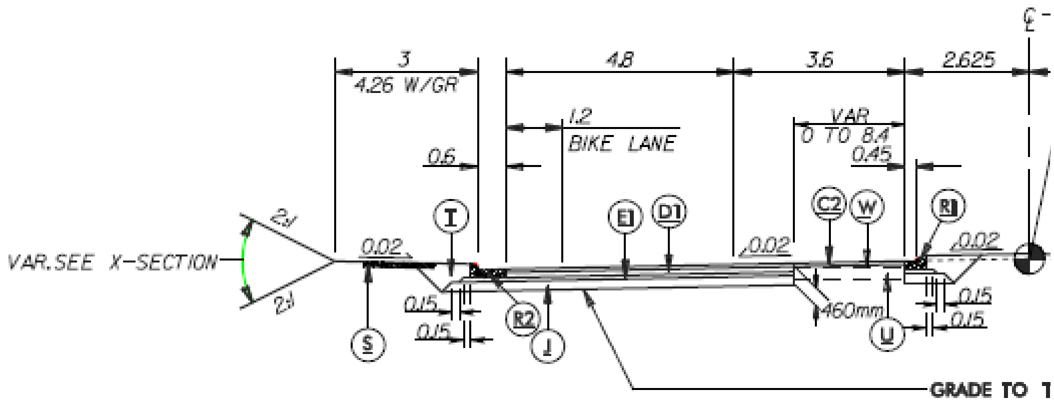


Figure 9. Divided Facility. 2'-6" (R1) and 1'-6" (R2) Curb and Gutter Treatment in Cross-Section View [metric units] (*Cross-Section Typicals, 2005*)

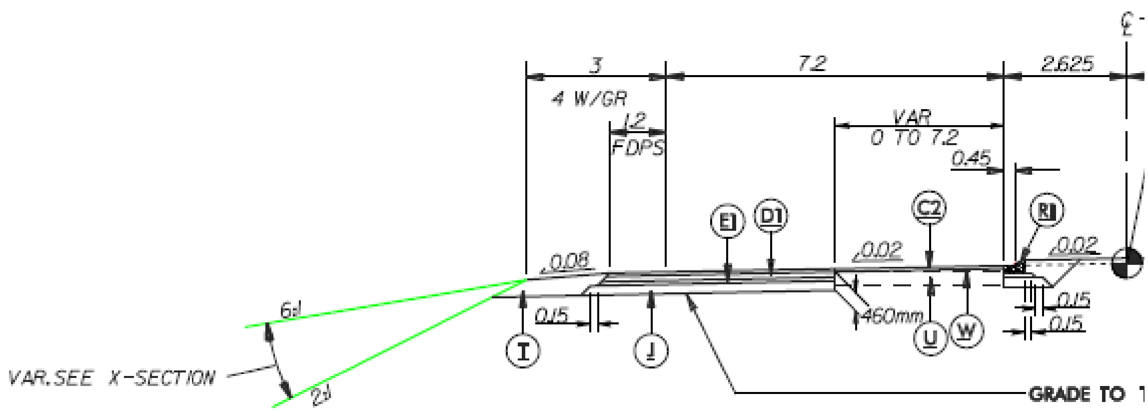


Figure 10. Divided Facility. Paved Shoulder in Combination with 1'-6" Curb and Gutter Median Treatment in Cross-Section View (*Cross-Section Typicals, 2005*)

On roadways with posted speeds exceeding 45 mph, curb and gutter applications typically do not apply. However, expressway gutter could be used in certain warranted situations. Expressway gutter contains no curb application by virtue of its name (Figure 11). However, the need for drainage, right-of-way reduction, or excessive cut areas (> 25 feet deep) with steep shoulder slopes may necessitate the need for this gutter. Therefore, using this gutter type helps minimize the construction footprint by removing a potential ditch and providing drainage through a piping system underground.

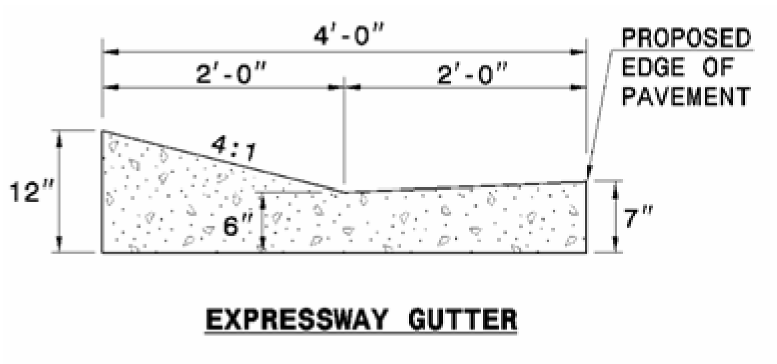


Figure 11. Expressway Gutter (*Highway Design Branch, 2005*)

Like curb and gutter combinations, expressway gutter has its limitations. Its shape and size do not allow it to "pool" water very well, unlike the two previous curb and gutter applications. Therefore, drainage in heavy downpours can be poor as water spills over the innermost edge of the gutter (*Bennett, 2005*). Figure 12 shows a typical cross-section using expressway gutter in a steep shoulder section.

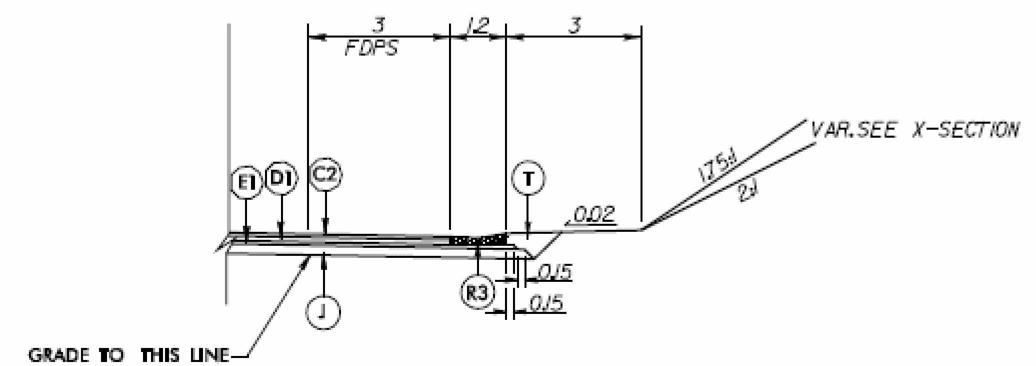


Figure 12. Cross-Section using Expressway Gutter (R3) in a Steep Shoulder Section (*Cross-Section Typicals, 2005*)

Curbing is sometimes used for channelization and right-of-way protection purposes. In this case, the NCDOT sometimes uses an 8" by 12" or 18" concrete curb as shown in Figures 13 and 14. In addition, NCDOT right-of-way is preserved for future use by prohibiting parking and parking spaces, as well as signage from fronting businesses (*Bennett, 2005*). This curb does not contain drainage features with the use of a gutter combination.

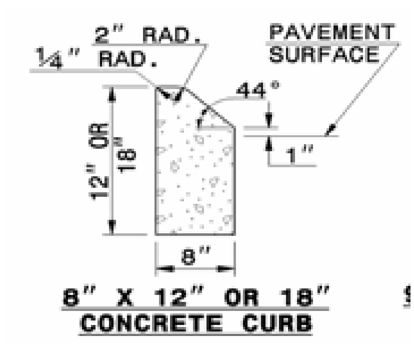


Figure 13. 8" x 12" or 18" Curb (*Roadway Standard Drawings, 2002*)

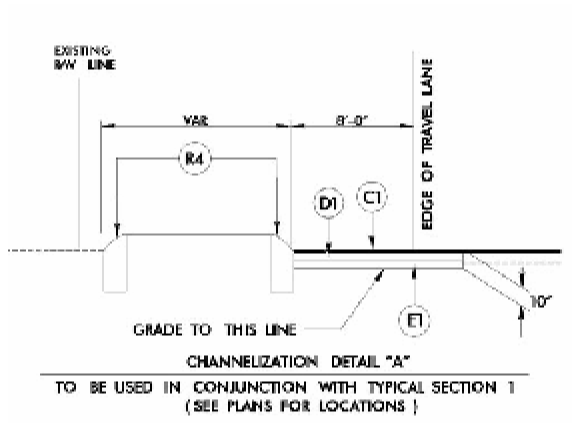


Figure 14. Cross-Section View of 8" x 12" or 18" Curb (*Highway Design Branch, 2005*)

Figure 15 illustrates the use of an 8" x 12" curb along an urban roadway with business frontage in plan

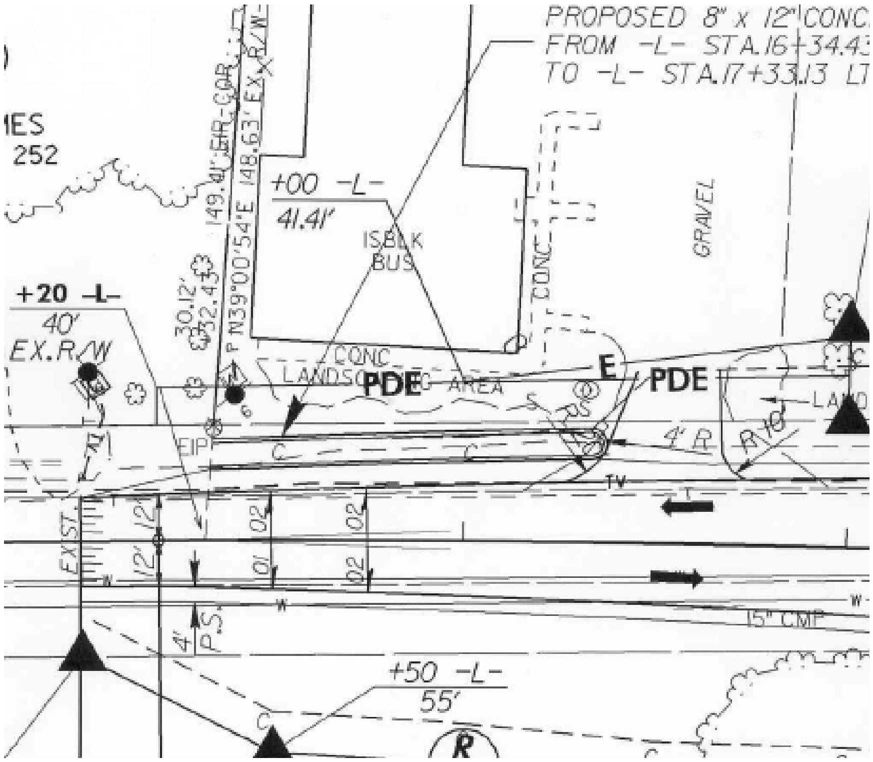


Figure 15. 8" x 12" Curb in Plan View Placed in Front of Business (*Highway Design Branch, 2005*)

3.2 Understanding the Design Process

Understanding the design process before construction of a new roadway or reconstruction of an existing roadway is critical to the understanding of the issues associated with using curb and gutter and setting speed limits along high speed corridors greater than 45 mph. This section outlines the typical process of the planning and design units in North Carolina as they consider cross section selection.

During the beginning stages of the design for a new or existing roadway, cross sections are suggested in the planning document (*Faulkner, 2004*). This is typically an extension of the local thoroughfare plan. Such examples could include the need for limited access, median curb and gutter use with limited right-of-way, or others. During preliminary design, these cross sections are revisited by the design engineers (by the Roadway Design Unit or by consultants hired by the NCDOT). This design is then presented to local officials, people living in the area, and other stakeholders through public meetings and hearings. Following the meetings and hearings, cross-sections may be further adjusted. At this time, the designer looks at the need for access control and amount of right-of-way necessary for the proposed highway corridor. If the need for drainage control, edge of pavement delineation, or right-of-way reduction becomes palpable, curb and gutter may be considered.

This stage is critical in the design process, especially along existing high-speed roadways posted at 55 mph and in statewide strategic highway corridors. Limited right-of-way, access control, drainage issues, and other reasons often limit what the designer can propose while staying within budget (*Daughtry, 2005*). Use of curb and gutter often negates many of these problems; however, based on the design guidelines recommended by AASHTO shown earlier, posted speed limits should be lowered to a maximum of 45 mph when the designer uses curb and gutter.

With the design nearing completion, project review meetings are scheduled by the designers to discuss the details of the design plan page by page with the Division Office that will be responsible for oversight, construction, and future maintenance. Issues arise with cross sections or recommended speed limits along many of these sections, especially when existing high speed roadways are under construction and the possibility of reducing speed limits comes into play. However, at this stage in the design process, major cross section changes are not usually recommended because it would incur major project redesign and produce delays. Therefore, if there are differences in opinions on cross section or speed posting, they are typically discussed and worked out (if possible) at that point.

Ultimately, the final decision on speed posting rests with the State Traffic Engineer (*Daughtry, 2005*). The limit is usually set at the speed recommended by the Division Traffic Engineer and Regional Traffic Engineer based on speed studies, experience, and/or AASHTO guidelines. Confusion between what speed studies indicate would be a reasonable posted speed limit based on operating speeds and vague national guidelines along higher speed curb and gutter roadways has brought the need for a better understanding of how to deal with this problem in the future.

3.3 Case Studies

Case studies were conducted across the State in order to gain a better understanding of the decision making process as it relates to the addition of curb and gutter along higher speed corridors (≥ 45 mph) and the choice of posted speed limits. Four divisions (4, 6, 7, and 10), as well as the Charlotte Department of Transportation, participated in question and answer sessions by email. Multiple respondents replied from each division, and the project team agreed that the identities of individual respondents would be kept confidential. Corridors used for case study evaluation were obtained from the sample used in our analysis later on in this report.

The primary focus of this case study investigation was to understand why some sites having curb and gutter in combination with various median treatments were posted with 55 mph speed limits. In addition to the aforementioned sites, we requested that the same information be given for the remainder of the sites (posted at 45 mph and 55 mph without curb and gutter and posted at 45 mph with curb and gutter) in their respective divisions. The hope was that additional information from choices made at other sites with varying characteristics would be useful for understanding the decision making process.

For each of the respective sites in the Divisions, respondents were asked to give the following information to the best of their knowledge:

- If possible, give a brief history of the site.
- How has the site changed over time?
- What caused the changes (especially those related to speed or curb/barrier use)?
- What decisions were made over time that were critical to the operation or design of the facility?
- Why were those decisions made?
- What is the policy your division uses in setting speeds along these types of corridors?

Respondents were also encouraged to give any other additional information that may have been relevant to the understanding of the site. A list of the case study sites is shown in Table 4 along with some of the important site characteristics.

Table 4. Case Study Sites of Interest

Division	Corridor	Segment Length (miles)	Speed Limit (mph)	Median Type
4	NC–42	2	55	Grass
6	NC–53	> 1	45	TWLTL
	SR–1403	1.1	45	TWLTL
	US–401 Business	> 1	55	Positive Barrier
7	US–70	1.1	45	Grass
	SR–1541	0.8	45	Grass
	US–29	N/A	55	Positive Barrier
10-CDOT	NC–49	0.8	45	Curb
	NC–16	1.1	45	Grass
	NC–51	0.7	45	Grass
	US–29	0.5	55	Curb
	NC–24/27	1.6	45	Grass
	NC–24/27	3	55	TWLTL
	NC–24/27	1.9	55	Grass
	NC–24/27	0.7	55	Grass

A brief summary of each of the division's comments, roadway characteristics, and key points follow. These key points are condensed later in this section under the summary and should aid future decision making, especially in conjunction with the findings from the field data analyses presented later in this report.

Division 4

NC-42 was the genesis for this project. Originally, the site was a curvy, poorly aligned, two-lane primary route with a statutory 55 mph speed limit. Over time, the site was realigned, widened to four lanes, and straightened; however, a maximum speed limit of 50 mph was posted due solely to the inclusion of curb and gutter. Figure 16 shows a view of the eastbound approach for NC-42 along the corridor analyzed during our effort.

This site has approximately six to eight access points (dependant on direction of travel) along the 2.5-mile corridor studied.

Figure 16. Eastbound NC-42

Public concern and outcry arose with the decrease in posted speed following the completion of major improvements to the roadway. Due to higher speed differentials, poor compliance, and observed disrespect for the traffic control device, the posted speed was changed back to 55 mph and this site was to serve as a “test site” for this research project.

In regards to the policy used, respondents from Division 4 typically agreed that they tend to follow AASHTO guidelines when setting curb and gutter on high speed corridors. It was noted that on corridors where design speeds are typically low and curb and gutter was considered, a speed study would be conducted to determine the posted speed of the facility.

Division 6

NC-53 is located primarily in an area of commercial and retail sites; however, the specific corridor we studied primarily contained a limited number of single-family residences with access. The speed limit was set at 45 mph following the construction of the four-lane highway and has remained unchanged since. Respondents noted that a similar site along NC-53 near I-95 was reduced from 55 mph to 45 mph posted speed limit when businesses started developing on the roadside. Curb and gutter was present along a stretch posted at 55 mph for approximately three to five years before the NCDOT reduced the posted speed. Figure 17 shows a view of westbound NC-53 along the corridor analyzed during our effort.

Figure 17. Westbound NC-53

SR-1403 is a bit more developed than the NC-53 corridor. It is posted with a 45 mph speed limit and is lined by some commercial and retail development. In addition, this site contains accesses to various subdivisions, apartments, and a school. There are eleven to fifteen access points (dependant on direction of travel) along this 0.86-mile corridor. Figure 18 shows a view of northbound SR-1403 along the corridor analyzed during our effort.

Figure 18. Northbound SR-1403

US-401 Business is posted as a 55 mph site with a positive barrier median treatment. It was originally part of the loop around Fayetteville's central business district. It has no access points, only interchanges. Although the US-401 Business loop appears to be a freeway, it is not classified as such due to the close spacing between interchanges. The median barrier, shown in Figure 19, is likely used for one of two reasons. The first possibility deals with safety concerns involving opposing directions of traffic being so close due to the limited right-of-way width. This, in turn, was likely due to historical property in the area which had to be avoided during the design. The second possibility was that there are bridge columns in the median in the corridor which likely provoked safety concerns.

Figure 19. Southbound US-401 Business

Curb and gutter is used in combination with a guardrail along a large portion of the route because of the large drop-off (believed to be greater than 3:1) on the roadside adjacent to the shoulder. The large outside shoulder along the corridor is the result of the old expressway design. The speed limit has only changed one time for a very short period, and was soon reinstated to 55 mph.

Division 6 does not typically advise posting speeds above 45 mph when using curb and gutter. In reviewing sites, the Division could only identify a very limited sample of sites signed greater than 45 mph with curb and gutter which had been there for an extended period of time. No one recalled how the speeds were set at these sites.

Division 7

The studied section of US-70 in Guilford County is posted at 45 mph and has a grass median. It contains minor retail and commercial development and housing developments; however, it transitions from rural to suburban and urban frequently. There are six to twelve access points (dependant on direction of travel) along this 0.84-mile stretch. The US-70 corridor used to serve as a primary east-west connecting route prior to the construction of Interstate 40. Figure 20 shows a view of the westbound approach for US-70 along the corridor analyzed during our effort.

Figure 20. Eastbound US-70

SR-1541 is also a site posted at 45 mph with a grass median. This site was originally a two-lane facility west of Interstate 40. Retail and commercial development are extensive along the extended corridor. Curb and gutter was used as a “channelization device” in some cases along this corridor. At the specific site we analyzed, limited development and driveways were present along the right of way. Figure 21 shows a view of the northbound approach for SR-1541 along the corridor analyzed during our effort. Note that there is no curb on the median side of the roadway.

Figure 21. Northbound SR-1541

US-29 is a site posted at 55 mph with a positive barrier plus fence as a median treatment. This facility was completed in the late 1940’s to early 1950’s. Large mixes of development types are located along this corridor. The specific site we analyzed contained nineteen access points in each direction of travel along the 2.2-mile corridor analyzed. Curb and gutter was primarily used to minimize impacts because a shoulder was not possible with the width of the roadway being so large. Although the corridor appears to have three primary travel lanes along the northbound direction, the outermost lane is an auxiliary lane used between the on and off ramps for safety purposes. The barrier came about because of issues with cross over collisions due to the narrow width of the median in this section in the late 1980's. The fence was added as a deterrent to pedestrians trying to cross the road instead of using the pedestrian bridge. Figure 22 shows a view of northbound US-29 along the corridor analyzed during our effort.

Figure 22. Northbound US-29 in Division 7

Division 7 respondents noted that they typically follow AASHTO policy when setting curb and gutter, particularly on higher speed corridors. However, when issues such as environmental constraints, right of way constraints, or access come into play, they could decide to create the least possible amount of impact to the area. In addition, Division 7 personnel state that they often use speed studies and knowledge of the roadway in setting speeds.

Division 10 and Charlotte Department of Transportation

NC-49 is a facility posted at 45 mph along the study site with curb present along the median and the roadside. Segment characteristics have not changed in approximately 22 years with the exception of increased traffic volume. This section is primarily residential with six to seven driveways (dependant upon direction of travel) abutting the roadway. Figure 23 shows a view of southbound NC-49 along the corridor analyzed during our effort.

Figure 23. Southbound NC-49

NC-16 is a site posted at 45 mph which was widened approximately five years ago. Curb and gutter now runs from Interstate 485 on the edge of the metropolitan area into downtown Charlotte. The posted speed has not changed in at least fifteen years. The 1.2-mile stretch studied in our analysis contains limited access points. Figure 24 shows a view of northbound NC-16 along the corridor analyzed during our effort.

Figure 24. Northbound NC-16

NC-51 is a 45 mph site, built by the Charlotte Department of Transportation (CDOT), with curb as the median and roadside treatment. The speed limit was lowered to 45 mph when the City of Charlotte annexed the area. A large high school which opened its doors approximately eight to ten year ago fronts this section (Providence High School). This corridor primarily contains residential development with little access along the 0.92-mile stretch we studied. Figure 25 shows a view of eastbound NC-51 along the corridor analyzed during our effort.

Figure 25. Eastbound NC-51

US-29, located in Division 10, is posted at 55 mph with curb as the median treatment. This roadway is located in a primarily rural area with very few access points on either side of the road. Speeds remain posted at 55 mph from I-485 to the Gaston County line. Figure 26 shows a view of westbound US-29 along the corridor analyzed during our effort.

Figure 26. Westbound US-29 in Division 10

NC-24/27 in Division 10 is a diverse corridor. Four varying sections were used in our field analysis (presented later) and case studies. The first section is posted at 45 mph and has a grass median. It is located primarily in a suburban area with approximately eight to nine access points (dependant on direction of travel) along a 1.6-mile stretch. These factors were the primary reason the speed was posted at 45 mph. Figure 27 shows a view of westbound NC-24/27 in this suburban area analyzed during our effort.

Figure 27. Westbound suburban NC 24-27

The second section of NC 24/27 we analyzed is posted at 55 mph and has a two-way left turn lane. This site is located in a predominantly rural area with approximately fourteen access points along a three-mile stretch of the corridor. Although recently annexed by the Town of Midland, it is still rural in appearance to motorists. The posted speed was recommended to be 55 mph based on these factors. Figure 28 shows a view of westbound NC 24/27 corridor analyzed during our effort.

Figure 28. Westbound NC rural 24-27

The third section of NC 24/27 we analyzed is also posted at 55 mph and has a grass median. This site is located in a primarily rural area with very little development fronting the roadway. Approximately five access points are located along this corridor in each direction for 1.9 miles. There are no curbs on the median side of the roadway. Figure 29 shows a view of westbound NC-24/27 in the rural, 1.9-mile NC 24/27 corridor we analyzed.

Figure 29. Westbound NC 24-27 (1.9-mile rural corridor)

The final section of NC 24/27 we analyzed has a 55 mph posted speed with a grass median. Again, there are no curbs on the median side of the roadway. This site is located in a very rural area with little-to-no development fronting the roadway along the 0.7-mile corridor. Speeds were recommended to be set at 55 mph based on the fact that there were no predominant factors warranting a lower posted speed. Figure 30 shows a view of westbound NC-24/27 in the rural, 0.7-mile corridor analyzed during our effort.

Figure 30. Westbound NC 24-27 (0.7-mile rural corridor)

Division 10 and CDOT respondents noted that they typically follow AASHTO policy when setting curb and gutter, particularly on higher speed corridors. However, experience has led to some corridors being placed at posted speeds of 55 mph with the use of curb and gutter. They noted that, "Many possible factors play into the posting of higher speeds on these types of corridors such as roadway characteristics (shoulder, grade, alignment, and sight distance), pace speed, roadside development and environment, parking and pedestrian activity, and reported crash experience." They also noted that, "Often state system roads inside corporate city limits require a joint agreement between city and state. If we cannot agree, then it becomes a statutory limit of 35 mph. Therefore, often we [state officials] may advise a 55 mph posted speed limit but town officials don't agree, and a compromise of 45 mph is used."

3.4 Summary

NCDOT's basic guidelines for typical utilization of curb and gutter were summarized to help understand current policy. Four basic curb and gutter combinations are used in North Carolina: 2'-6" and 1'-6" curb and gutter (primarily for roads posted ≤ 45 mph), expressway gutter (primarily for roads posted > 45 mph), and 8" by 12" or 18" curb (primarily for channelization and right-of-way protection). Of these four, the most commonly used are the 2'-6" and 1'-6" curb and gutter along the outer pavement and median, respectively.

Designing roadways using curb and gutter has become challenging in instances where roadways warrant posted speeds in excess of 45 mph. Preliminary designs are often revisited following public hearings and readjustments are made. Use of curb and gutter often negates or lessens many of the problems brought up during these hearings. However, speeds along many of the corridors have to be decreased when using curb and gutter because AASHTO guidelines indicate that there may be additional collision risk. Thus roads that in all other respects would typically be posted at 55 mph are decreased to 45 mph, sometimes adding to public outrage.

AASHTO guidelines on the use of curb and gutter along corridors with posted speeds greater than 45 mph are vague. There is no clear guidance on what conditions could potentially warrant curb and gutter installations along higher speed corridors. Case studies were conducted in attempt to understand the conditions under which curb and gutter was used along high speed roadways with 55 mph posted speeds in North Carolina, as well as to look at the characteristics of more typical cross-sections along 45 mph posted corridors. The feedback from field personnel we received seemed to indicate various features that are associated with the use of curb and gutter along high speed roadways posted at 55 mph in North Carolina. Two of the more prominent aspects of these roadways are very low access point densities and extreme right-of-way restrictions. These observations could be helpful in conjunction with the findings of the speed and collision analyses presented later in this report.

4. METHODOLOGY

To achieve the objectives of this project the team conducted several tasks. The main efforts in this research were to find a sample of higher-speed roads with 2'-6" curbs and examine the collision records and vehicle speed distributions on those roads. In this chapter, the methodology for identifying study segments, field data collection, and acquiring collision data is described in detail.

4.1 Site Selection

The study team set several criteria for study site selection to meet the purpose of this research. Study sites for this project had to have the following characteristics to be selected:

1. *Contain curbs*. In view of purpose of this project, the project team searched for sites containing 2'-6" curbs next to the outside lanes of each direction throughout the segments.
2. *Four-lane roads located in developing fringe areas*. The problem which motivated the project is typically an interim difficulty for a few years after widening an old two-lane road into four-lane road mostly in fringe areas between more settled urban area and rural areas. From this point of view, the research focused specifically on four-lane roads in fringe areas.
3. *45 mph and 55 mph posted speed limit*. According to the purpose and the scope of this project, the team tried to find samples of roads with 45 mph and 55 mph posted speed limits.

4. *TWLTL and non-traversable median type*. For the research purpose, the team tried to select half of the sample with two-way left turn lanes and half with non-traversable medians. These two types of median are most common in four-lane roads with curb cross-sections in North Carolina.
5. *At least 0.5-mile in length containing no signals or signal approaches*. The project team intended to investigate the speed distributions and the characteristics of curb-involved collisions of the study sites. The team selected sites that were at least one-half mile in length containing no signals or signal approaches within the segments to eliminate important confounding factors that could affect speed distribution and collisions.
6. *No major changes to cross section in last three years*. From the viewpoint of a safety study which needs three years of collision data, the team chose the study sites with no major changes to cross section during the three years from 2001 to 2003.

A total of 60 sites, consisting of four groups distinguished by posted speed limits and median types as shown in Table 5, were desired for this study.

Table 5. Desired Number of Study Sites

		Median type		Total
		Non-traversable	TWLTL	
Speed limit	45 mph	15	15	30
	55 mph	15	15	30
Total		30	30	60

Based on these criteria, an initial list of over 200 potential sites was created (see Appendix A). Some of these potential sites were identified in e-mails from NCDOT engineers while most were identified from our analysis of a comprehensive NCDOT database of 4-lane and 5-lane roads. The potential site list included sites from about 50 counties, covering all terrain types, as shown in Figure 31.

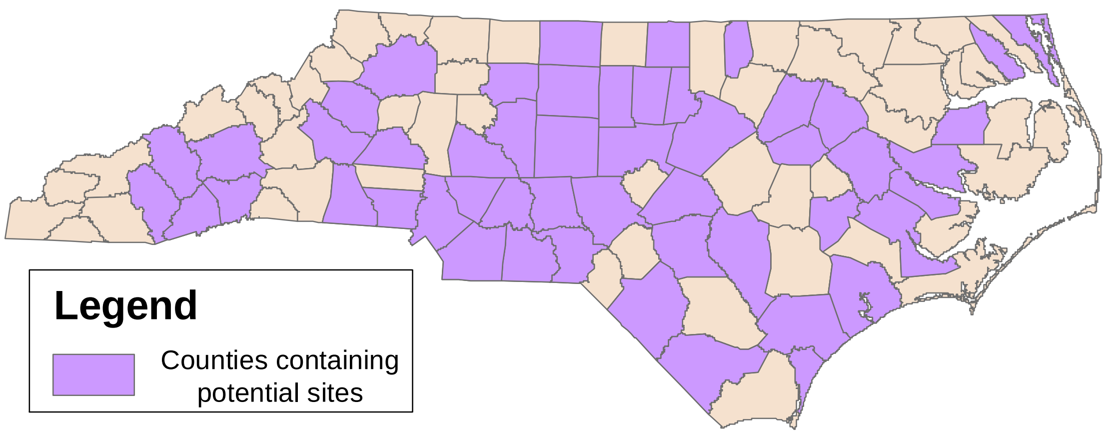


Figure 31. Map of Potential Sites

Next, the team selected initial candidate 60 sites from the list of potential sites. It was important that there was randomness in this site selection process, so that the final results may be fairly generalized to the entire list of over 200 potential sites and other similar sites. We started site selection by placing each of the 200+ potential sites into one of the four categories shown in Table 5. Then, we chose, at random, 15 sites from the 55 mph non-traversable category and 15 sites from the 55 mph TWLTL category. Next, we deliberately (not randomly) chose 45 mph sites that were near to the chosen 55 mph sites, being careful to end up with 15 of those that had non-traversable medians and 15 that had TWLTLs. Choosing 45 mph sites deliberately near the 55 mph sites allowed us to save travel time during data collection and ensured some similarity in terrain, driver demographics, etc. between the 45 mph and 55 mph sites.

The team next tried to identify sufficient back-up sites to replace initial sites that did not pan out due to errors in the database, recent construction, newly-installed signals, etc. Back-up sites were chosen randomly from the list of sites not chosen originally. The team, however, couldn't find sufficient potential sites for the group with 55 mph posted speed limit and non-traversable median type for which only two back-up sites could be identified statewide.

In the end, the team visited 74 sites including 14 sites from the back-up list. The team collected speed and site data from 51 sites from 17 counties that were evenly distributed across the state as shown in Figure 32. Table 6 shows the number of sites the team visited and measured by speed limit and median type.

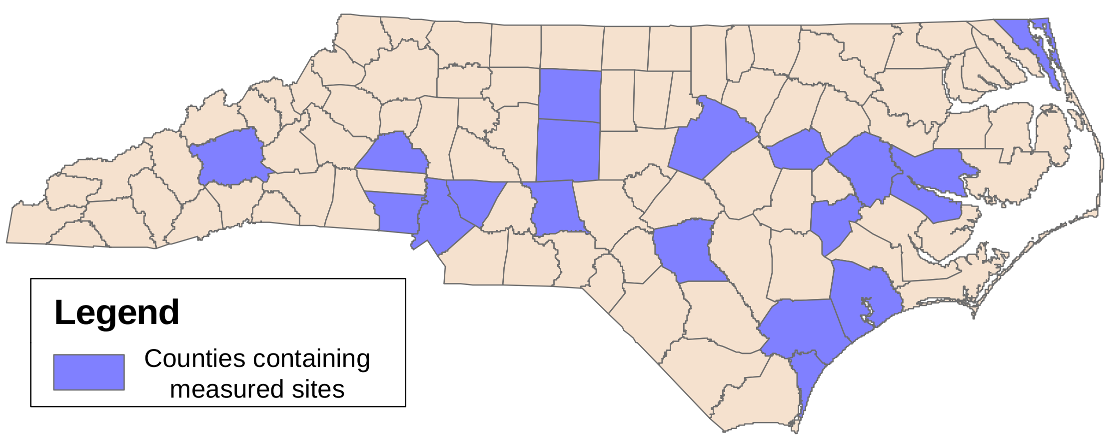


Figure 32. Map of Measured Sites

Table 6. Number of Sites Measured and Visited (measured/visited)

Speed Limit \ Median Type	Non-traversable	TWLTL	Total
45 mph	15/21	15/17	30/38
55 mph	6/17	15/19	21/36
Total	21/38	30/36	51/74

As expected, the team found that some (23) of the sites visited were not suitable for this study. The main reason for not collecting data at such sites was that the sites did not have one or more of the key characteristics mentioned earlier, i.e. 2'-6" curbs, at least 0.5 miles without any signal, four lanes, posted speed limits of 45 or 55 mph, and appropriate median type. The team also did not collect data at a site that had an adjacent study site.

Table 7 shows the list of 51 sites studied in this research. All study sites had curbs, of course, and other required characteristics mentioned earlier. As shown in Table 7, the team found 15 sites suitable for this study in each group except the group of 55 mph speed limit and non-traversable median type for which the team, in the end, only found six sites. Even some of the six studied sites had problems, such as the site in Guilford County listed in Table 7 that has a concrete safety-shape median barrier. Several Technical Committee members suggested potential sites for this category but these turned out to be too short or were places where the speed limit had been changed. We do not believe any other qualifying sites in this category exist in North Carolina.

Table 7. The List of 51 Sites Studied

Site No.	County Name	Road Name	Speed Limit (mph)	Median Type	Segment Length (mile)
35	Gaston	SR 1255 (Hudson Blvd.)	45	Non-traversable	1.21
15	Guilford	US-70 (E Wendover)	45	Non-traversable	0.84
16	Guilford	SR-1541	45	Non-traversable	0.89
40	Mecklenburg	NC-16 (Providence Rd.)	45	Non-traversable	1.21
42	Mecklenburg	NC-49 (S Tryon St.)	45	Non-traversable	0.71
44	Mecklenburg	NC-51 (Pineville Matthews)	45	Non-traversable	0.92
49	Mecklenburg	NC 24/27	45	Non-traversable	1.60
51	Mecklenburg	NC-24 (Harris Blvd.)	45	Non-traversable	1.51
1	Wake	Millbrook Rd.	45	Non-traversable	0.48
2	Wake	NC 50 (Creedmoor Rd.)	45	Non-traversable	0.65
65	Wake	Cary Parkway	45	Non-traversable	1.10
66	Wake	Harrison Ave. (SR 1652)	45	Non-traversable	0.60
67	Wake	Edwards Mill Rd.	45	Non-traversable	0.70
68	Wake	NC 54 (Maynard Rd.)	45	Non-traversable	0.50
74	Wake	SR-2812 (Timber Dr.)	45	Non-traversable	0.55
22	Beaufort	US 264 (John Small Ave.)	45	TWLTL	0.71
58	Buncombe	NC-63	45	TWLTL	0.50
59	Buncombe	NC-63 (New Leicester Hwy.)	45	TWLTL	0.90
61	Catawba	SR 1213 (2nd st sw)	45	TWLTL	1.30
62	Catawba	NC-127	45	TWLTL	0.62
9	Cumberland	NC-53 (NC-210)	45	TWLTL	0.84
10	Cumberland	SR-1403 (Reilly)	45	TWLTL	1.07
32	Currituck	US-158	45	TWLTL	1.30
12	Lenoir	NC-11/NC-55	45	TWLTL	1.82
30	New Hanover	US-421	45	TWLTL	0.70
24	Onslow	US-258	45	TWLTL	1.05
25	Onslow	SR-1308 (Gum Branch Rd.)	45	TWLTL	1.00
28	Pender	US-17	45	TWLTL	1.10
20	Randolph	US-64	45	TWLTL	0.69
70	Wake	Kildaire Farm Rd. (SR 1300)	45	TWLTL	1.00
7	Cumberland	us-401 bus.(Martin Luther King)	55	Non-traversable	0.86
13	Guilford	US-29 (Ohenry)	55	Non-traversable	2.20
48	Mecklenburg	US-29 (US-74)	55	Non-traversable	0.76
50	Mecklenburg	NC 24/27	55	Non-traversable	1.90
64	Mecklenburg	NC 24/27	55	Non-traversable	0.70
3	Wilson	NC 42	55	Non-traversable	2.48

Table 7. The List of 51 Sites Studied (continued)

Site No.	County Name	Road Name	Speed Limit (mph)	Median Type	Segment Length (mile)
21	Beaufort	US-264	55	TWLTL	0.35
55	Buncombe	US 70	55	TWLTL	1.10
56	Buncombe	US 70	55	TWLTL	1.60
57	Buncombe	US 70	55	TWLTL	1.80
60	Buncombe	NC-280 (Airport Rd.)	55	TWLTL	0.40
73	Cabarrus	NC 24/27	55	TWLTL	3.00
6	Cumberland	US-401	55	TWLTL	1.11
37	Gaston	NC 150 (Lincolnton Hwy.)	55	TWLTL	0.90
11	Lenoir	NC-11/NC-55	55	TWLTL	1.46
72	Montgomery	NC 24/27	55	TWLTL	0.60
29	New Hanover	US-17 (Market St.)	55	TWLTL	1.60
23	Onslow	US-258	55	TWLTL	2.07
63	Onslow	NC-24 (US 258)	55	TWLTL	1.35
27	Pender	US-17	55	TWLTL	0.70
19	Randolph	US-64	55	TWLTL	0.98

4.2 Data Needs

For the study, various types of information on each road segment were needed. These included field data such as speed and geometric data and other data from NCDOT databases like volume and collision data.

4.2.1 Field Data

Speed Data

The team began by estimating the minimum number of speed observations per direction per site for a statistical analysis of the study results. The minimum required sample size was calculated for a desired degree of statistical accuracy by using Equation 1 (*Robertson et al., 1994*):

$$N = \frac{S^2 K^2 (2 + U^2)}{2E^2} \quad \text{(Equation 1)}$$

where,

N = minimum number of measured speeds

S = estimated sample standard deviation, mph

K = constant corresponding to the desired confidence level

E = permitted error in the average speed estimate, mph

U = constant corresponding to the desired percentile speed

Using Equation 1, the determined minimum number of speed observations per direction per site assuming 5.3 mph for estimated sample standard deviation for intermediate traffic area, 1.96 constant for 95 % confidence level, 1 mph for permitted error in the average speed estimate, and 1.64 as the constant for the 5th or 95th percentile speed, was 255 observations. Note that these are very conservative assumptions and should provide a sample size capable of a thorough analysis. Based on this calculation, our goal was to measure the speeds of at least 300 vehicles per direction per road segment during non peak times of week days.

Geometric Data

Data on the following physical characteristics per direction per segment were collected:

- Road names for the study segments and all side streets within the segments
- Curb type (outside and median side, if any)
- Median type
- Posted speed limit

- Lane width
- Shoulder width, if any
- Segment length
- Number of access points

Some road sections have one or more coinciding road names and in this case, collision reports can refer to different road names for the same road sections. Therefore, it was very important to find all of those coinciding road names so that we did not miss any of those collision reports.

The number of access points was used to calculate access point density which provides a gross measure of the relative amount of conflict opportunities caused by entering and exiting vehicles. Active unsignalized intersections and driveways larger than for a single-family residential house were included in counting the number of access points.

4.2.2 Data from NCDOT Databases

Volume Data

Annual average daily traffic (AADT) data of each road segment for the three years from 2001 to 2003 were collected from NCDOT. An average of the three year's AADTs was used in calculating collision rates. In case that there is no appropriate AADT data for a study segment, it was assumed that the AADT data for the nearest point was the same as that of the study segment.

Collision Data

Collision data for each road segment for the time period from January 1, 2001 to December 31, 2003 were pulled from NCDOT's database using the Traffic Engineering Accident Analysis System (TEAAS). Section 4.4 describes the processing of these data in detail.

4.3 Field Data Collection

The purpose of the field data collection was to obtain information regarding vehicle speed distributions and geometric characteristics of the study sites. The field data collection was conducted from February through July in 2004.

4.3.1 Equipment for Data Collection

Laser Speed Gun

The project team used a laser speed gun for the speed study to reduce the possibility that the results were biased by radar detectors. This bias occurs when drivers of radar-detector equipped vehicles change their speeds when they perceive microwaves from a radar speed gun. The team bought and used two SpeedLaser® model laser speed guns as shown in Figure 33.

Figure 33. The SpeedLaser® Model of Laser Speed Gun (Source: http://www.laseratlanta.com)

Referring to the specifications presented by the manufacturer, the accuracy of speed measured by this laser speed gun is +/- 1 mph, and the speed range is approximately 4,000 feet.

The laser speed guns use a PCMCIA SRAM Type 2 memory card to capture speed and distance readings from the speed gun by saving the readings to a data file simultaneously with speed measurement. The capability of creating electronic data files greatly facilitated analysis of the speed observations and eliminated possible manual data coding errors.

GPS Locator

The team used a GPS receiver to record accurate field study location information. The team recorded the coordinates of the spots where the laser gun was positioned. The positioned coordinates were measured using the eTrex® model GPS receiver as shown in Figure 34.

Figure 34. The eTrex® Model of GPS Receiver (Source: http://www.garmin.com)

One of the purposes of recording the coordinates using a GPS receiver was to help the team to find the exact spot where the speed gun was set in case that the team needed to revisit the spot for any reason.

Digital Camera

The team used a digital camera to take pictures of the sites. Back in the office, it was very helpful to see the images taken from the sites to get missing information or confirm doubtful information.

A digital camera was more convenient than a film camera in view of time and cost. Furthermore, using a digital camera made it possible to see photos immediately, erase unnecessary photos, and import the images to a computer easily.

Other Equipment

The team brought a laptop computer to the field to read, check, and backup the data captured in the memory card from the speed gun. This also saved time and eliminated errors.

A tripod was used for stability whether the speed gun was positioned in the vehicle or on the ground to reduce the possibility of an error in speed measurement caused by instability of human hands. Even though there is little possibility of measurement error with the laser gun, it is not easy to hold the speed gun throughout the field study because a field speed measurement took the team member an hour or two to conduct per direction per site.

4.3.2 Field Studies

At the beginning of the field data collection task, the team drafted a data collection protocol. The team then field tested the data collection procedure and developed the data collection form shown in Figure 35. From this pilot study the team learned how to use the laser speed gun and the memory card and gained experience about appropriate measuring distance from the gun to a target vehicle.

INVESTIGATION OF SPEED DISTRIBUTION ON CURBED HIGHWAYS

Investigator: Date: / / '04 Site #:

County:		Road name:			Direction	N / S / E / W
Location:			Speed limit:	mph	Total lane:	4
Curb type:		Median type:		Lane width:	Inner:	Outer:
Shoulder width:		Other special circumstances:				
Sketch of site:						Indicate north
Method of hiding speed gun:						
Time of Speed Measurements:	Data file #					
	Start	: am/pm	: am/pm	: am/pm		
	End	: am/pm	: am/pm	: am/pm		
Level of platooning:	L / M / H	If high, average platoon size	Veh			
Note:						

Figure 35. Site Data Collection Sheet

After refining the data collecting method, each of the study segments was visited. The field speed studies were conducted by one observer for three to four hours per site on average, depending on the traffic volume of each site. The team conducted the field speed measurements during non-peak hours, usually between 9:00 AM and 4:00 PM from Monday to Thursday. All studies were conducted in dry weather conditions except the westbound direction of the segment on NC 24/27 (site no. 50) where the road was negligibly wet after a couple minutes of very light rain.

Site Verification

Upon arriving at the sites, the observer verified that the site was suitable for this study by confirming that the site had the following required characteristics as mentioned earlier:

- 2'-6" curbs on the right side of each direction of the segment
- Posted speed limit of 45 mph or 55 mph
- Median type of TWLTL or non-traversable
- 4 lanes for through traffic
- 0.5 miles in minimum length of the segment without signals and major changes to the cross section

Positioning the Speed Gun

Once the segment was verified, the observer had to set the speed gun for the speed study. One key to unbiased data collection was to choose laser gun positions where the speed gun and its user were mostly hidden from the view of the passing vehicles being studied. For this reason, the team usually hid the speed gun by setting it in the rear of a minivan (as shown in Figure 36) or beside a station wagon which was also hidden from the view of the passing vehicles using trees or a curve as shown in Figure 37.

Figure 36. The speed gun hidden in a minivan

Figure 37. The vehicle and speed gun hidden in a bay

Furthermore, the observer measured the speeds of vehicles from the back of those vehicles moving away from the speed gun to hide the speed gun from the view of the passing vehicles. This reduced the chance that the speeds of the passing vehicles being measured were biased by the drivers adjusting their speeds as they recognized the speed gun.

Measurement of the Speeds

The observer tested the speed gun to check whether the gun operated properly before the start of a speed study by using a built-in auto checking program for functions, power, memory, etc. and by measuring a known short distance such as the depth of a small box.

The team tried to measure free flow speeds. For this, the team measured the speeds of the first vehicle of a platoon and did not measure the speeds of vehicles that slowed down to make turns into driveways. Moreover, the team made sure not to measure the speeds of vehicles that approached the ends of the segment (i.e., got too close to a signal). In case two vehicles arrived at the same time, though this happened infrequently, the team measured the speed of the outside (closest to the shoulder) vehicle.

To reduce possible error in the results caused by difference in measuring distance, the team tried to measure the speeds of the vehicles when the vehicles were in a certain range of distance (from 200 feet to 1,000 feet approximately) from the speed gun even though the speed range of the gun is about 4,000 feet as mentioned earlier.

It took the team about an hour on average to measure about 300 speeds per direction per site depending on the traffic volume. The data files were transferred from the memory card to the laptop computer immediately after each directional sample for the purpose of data backup and checking. The names of data files for each measurement were written down on the data collection sheet shown in Figure 35.

Collection of Physical Data

After the speed measurements the observer collected data on the physical characteristics of each segment by each direction. The data collection form shown in Figure 35 was used to record all the necessary information regarding each segment such as the road names, location, speed limit, number of lanes, curb and median type, lane width, etc. The observer wrote down other special circumstances like guardrail, horizontal curves, lower heights of some curbs caused by repavement, etc.

The observers attempted to sketch each site to confirm information regarding the sites including:

- the approximate alignment of the segment,
- the names of all side streets and driveways in the segment,
- the number of all access points including all active unsignalized intersections, and driveways larger than for a single-family residential house,
- the location of the speed gun expressed by the coordinates from the GPS locator and the distance from one of the two ends of the segment,
- the location of the objects on which the observer took pictures, and
- important traffic attractors like shopping malls, public parks, gas stations, churches, etc.

The number of access points along each segment was determined using several sources. Table 8 shows the sources of these data. The count of access points was started according to the technical advice from the committee meeting that was held after field studies for some study sites (about 1/3 of the total) were completed. For the sites where the team measured speeds before the committee meeting, NCDOT Division personnel assisted with the counts. The team also used orthographic photos (aerial photos) from several sources as shown in Table 8 to complete the counts.

Table 8. The Methods and Sources for Access Point Counting

County	# of sites	Method	Source	Year
Cabarrus	1	Orthographic photo	Cabarrus County GIS [1]	2001
Currituck	1	Orthographic photo	NCOneMap [2]	2003
Gaston	2	Orthographic photo	Gaston County GIS [3]	2000
Mecklenburg	8	Orthographic photo	Mecklenburg County GIS [4]	2002
Montgomery	1	Orthographic photo	NCSU Libraries' Geodata Server [5]	2002
Randolph	2	Orthographic photo	NCSU Libraries' Geodata Server [6]	2004
Beaufort	2	Counted at the site	NCDOT Divisions personnel	2004
Buncombe	6	Counted at the site	NCDOT Divisions personnel	2004
Catawba	2	Counted at the site	NCDOT Divisions personnel	2004
Lenoir	2	Counted at the site	NCDOT Divisions personnel	2004
New Hanover	2	Counted at the site	NCDOT Divisions personnel	2004
Cumberland	4	Counted at the site	Researcher	2004
Guilford	3	Counted at the site	Researcher	2004
Onslow	4	Counted at the site	Researcher	2004
Pender	2	Counted at the site	Researcher	2004
Wake	8	Counted at the site	Researcher	2004
Wilson	1	Counted at the site	Researcher	2004
Total	51			

1. http://166.82.128.222/gis.html
2. http://www.nconemap.net/
3. http://public_gis.co.gaston.nc.us/website/ParcelDataSite/WelcomePage.html
4. http://maps2.co.mecklenburg.nc.us/website/realestate/viewer.htm
5. http://www.lib.ncsu.edu:2824/TEMP/local/montgom/sids400/
6. http://www.lib.ncsu.edu:2824/TEMP/randolph/new_orthos/

Finally, the observer took several digital photos of each direction of the study sites to record visually the circumstances of the sites and the appearance of the curbs. Figure 38 through 41 show example photos taken in the field for the four categories of speed limits and median types.

Figure 38. A site with a 45 mph speed limit and TWLTL median (NC-53 and NC-210 in Cumberland County)

Figure 39. A site with a 45 mph speed limit and grass median (NC-51 in Mecklenburg County)

Figure 40. A site with a 55 mph speed limit and TWLTL median (US-258 and NC-24 in Onslow County)

Figure 41. A site with a 55 mph speed limit and grass median (NC 24 and NC-27 in Mecklenburg County)

4.4 Collision Data Acquisition

Collision data for this project were collected from the NCDOT database of police-reported collisions. Figure 42 shows the procedure for collecting the collision data.

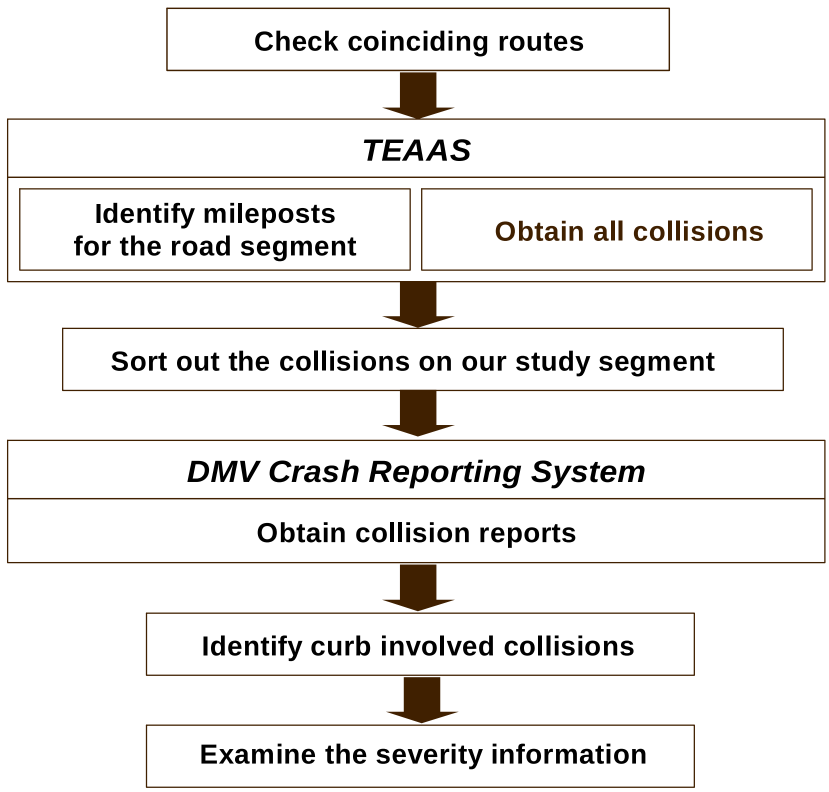


Figure 42. The procedure for collecting collision data

4.4.1 Time Period of the Collision Data

The project team collected collision data for the three years from January 1, 2001 to December 31, 2003 except four sites as shown in Table 9. This was the most recent period available using the database at the beginning of the collision data collection effort. A three-year period was selected to best avoid the effects of development and geometry changes on the data while providing a reliable amount of collision data.

Table 9. Sites for Which Three Years of Collision Data Was Not Collected

Site No.	County Name	Road Name	Years of the Data Collected	Reason of Not Collecting 3 Years of Data
61	Catawba	SR 1213 (2nd St. SW)	2002 - 2003	Change in cross section in 2001
3	Wilson	NC 42	2003	Change in cross section in 2002
66	Wake	Harrison Ave. (SR 1652)	N/A	Change in cross section in 2003
67	Wake	Edwards Mill Rd.	N/A	Opened in Nov. 2002/ Database was not ready

The team looked for changes to the roadway cross sections during the three-year study period when the team looked at each individual collision report. At the time of collision data acquisition, no relevant collision data were available for Sites 66 or 67 due to recent construction projects.

4.4.2 Collection of Collision Data

In the following sections the procedure for collecting collision data (summarized in Figure 42) is described in detail.

Check for Coinciding Routes

As mentioned earlier, some road sections have one or more coinciding routes. A coinciding route is a named route that follows along the same section of roadway as another named route. Moreover, many routes are named by both a route number and a local city street name. For example, the road segment for site no. 49 has three coinciding names: NC 24, NC 27, and Albemarle Road. Therefore, collision reports can refer to different coinciding road names for the same road segment.

The team made an effort, therefore, to identify all coinciding road names for each study segment in order to avoid missing any valid collision reports. For this task, the team referred to the data collection forms, NCDOT GIS county maps, and the Features Report application of the Traffic Engineering Accident Analysis System (TEAAS) from the Traffic Safety Systems Management Unit (TSSMU) at the NCDOT. The Features Report, as shown in Figure 43, shows all important mileposted features including crossing roads, boundaries, and structures on an entire inventoried mileposted route within a county recorded by milepost and feature ID.

North Carolina Department of Transportation
Traffic Engineering Accident Analysis System
Features Report

County	Inventoried Route ID	Begin Milepost	End Milepost
MECKLENBURG	30000024	0.0	10.520

MP No	FeatureID	Feature Name/Type	Special Type	Distance to Next	Direction to Next	Loop	Beyond Route Limits
0.000	20000074	US 74	At grade intersection, 3 legs	0.000	North and East		
0.000	30000027	NC 27	At grade intersection, 3 legs	0.000	North and East		
0.000	50014098	INDEPENDENCE	At grade intersection, 3 legs	0.280	North and East		
0.280	50023664	PEARSON	At grade intersection, 4 legs	0.170	North and East		
0.450	50012151	[illegible]	At grade intersection, 3 legs	0.080	North and East		
0.530	50008049	DRIFTWOOD	At grade intersection, 3 legs	0.120	North and East		
0.650	50027763	SHARON AMITY	At grade intersection, 4 legs	0.015	North and East		
0.665	50034752	[illegible] GROVE	At grade intersection, 3 legs	0.025	North and East		
0.690	50029075	[illegible]	At grade intersection, 3 legs	0.080	North and East		
0.770	50012237	GRAFTON	At grade intersection, 3 legs	0.300	North and East		
1.070	50025575	[illegible]	At grade intersection, 4 legs	0.098	North and East		
1.168	50005615	CENTRAL	At grade intersection, 3 legs	0.102	North and East	Y	
1.270	50005615	CENTRAL	At grade intersection, 3 legs	0.080	North and East	Y	
1.350	50033183	WILORA LAKE	At grade intersection, 3 legs	0.060	North and East		
1.410	40002959	SR 2959	At grade intersection, 3 legs	0.000	North and East		
1.410	50010025	EXECUTIVE CENTRE	At grade intersection, 3 legs	0.000	North and East		
1.410	50015378	[illegible]	At grade intersection, 3 legs	0.180	North and East		
1.590	590009	Structure	Bridge	0.150			
1.740	50010234	PARK ROAD	At grade intersection, 4 legs	0.320	North and East		

Figure 43. Sample Features Report (part)

Collection of Collision Data

First, the team procured summary data for all reported collisions on a particular route from 2001 to 2003 using the Fiche Report application in the TEASS. The Fiche Report extracts all collisions on a given route within the county specified. At this time, the team needed to input all coinciding road names found in the former task into the Fiche Report application to insure all collisions were returned. A report from the Fiche Report application contained a list of all collisions that occurred on a route within a county during the specified time period, including summary data such as milepost, crash ID number, date, and type of crash.

The team could have used the Strip Analysis (Report) application in the TEASS to extract collisions that occurred within a defined mileposted segment along a strip of roadway. The team, however, would have had to evaluate this report to check if there are any collisions that needed to be added or deleted. For this, the team would also need to generate a Fiche Report. Therefore, in view of time, the team decided to use only the Fiche Report.

Next, the team identified the mileposts of the both ends of the 51 study segment using the data written in the data collection form and the Features Report of the TEASS. Using these mileposts for a study segment, the team sorted out the collisions that occurred in the study segment from the list of all collisions along the entire route. In an effort to remove collisions that may have been affected by a signalized intersection, the team discarded all collisions that occurred within 150 feet of a signalized intersection.

About 15% of collisions in the list of all collisions per site in average were mileposted as “999.999” which means there is no available milepost information for the collisions. In view of time and cost, the team did not look at these collisions individually to verify whether these collisions belonged to the study segment. A major part of these collisions occurred in a public vehicular area (PVA) which is typically a parking lot outside the public right of way.

Currently, the Fiche Report application does not provide any information to denote whether curbs were involved in a collision. Therefore, the team needed to examine individual collision reports to sort out and examine curb-involved collisions. For this, the ID numbers of each collision in a study segment were entered into the NC DMV Crash Reporting System to procure the official individual collision reports in the form of a graphic file.

The team relied on the officer's narrative and the collision diagram for identifying whether collisions were "curb-involved." If the officer's diagram showed that one or more vehicles crossed a curb during the collision or the officer's narrative mentioned the word "curb", the corresponding collision was classified as "curb-involved." Figure 44 shows part of an example collision report showing the diagram and narrative indicating that the collision involved the roadside curb. Table 10 shows a summary of curb-involved collisions by site.

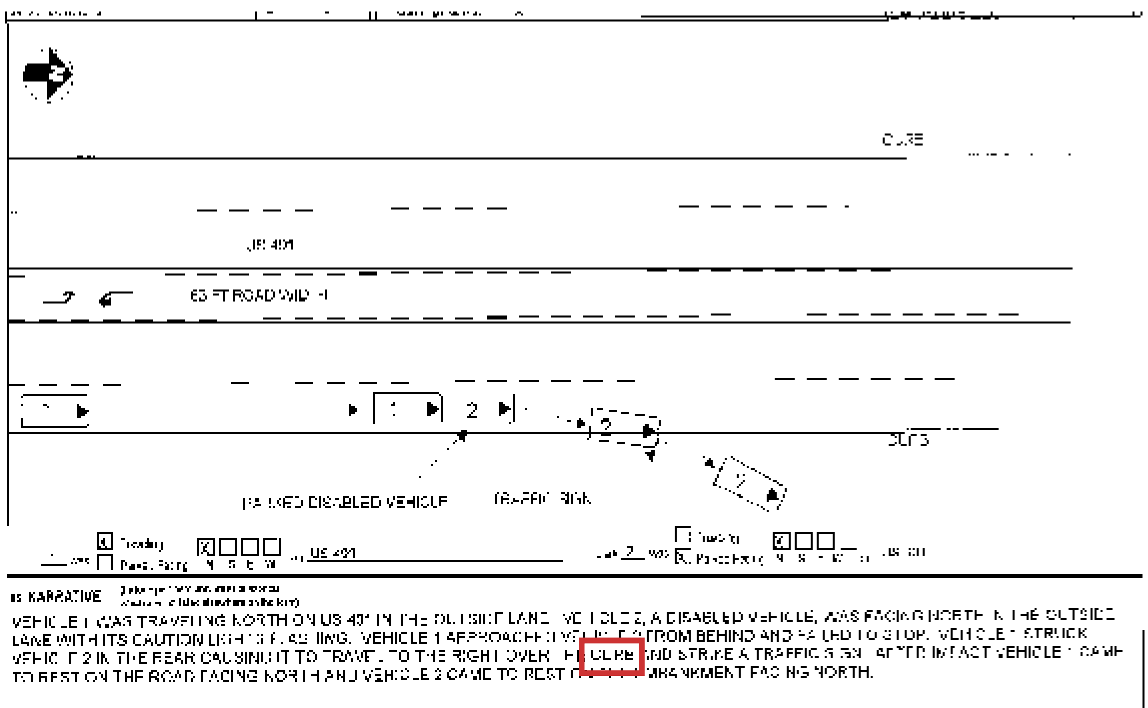


Figure 44. Sample Collision Report with Curb-Involved Collision

Table 10. Summary of Curb-Involved Collisions by Site

Site No.	Total	Curb Involved	Not Involved	% of Curb Involved Coll.
1	11	7	4	63.6
2	14	4	10	28.6
3	5	2	3	40.0
6	26	3	23	11.5
7	5	2	3	40.0
9	0	0	0	N/A
10	68	5	63	7.4
11	16	6	10	37.5
12	30	7	23	23.3
13	173	40	133	23.1
15	21	5	16	23.8
16	13	0	13	0.0
19	26	4	22	15.4
20	11	3	8	27.3
21	2	0	2	0.0
22	46	7	39	15.2

Table 10. Summary of Curb-Involved Collisions by Site (continued)

Site No.	Total	Curb Involved	Not Involved	% of Curb Involved Coll.
23	38	17	21	44.7
24	55	13	42	23.6
25	25	7	18	28.0
27	11	4	7	36.4
28	31	8	23	25.8
29	95	14	81	14.7
30	12	2	10	16.7
32	12	3	9	25.0
35	12	1	11	8.3
37	6	1	5	16.7
40	30	2	28	6.7
42	22	3	19	13.6
44	64	7	57	10.9
48	24	3	21	12.5
49	35	5	30	14.3
50	38	8	30	21.1
51	80	7	73	8.8
55	9	4	5	44.4
56	16	11	5	68.8
57	7	3	4	42.9
58	47	8	39	17.0
59	35	8	27	22.9
60	6	2	4	33.3
61	0	0	0	N/A
62	2	2	0	100.0
63	15	7	8	46.7
64	1	1	0	100.0
65	12	4	8	33.3
66	0	0	0	N/A
67	N/A	N/A	N/A	N/A
68	2	1	1	50.0
70	26	3	23	11.5
72	7	3	4	42.9
73	36	15	21	41.7
74	5	0	5	0.0
SUM	1283	272	1011	21.2

5. SPEED DATA

As mentioned earlier, of the 74 sites visited, 51 sites were found to be appropriate for this research. Detailed site characteristics and speed data were gathered for these sites. Descriptive statistics and analysis results for the speed data are described in this chapter.

5.1 Descriptive Statistics

Using the numbers of access points and segment lengths of each site, the team calculated access point densities for each site. Access point density is the total number of access points of the both sides of the road segment divided by the length of the facility (*Transportation Research Board, 2000*). Table 11 shows the access point densities of the study sites. In Table 11, the threshold value for dividing the access point densities into two categories was 15 access points per mile, which divided the data almost equally. The mean access point density of the 51 study sites was 17.38 access points per mile.

Table 11. Access Point Density of the Study Sites

Site No.	Segment Length (mile)	No. of Access Points (both sides)	Access Point Density (access points/mile)	Category (>15: High, ≤15:Low)
1	0.48	2	4.17	Low
2	0.65	16	24.62	High
3	2.48	14	5.65	Low
6	1.11	5	4.50	Low
7	0.86	0	0.00	Low
9	0.84	9	10.71	Low
10	1.07	26	24.30	High
11	1.46	33	22.60	High
12	1.82	63	34.62	High
13	2.20	38	17.27	High
15	0.84	18	21.43	High
16	0.89	6	6.74	Low

Table 11. Access Point Density of the Study Sites (continued)

Site No.	Segment Length (mile)	No. of Access Points (both sides)	Access Point Density (access points/mile)	Category (>15: High, ≤15:Low)
19	0.98	13	13.27	Low
20	0.69	9	13.04	Low
21	0.35	11	31.43	High
22	0.71	30	42.25	High
23	2.07	38	18.36	High
24	1.05	20	19.05	High
25	1.00	7	7.00	Low
27	0.70	5	7.14	Low
28	1.10	16	14.55	Low
29	1.60	45	28.13	High
30	0.70	46	65.71	High
32	1.30	23	17.69	High
35	1.21	8	6.61	Low
37	0.90	23	25.56	High
40	1.21	13	10.74	Low
42	0.71	13	18.31	High
44	0.92	4	4.35	Low
48	0.76	6	7.89	Low
49	1.60	17	10.63	Low
50	1.90	10	5.26	Low
51	1.51	26	17.22	High
55	1.10	52	47.27	High
56	1.60	31	19.38	High
57	1.80	41	22.78	High
58	0.50	31	62.00	High
59	0.90	32	35.56	High
60	0.40	7	17.50	High
61	1.30	15	11.54	Low
62	0.62	8	12.90	Low
63	1.35	6	4.44	Low
64	0.70	0	0.00	Low
65	1.10	11	10.00	Low
66	0.60	4	6.67	Low
67	0.70	2	2.86	Low
68	0.50	1	2.00	Low
70	1.00	19	19.00	High
72	0.60	21	35.00	High
73	3.00	28	9.33	Low
74	0.55	4	7.27	Low

Table 12 shows descriptive speed statistics for the 51 sites. The average speeds for the 55 mph sites are about 6 to 7 mph higher than those for the 45 mph sites, and the averages for the 55 mph sites are right around the 55 mph speed limit. The variance for the 55 mph sites are about 1 mph higher than that for the 45 mph sites.

Table 12. Descriptive Speed Statistics for the 51 Sites

Statistic	45 mph			55 mph		
	NTM *	TWLTL *	Total	NTM *	TWLTL *	Total
Mean Speed (mph)	49.01	49.47	49.29	56.00	54.88	55.24
Variance (mph)	28.03	32.01	30.14	32.14	30.21	31.09
Standard Deviation (mph)	5.29	5.66	5.49	5.67	5.50	5.58
Median (mph)	49.0	49.4	49.0	56.1	55.2	55.0
Mode (mph)	49.2	49.1	48.0	58.4	54.1	56.0
Kurtosis	1.11	0.60	0.83	0.79	0.88	0.83
Skewness	-0.03	-0.05	-0.03	-0.24	-0.25	-0.24
Sample Size	10,402	10,167	20,569	3,842	10,041	13,883

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

Other key statistics for the study segments include: the average segment length for the study sites was approximately one mile, the minimum and maximum AADTs of the study sites were 3,300 and 57,138 vehicles/day, respectively, and the average AADT of all study sites was 21,200 vehicles/day. Note that these midblock sections were almost all uncongested and free-flowing. Overall, sample sites posted at 55 mph had about 3 fewer access points per mile (average 19) than sites posted at 45 mph (average 16).

The speed distributions for the four groups, shown in Figures 45 through 48, appear to be quite normal. This normality was analyzed quantitatively in the following section.

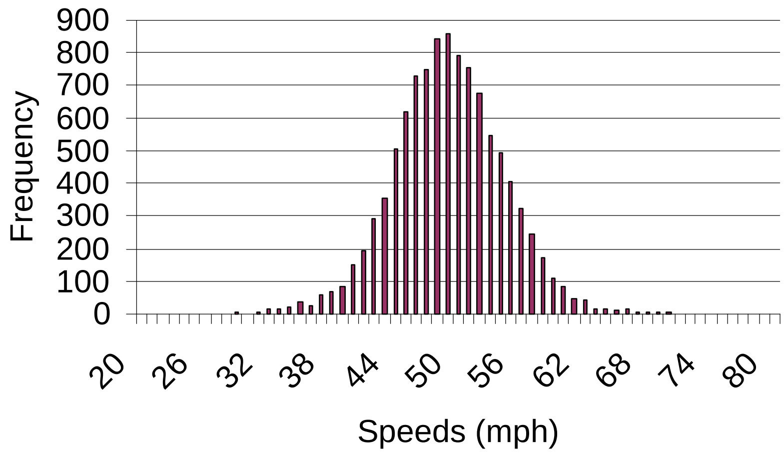


Figure 45. Speed Distribution for the 45 mph Sites with Non-Traversable Medians

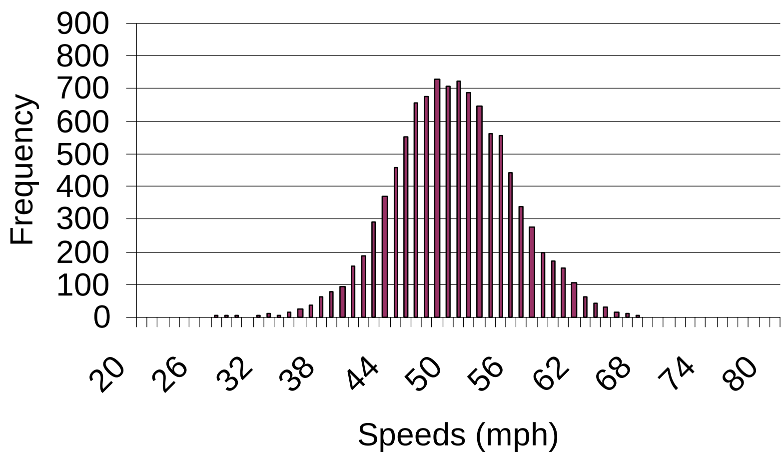


Figure 46. Speed Distribution for the 45 mph Sites with TWLTL

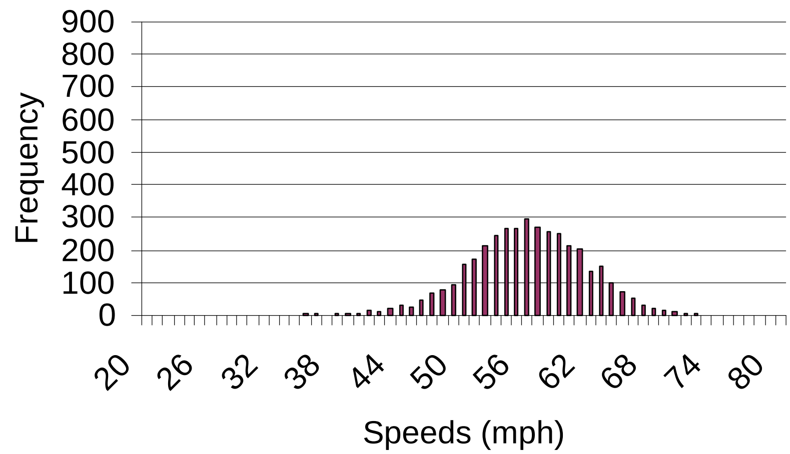


Figure 47. Speed Distribution for the 55 mph Sites with Non-Traversable Medians

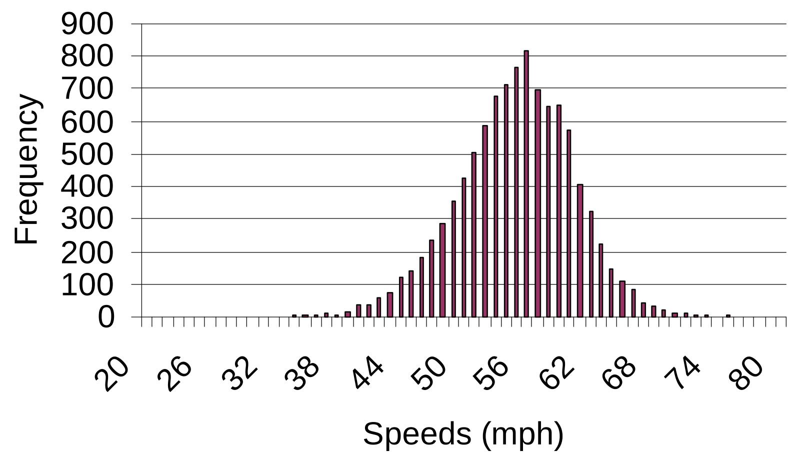


Figure 48. Speed Distribution for the 55 mph Sites with TWLTL

5.2 Analysis and Findings

5.2.1 Tests for Normality

The team performed tests for normality of the speed distributions using the skewness and kurtosis statistics. Skewness is a measure that characterizes the degree of asymmetry of a distribution around its mean (*Zar, 1999*). For data x_1, x_2, …, x_n, skewness is defined as:

$$\frac{n}{(n-1)(n-2)}\sum\left(\frac{x_i-\bar{x}}{s}\right)^3 \qquad \text{(Equation 2)}$$

where,

n = number of data points

x_i = ith data point

$\bar{x}$ = mean of data points

s = sample standard deviation

Negative values for the skewness indicate data that are skewed to the left and have a long tail below the mean (the left tail is heavier than the right tail). Positive skewness values indicate data that are skewed to the right and have a long tail above the mean (the right tail is heavier than the left tail). The skewness for a normal distribution is zero, and symmetric data have skewness near zero.

As shown previously in Table 12, the values of skewness for the four categories were all negative but near zero. The data for the 55 mph sites were relatively skewed to the left more than that of the 45 mph sites. This indicates that the 55 mph sites have a longer tail below the mean than the 45 mph sites.

Kurtosis is a measure that characterizes the relative peakedness or flatness of a distribution compared with a normal distribution. That is, high kurtosis indicates a data set that has a relatively peaked distribution near the mean and heavy tails. Data sets with low kurtosis tend to have relatively flat distributions and have light tails relative to the normal distribution. The team calculated kurtosis using the following equation (*Zar, 1999*):

$$\left\{ \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^4 \right\} - \frac{3(n-1)^2}{(n-2)(n-3)} \qquad \text{(Equation 3)}$$

where,

n = number of data points

x_i = ith data point

$\bar{x}$ = mean of data points

s = sample standard deviation

Using this equation, the kurtosis for the normal distribution is zero. A peaked distribution should have positive kurtosis while a flat distribution should have negative kurtosis. As shown in Table 12, the values of kurtosis for the four categories were all positive but not high. It means the distributions of the four categories were not too flat or too peaked.

Based on the measures of skewness and kurtosis mentioned, it can be concluded that the four categorized data sets for this study have distributions close to the normal distribution.

5.2.3 Comparing the Speed Characteristics (*F*-tests of Variances)

The team conducted *F*-tests to check if the variances of the 45 and 55 mph speed limit sites are equal. The null hypothesis for this test was that the two variances for the 45 and 55 mph sites are equal. The results from the '*t*-test' procedure of the statistical program package SAS revealed that the F-value was 1.03 and p-value was 0.0464 as shown in Table 13. This indicates that the data did not give credence to the hypothesis that the two variances for the 45 and 55 mph sites are equal.

Table 13. The results of the *F*-tests (Mean Speeds)

F-test	F-value	p-value
45 mph vs. 55 mph	1.03	0.0464
45 mph – NTM* vs. 45 mph – TWLTL*	1.14	< 0.0001
55 mph – NTM* vs. 55 mph – TWLTL*	1.06	0.0205
45 mph – NTM* vs. 55 mph – NTM*	1.15	< 0.0001
45 mph – TWLTL* vs. 55 mph – TWLTL*	1.06	0.0036

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

Although the two variances for the 45 and 55 mph sites were statistically different at the significant level of 0.05, the difference in variances, less than 1 mph, was not large enough to be of practical significance, and was due primarily to large sample sizes. This indicates that the 55 mph speed limit sites were not more strongly associated with high speed drivers.

The team also conducted *F*-tests to test the differences in the variances between the median types holding speed limit constant and between speed limits holding median type constant using SAS. The null hypotheses for these tests were that the two population variances are equal. The results of SAS runs were shown in Table 13. As seen in Table 13, the variances for two median types of each speed limit and the variances for two speed limits of each median type were significantly different at the 95% confidence level.

5.2.2 Comparing the Speed Characteristics (*t*-tests of Means)

To test the difference in mean speeds between the types of medians for each speed limit, the team performed *t*-tests. For this, the team made null and alternative hypotheses as shown in Table 14.

Table 14. Hypotheses in the *t*-test (Mean Speeds and Median types)

Difference in mean speeds	Null hypothesis	Alternative hypothesis
Between median types of 45 mph sites	$H_0 : m_{45,non-traversable} = m_{45,TWLTL}$	$H_1 : m_{45,non-traversable} \neq m_{45,TWLTL}$
Between median types of 55 mph sites	$H_0 : m_{55,non-traversable} = m_{55,TWLTL}$	$H_1 : m_{55,non-traversable} \neq m_{55,TWLTL}$

To test these hypotheses, two sample unequal variance independent *t*-tests with significance level of 0.05 were performed using SAS. Table 15 shows the results of these *t*-tests. For both the 45 and 55 mph sites, the mean speeds for the non-traversable and TWLTL median types were significantly different. For the 45 mph sites, the mean speed for the TWLTL medians were higher than that for the non-traversable medians while for the 55 mph sites, the mean speed for the non-traversable medians were higher than that for the TWLTL medians.

Table 15. The Results of the *t*-tests (Mean Speeds and Median types)

t-test		45 mph sites	55 mph sites
Unequal variance	t-value	6.06	-10.47
	p-value	< 0.0001	< 0.0001
Result		Rejected the null hypothesis	Rejected the null hypothesis

We do not need *t*-tests for testing the differences in mean speeds between the two speed limits of each median type because it is clear that the mean speeds for the 55 mph sites are higher than those for the 45 mph sites. Also, the differences in mean speeds between the two speed limits of each median type are much higher than those between the median types of each speed limit.

5.2.4 85th Percentile Speeds

To further examine the tendencies of the speeds at the study sites, the team analyzed the 85th percentile speeds at each site. Table 16 shows a summary of the 85th percentile speeds of each study site. The 85th percentile speeds of the 45 mph speed limit sites were from 49 mph to 60 mph while the 85th percentile speeds of the 55 mph sites were from 56 mph to 64 mph.

Table 16. 85th Percentile Speeds at the Study Sites

Speed limit - 45 mph				Speed limit - 55 mph			
Non-traversable median		TWLTL median		Non-traversable median		TWLTL median	
Site #	85th percentile speed (mph)	Site #	85th percentile speed (mph)	Site #	85^{th} percentile Speed	Site #	85^{th} percentile speed
1	49.9	9	54.3	3	60.8	6	61.0
2	54.1	10	50.7	7	62.8	11	59.1
15	57.0	12	55.0	13	64.1	19	59.1
16	56.0	20	57.3	48	58.3	21	60.0
35	54.5	22	54.8	50	61.8	23	61.8
40	55.3	24	56.1	64	59.9	27	61.8
42	51.4	25	52.2			29	59.2
44	50.3	28	60.2			37	57.6
49	54.3	30	49.5			55	56.5
51	51.5	32	56.8			56	60.8
65	51.1	58	53.0			57	59.6
66	54.8	59	55.4			60	57.3
67	58.2	61	51.7			63	62.3
68	51.1	62	52.5			72	60.8
74	52.2	70	48.9			73	61.9

Table 17 shows the 85^{th} percentile speeds by the four categories. Overall, the 85^{th} percentile speeds of the sites posted at 45 mph were 54-55 mph while the 85^{th} percentile speeds of the sites posted at 55 mph were 5-7 mph higher at 60-62 mph.

Table 17. 85th Percentile Speeds of the Four Categories (mph)

Speed limit	45 mph		55 mph	
Median type	Non-traversable	TWLTL	Non-traversable	TWLTL
85th percentile speed (mph)	54.3	55.2	61.7	60.3

5.2.5 Relation between Speeds and Access Point Density

To examine the relation between speed distributions and access point density, the team calculated the average speeds categorized by speed limit and access point density. Table 18 shows the average speeds of the sites categorized by speed limit and access point density. The average speeds of the sites with low access point density were about 1 mph higher than those of the sites with low access point density at both speed limits.

Table 18. Average Speeds by Speed Limit and Access Point Density

Speed Limit	45 mph		55 mph	
Access Point Density (access point/mi)	High (>15)	Low (≤15)	High (>15)	Low (≤15)
Average Speed (mph)	48.85	49.53	54.70	55.78

5.3 Summary

From the analyses of the speed data the team obtained the following results:

1. The mean speeds for the 55 mph sites were right around the 55 mph speed limit while the means for the 45 mph sites were about 4 mph higher than the 45 mph speed limit. The 55 mph sites had about 6 to 7 mph higher mean speeds than the 45 mph sites.
2. Based on the test of skewness and kurtosis statistics, the team concluded that the distributions of four categorized speed data sets were very close to the normal distribution.

3. The results of *t*-tests revealed that the mean speeds for the two median types were significantly different for both the 45 and 55 mph sites.

4. The 85th percentile speeds of 45 mph sites were 54-55 mph while those of 55 mph sites were 5-7 mph higher at 60-62 mph.

5. The mean speeds of the site with low access point density were about 1 mph higher than those of the sites with high access point density at both of the 45 and 55 mph speed limits.

6. COLLISION DATA

Of the 51 sites studied for speed distributions, 49 sites had collision data available and were used for collision study (Table 19). As mentioned earlier, the team could not acquire collision data for two of the sites with 45 mph speed limits and non-traversable medians (sites 66 and 67) because of recent cross section changes. About 55 miles of study segments were included in this study. In this chapter, the analyses and findings of the collision data are described.

Table 19. Number of Sites Used in Collision Data Analysis

		Median type		Total
		Non-traversable	TWLTL	
Speed limit	45 mph	13	15	28
	55 mph	6	15	21
Total		19	30	49

6.1 Data Preparation

6.1.1 Collision Data

The team found 1,283 collisions that occurred at the 49 total study sites for the three years from 2001 to 2003 and acquired all collision reports for these collisions. The team took a detailed look at all 1,283 collision reports to distinguish curb-involved collisions and found 272 curb-involved collisions (about 21 percent of total collisions) as mentioned previously (see Table 10). Collision studies were conducted for total collisions and curb-involved collisions separately. For the collision study, the team gathered specific information like the number of collisions, collision severity, and road and light conditions of the collisions from the summary data in the NCDOT Fiche Reports.

The numbers of collisions for each segment for both total and curb-involved collisions are presented in Appendix B. Table 20 summarizes this information by the four road categories. As shown in this table, the average numbers of collisions per site for the three years were 26.2 and 5.6 collisions for total and curb-involved collisions, respectively.

Table 20. Summary Collision Frequency Data (Collisions/3 years)

Category		45 mph			55 mph			Total
		NTM *	TWLTL*	Total	NTM *	TWLTL*	Total	
Total Collision	Minimum	2	0	0	1	2	1	0
	Average	24.7	26.7	25.8	41.0	21.1	26.8	26.2
	Maximum	80	68	80	173	95	173	173
	Total	321	400	721	246	316	562	1,283
Curb-involved Collision	Minimum	0	0	0	1	0	0	0
	Average	3.5	5.1	4.4	9.3	6.3	7.1	5.6
	Maximum	7	13	13	40	17	40	40
	Total	46	76	122	56	94	150	272

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

To take the greater cost of fatal and injury collisions into account, the team also gathered collision severity data. The severity of each collision is categorized in the NCDOT Fiche Reports into fatal, injury (A-, B-, and C-level), and property damage only (PDO) collisions. Table 21 shows some summary collision severity data for total and curb-involved collisions. As seen in this table, the proportions of fatal and injury collisions of the total and curb-involved collisions were approximately 41.8 and 57.4

percent, respectively; the proportion of PDO collisions in the total collisions was higher than that in the curb-involved collisions. For total collisions, the proportions of fatal and injury collisions for 45 mph with NTM sites, 45 mph with TWLTL sites, 55 mph with NTM sites, and 55 mph with TWLTL sites were 34.0, 45.5, 42.3, and 44.6 percent, respectively. Again, for curb-involved collisions, the proportions of fatal and injury collisions for the same four road types were 50.0, 59.2, 48.2, and 64.9 percent, respectively. See Appendix B for collision severity data for each segment.

Table 21. Summary Collision Severity Data

Collision Severity Type		Number of Collisions per Segment (Collisions/3 years)				
		Minimum	Average	Maximum	Total	%
Total Collision	Fatal	0	0.22	1	11	0.9
	A-Level Injury	0	0.41	3	20	1.6
	B-Level Injury	0	2.41	14	118	9.2
	C-Level Injury	0	7.51	56	368	28.7
	PDO *	0	15.24	92	747	58.2
	Total	0	26.18	173	1,283	100.0
Curb-involved Collision	Fatal	0	0.16	1	8	2.9
	A-Level Injury	0	0.14	2	7	2.6
	B-Level Injury	0	1.00	5	49	18.0
	C-Level Injury	0	1.71	11	84	30.9
	PDO *	0	2.37	19	116	42.6
	Total	0	5.55	40	272	100.0

* PDO: Property Damage Only

Table 22 shows some summary collision data sorted by road and light condition. The team did not include in these tables collisions for which the conditions were unknown. As Table 22 shows, the average numbers of collisions per segment of the total and curb-involved collision categories with dry road condition were 19.7 and 3.8 collisions for 3 years, respectively. The proportion of collisions that occurred with "not dry" road conditions among the curb-involved collisions was higher than that of the total collisions. Similarly, the curb-involved collisions seemed to have a higher proportion of dark condition collisions than did the total collisions. See Appendix B for segment collision data for road and light conditions.

Table 22. Summary Collision Data by Road and Light Conditions

Category			Number of Collisions per Segment (Collisions/3 years)				
			Minimum	Average	Maximum	Total	%
Road Condition	Total Collision	Dry	0	19.65	107	963	75.1
		Not Dry [1]	0	6.49	66	318	24.8
		Total	0	26.18	173	1,283	100.0
	Curb-involved Collision	Dry	0	3.84	17	188	69.1
		Not Dry [1]	0	1.69	23	83	30.5
		Total	0	5.55	40	272	100.0
Light Condition	Total Collision	Daylight	0	18.29	127	896	69.8
		Dark [2]	0	6.49	38	318	24.8
		Total	0	26.18	173	1,283	100.0
	Curb-involved Collision	Daylight	0	3.14	24	154	56.6
		Dark [2]	0	2.12	13	104	38.2
		Total	0	5.55	40	272	100.0

1. Not dry condition includes code 2 through 9 of the Road Condition Codes of NCDOT Fiche Report Code Index system. The codes are as follows:

1 = Dry
2 = Wet
3 = Water(standing, moving)
4 = Ice
5 = Snow
6 = Slush
7 = Sand, Mud, Dirt, Gravel
8 = Fuel, Oil
9 = Other
10 = Unknown

2. Dark condition includes code 4 and 5 of the Light Condition Codes of NCDOT Fiche Report Code Index system. The codes are as follows:

1 = Daylight
2 = Dusk
3 = Dawn
4 = Dark-lighted roadway
5 = Dark-roadway not lighted
6 = Dark-unknown lighting
7 = Other
8 = Unknown

6.1.2 Exposure Data

To calculate collision rates for each study segment, AADT and segment length data were obtained and used as measures of exposure for the 49 study segments (Appendix B). Exposure means the chance that a collision will occur to a particular driver, vehicle, or roadway segment (Robertson et al., 1994). Table 23 shows summary segment length and AADT data for each of the four categories. As this table shows, the average segment length through all study sites was approximately one mile. The minimum and maximum AADTs of the study sites were 3,300 and 57,138 vehicles/day, respectively. The average AADT of all 49 study sites was 21,200 vehicles/day.

Table 23. Summary Exposure Data

		45 mph		55 mph		Total
		NTM *	TWLTL *	NTM *	TWLTL *	
Average Segment Length (mile)		0.94	0.97	1.48	1.27	1.12
AADT (vehicles/day)	Minimum	11,000	3,300	6,833	10,950	3,300
	Average	25,400	20,600	22,900	17,600	21,200
	Maximum	40,500	31,500	57,138	35,000	57,138

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

6.2 Relationship between AADT and Collision Frequency

As one of the first steps of our analysis, the team examined the relationship between AADT and collision frequency to decide whether a collision rate could be used as a safety indicator for this study. Collision frequency means total collisions per mile per year. Figures 49 and 50 show the results of initial analyses of the relationship between AADT and collision frequency for 45 and 55 mph sites, respectively.

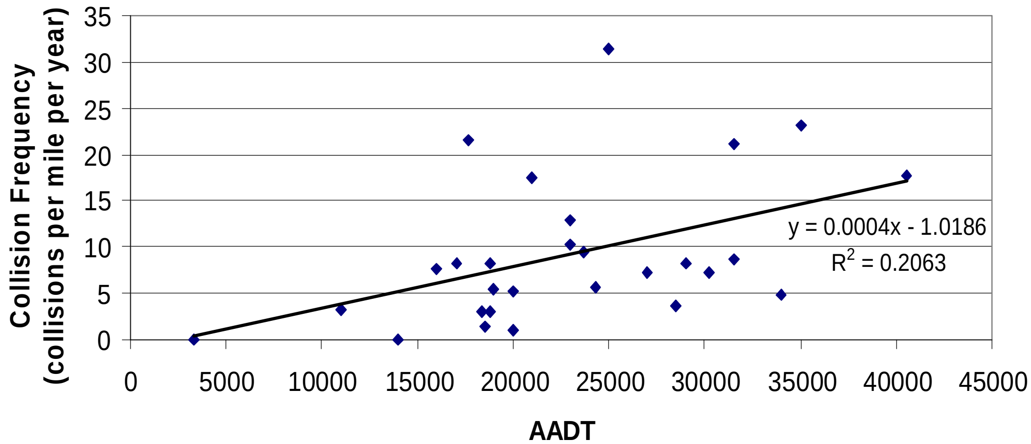


Figure 49. Relationship between AADT and Collision Frequency for 45 mph Sites (Before Removing Outliers)

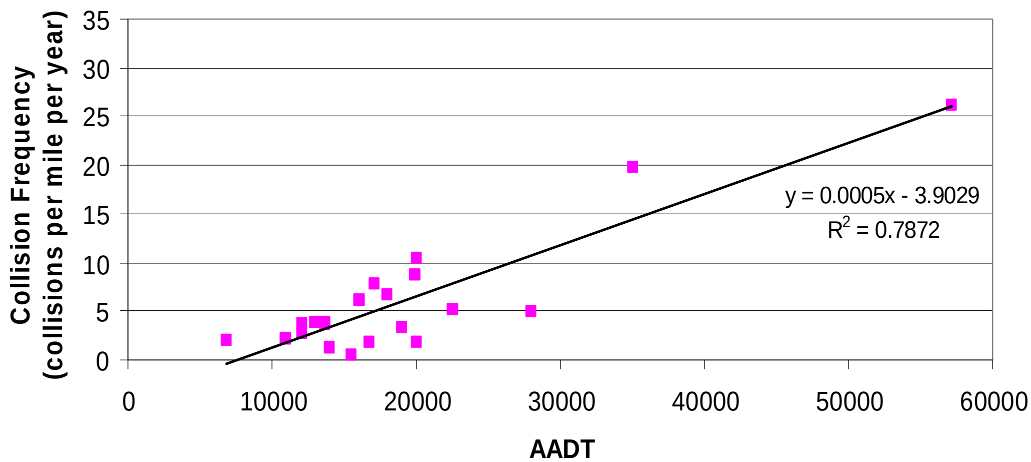


Figure 50. Relationship between AADT and Collision Frequency for 55 mph Sites (Before Removing Outliers)

Viewing the plots, the team realized that there were some outliers in the relationships, especially for 45 mph sites. The team found a common characteristic for these outliers, i.e., higher access point density. The average access point density of 45 mph sites was approximately 19 access points/mile, but a few sites had considerably more access points per mile. Figure 51 shows the distribution of access point density for the 45 mph sites.

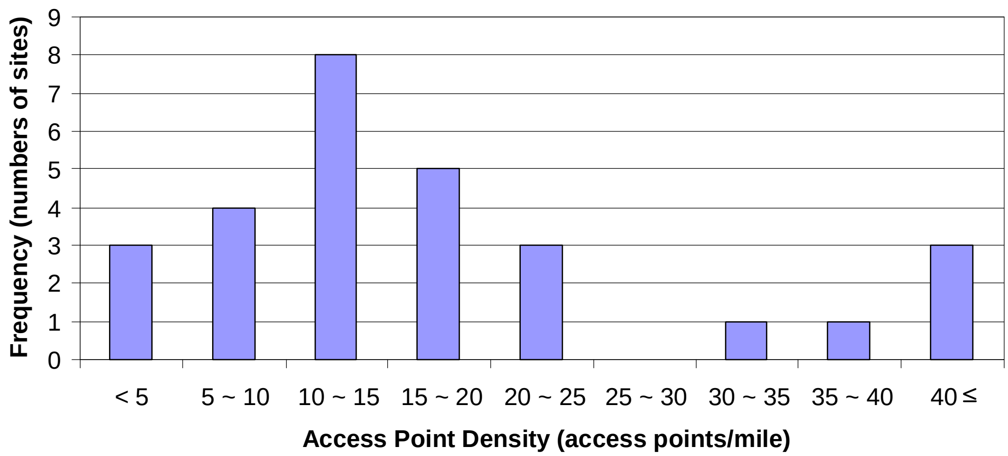


Figure 51. Distribution of Access Point Density for 45 mph Sites

Based on these statistical facts, the team considered the sites that have access point density of more than 40 access points/mile as outliers. As a result, the team eliminated three outliers (sites. 22, 30, and 58) from the 45 mph sites for this analysis. For consistent analysis, the team also eliminated one site (site 55) which had more than 40 access points/mile from the 55 mph sites. After removing outliers, the team obtained the revised relationships between AADT and collision frequency for 45 and 55 mph sites as shown in Figure 52 and 53, respectively.

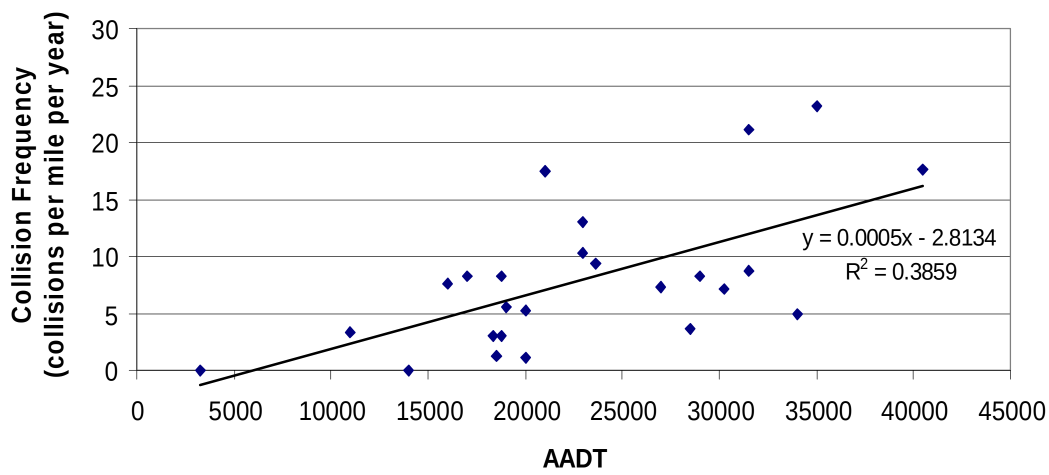


Figure 52. Relationship between AADT and Collision Frequency for 45 mph Sites (After Removing Outliers)

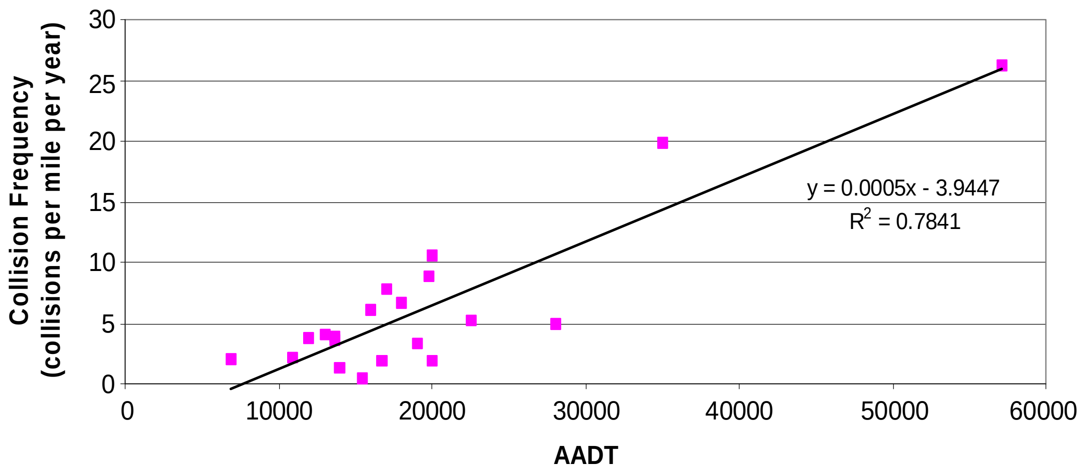


Figure 53. Relationship between AADT and Collision Frequency for 55 mph Sites (After Removing Outliers)

The correlation coefficient between AADT and collision frequency improved with the removal of outliers (compare Figure 49 to Figure 52). Even when points representing high and low AADT values were removed from Figure 53, the fact that the relationship was linear remained clear. Based on Figures 52 and 53, the team found significant linear relationships between these two variables for both the 45 mph and 55 mph sites, so we concluded that we could use collision rate as the dependent variable while analyzing the study sites without creating serious distortions.

6.3 Collision Rates

The researchers proceeded to calculate collision rates for each site for both total collisions and curb-involved collisions. In this study, the collision rate in terms of total number of collisions per million vehicle miles traveled (MVMT) was used using the following equation:

$$\text{Collision Rate} = \frac{1{,}000{,}000 \times C}{AADT \times 365 \times T \times L} \qquad \text{(Equation 4)}$$

where,

C = number of collisions,

$AADT$ = average annual daily traffic (vehicles/day),

T = number of years the data spanned (years), and

L = segment length (miles).

To illustrate, if 30 collisions occurred on a 1.21-mile roadway segment on which the AADT was 29,000 vehicles/day during a three-year period, the collision rate is $(30 \times 1{,}000{,}000)/(29{,}000 \times 365 \times 3 \times 1.21) = 0.781$ collisions per MVMT.

6.3.1 Segment Collision Rates

Segment collision rates for both total and curb-involved collisions are presented in Appendix B. Table 24 summarizes these collision rate data. As shown in Table 24, the mean collision rates for the total and curb-involved collisions were approximately 0.94 and 0.22 collisions per MVMT, respectively. In both the total and curb-involved collisions, the collision rates of the 45 mph sites with TWLTL were highest among the four categories. The results of some statistical analyses and more detailed comparisons are presented in the next section.

Table 24. Summary Collision Rate Data (collisions per MVMT)

		45 mph			55 mph			Total
		NTM *	TWLTL*	Total	NTM *	TWLTL*	Total	
Total Collision	Minimum	0.197	0.000	0.000	0.084	0.254	0.084	0.000
	Average	0.857	1.227	1.055	0.803	0.775	0.783	0.939
	Maximum	1.815	3.434	3.434	1.442	1.549	1.549	3.434
Curb-involved Collision	Minimum	0.000	0.000	0.000	0.084	0.000	0.000	0.000
	Average	0.171	0.241	0.209	0.196	0.239	0.227	0.216
	Maximum	0.832	0.584	0.832	0.303	0.469	0.469	0.832

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

6.3.2 Collision Rates by Road and Light Conditions

Table 25 shows summary collision rate data sorted by road and light condition. As shown in this table, the average collision rate with dry road conditions for total and curb-involved collisions were about 0.71 and 0.15 collisions per MVMT, respectively. There were about 0.063 curb-related collisions in 'not-dry' conditions per MVMT which was about 29.2 percent of the overall curb-related collision rate. This percentage was higher than the corresponding percentage for all collisions. Similarly, the proportion of the average collision rate occurring in dark conditions for curb-involved collisions was higher than that for total collisions.

Table 25. Summary Collision Rate Data by Road and Light Conditions

Category			Average Collision Rate (collisions per MVMT)	%
Road Condition	Total Collision	Dry	0.714	76.0
		Not Dry *	0.222	23.6
		Total	0.939	100.0
	Curb-involved Collision	Dry	0.152	70.4
		Not Dry *	0.063	29.2
		Total	0.216	100.0
Light Condition	Total Collision	Daylight	0.638	67.9
		Dark *	0.246	26.2
		Total	0.939	100.0
	Curb-involved Collision	Daylight	0.120	55.6
		Dark *	0.085	39.4
		Total	0.216	100.0

* See the foot note of Table 17.

6.3.3 Collision Rates by Road System

Table 26 shows the collision rates of the study sites by road system. As this table shows, the collision rates on US routes were relatively higher than those of other road systems for total collisions. For curb-involved collisions, US routes were also ranked as a road system that had relatively high collision rates. The collision rate of non-system roads with non-traversable medians was the highest one at 0.475 collisions per MVMT for curb-involved collisions.

Table 26. Study Sites and NC Statewide Collision Rates by Road System and Type

<table>
<tr><th colspan="2" rowspan="3">Road System and Type</th><th colspan="3">Collision Rate
(collisions per MVMT, 2001-2003)</th></tr>
<tr><th colspan="2">Study Sites [1]</th><th rowspan="2">NC Statewide [2]</th></tr>
<tr><th>Total Collision</th><th>Curb-involved Collision</th></tr>
<tr><td rowspan="2">US Routes</td><td>TWLTL</td><td>1.062</td><td>0.249</td><td>0.334 [3]</td></tr>
<tr><td>Non-traversable median</td><td>1.046</td><td>0.217</td><td>0.238 [4]</td></tr>
<tr><td rowspan="2">NC Routes</td><td>TWLTL</td><td>0.924</td><td>0.262</td><td>0.264 [3]</td></tr>
<tr><td>Non-traversable median</td><td>0.846</td><td>0.152</td><td>0.376 [4]</td></tr>
<tr><td rowspan="2">SR Routes</td><td>TWLTL</td><td>1.062</td><td>0.170</td><td>0.515 [3]</td></tr>
<tr><td>Non-traversable median</td><td>0.553</td><td>0.023</td><td>0.259 [4]</td></tr>
<tr><td rowspan="2">Non-system [5]</td><td>TWLTL</td><td>0.754</td><td>0.087</td><td rowspan="2">0.430 [6]</td></tr>
<tr><td>Non-traversable median</td><td>0.829</td><td>0.475</td></tr>
</table>

1. Average collision rates
2. Source: 2001-2003 Three Year Crash Rates from NCDOT's Traffic Safety Systems Management Unit (http://www.doh.dot.state.nc.us/preconstruct/traffic/Safety/ses/rates/2003/statewide.pdf). Unit is converted from collisions per 100 MVMT to collisions per MVMT.
3. Road type of "4+ lanes continuous left turn lane"
4. Road type of "4 or more lanes divided with no control access"
5. Routes that are not owned and maintained by NCDOT (local city streets in this study)
6. Urban non-system total crash rate

NC statewide collision rates for the same 3-year period (2001-2003) by road system and type are also presented in Table 26 for comparison. Notice that, however, the NC statewide collision rates for US, NC, and SR routes are for road sections with 4 or more lanes and with or without curbs while the collision rates of study sites are only for road segments with 4 lanes and curbs. Furthermore, the NC statewide non-system collision rate shown in Table 26 is total collision rate not only for 4 lanes roads but also for all types of urban non-system roads. It was difficult to compare the collision rates of the study sites with NC statewide collision rates for these reasons. In spite of these limitations, it was obvious that the collision rates for the total collisions of the study sites are higher than the reported NC statewide collision rates. One of the reasons for this might be that most of the study sites had numerous access points whereas the NC statewide population would be dominated by roads with fewer access points.

6.4 Analyses of Collision Rates

6.4.1 Collision Rates and Speed Limits

The team conducted *F*-tests to test if the variances of the collision rates for 45 and 55 mph sites were different for both the total and curb-involved collisions using SAS. Table 27 shows the result of the *F*-tests. These results revealed that the variances for 45 and 55 mph sites were significantly different at the 0.05 level for both the total and curb-involved collisions.

Table 27. The results of the *F*-tests (Collision Rates and Speed Limits)

F-test	F-value	p-value
Between speed limits for total collisions	4.52	0.0010
Between speed limits for curb-involved collisions	2.98	0.0144

To determine if the mean collision rates of 45 and 55 mph posted speed limit sites were significantly different, the team performed two-sample *t*-tests for both the total and curb-involved collisions. The null and alternative hypotheses made for these *t*-tests are shown in Table 28.

Table 28. Hypotheses for the *t*-tests (Collision Rates and Speed Limits)

Difference in Mean Collision Rates	Null hypothesis	Alternative hypothesis
Between speed limits for total collisions	$H_0 : m_{total,45} = m_{total,55}$	$H_1 : m_{total,45} \neq m_{total,45}$
Between speed limits for curb-involved collisions	$H_0 : m_{curb,45} = m_{curb,55}$	$H_1 : m_{curb,45} \neq m_{curb,55}$

Based on these hypotheses, two unequal variance independent *t*-tests with significance levels of 0.05 were performed for both the total and curb-involved collisions using SAS. Table 29 shows the results of these *t*-tests. There was not sufficient evidence in the data to support the hypotheses that the mean collision rates for 45 and 55 mph speed limit sites were significantly different for both the total and the curb-involved collisions as shown in Table 29. In other words, it can be said that speed limit has no statistically significant effect on the total and curb-involved collision rates of the study sites based on the *t*-test results.

Table 29. The Results of the *t*-tests (Collision Rates and Speed Limits)

t-test	Variances	t-value	p-value	Result
Between speed limits for total collisions	Unequal	1.46	0.1532	Accepted the null hypothesis
Between speed limits for curb-involved collisions	Unequal	-0.40	0.6898	Accepted the null hypothesis

6.4.2 Collision Rates and Median Types

The team performed *F*-tests to see the difference in the variances of the collision rates for non-traversable and TWLTL median sites for both the total and curb-involved collisions using SAS. The results of the *F*-tests are shown in Table 30. These results showed that the variances for non-traversable and TWLTL median sites were significantly different at the 0.05 level for total collisions while the variances for non-traversable and TWLTL median type sites were not significantly different at the same significance level for the curb-involved collisions.

Table 30. The results of the *F*-tests (Collision Rates and Median Types)

F-test	F-value	p-value
Between median types for total collisions	3.03	0.0167
Between median types for curb-involved collisions	1.31	0.5005

To determine if the mean collision rates of the sites with two different types of median were significantly different, the team used two-sample *t*-tests for both the total and curb-involved collisions. The similar null and alternative hypotheses were made for these *t*-tests as shown in Table 31.

Table 31. Hypotheses in the *t*-tests (Collision Rates and Median Types)

Difference in mean collision rates	Null hypothesis	Alternative hypothesis
Between median types for total collisions	$H_0 : m_{total,non-traversable} = m_{total,TWLTL}$	$H_1 : m_{total,non-traversable} \neq m_{total,TWLTL}$
Between median types for curb-involved collisions	$H_0 : m_{curb,non-traversable} = m_{curb,TWLTL}$	$H_1 : m_{curb,non-traversable} \neq m_{curb,TWLTL}$

To test these hypotheses, unequal and equal variance independent *t*-tests with significance levels of 0.05 were performed for total and curb-involved collisions, respectively, using SAS. Table 32 shows the results of these *t*-tests. As was the case previously in Table 29, the data did not provide sufficient evidence to support the hypotheses that the mean collision rates of the sites with non-traversable and TWLTL median types were significantly different for either total or curb-involved collisions. In other words, there is no statistically significant effect of median type on collision rate for both total and curb-involved collisions at the study sites based on these *t*-test results.

Table 32. The Results of the *t*-tests (Collision Rates and Median Types)

t-test	Variances	t-value	p-value	Result
Between median types for total collisions	Unequal	-0.86	0.3951	Accepted the null hypothesis
Between median types for curb-involved collisions	Equal	-1.24	0.2202	Accepted the null hypothesis

6.4.3 Collision Rates and Access Point Density

To take a qualitative look at the relationship between collision rate and access point density for the study sites, the team made scatter plots with these two variables for total and curb-involved collisions as shown in Figures 54 and 55.

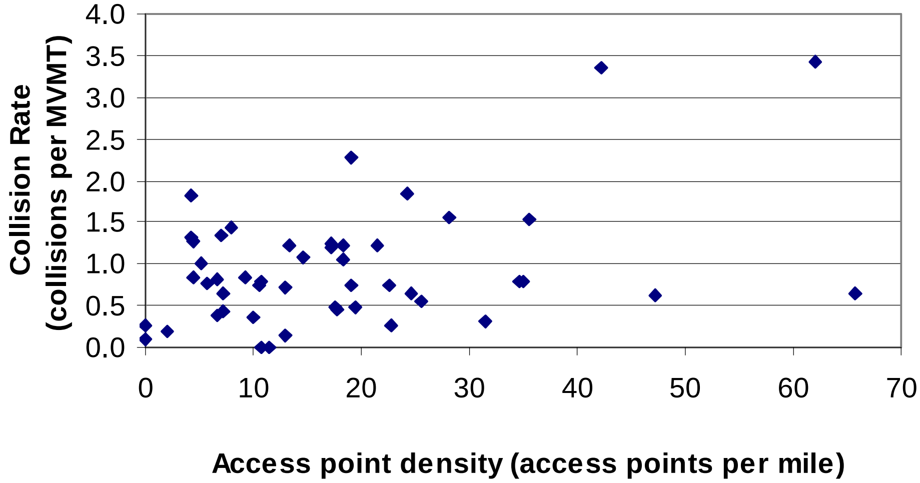


Figure 54. Relationship between Total Collision Rate and Access Point Density

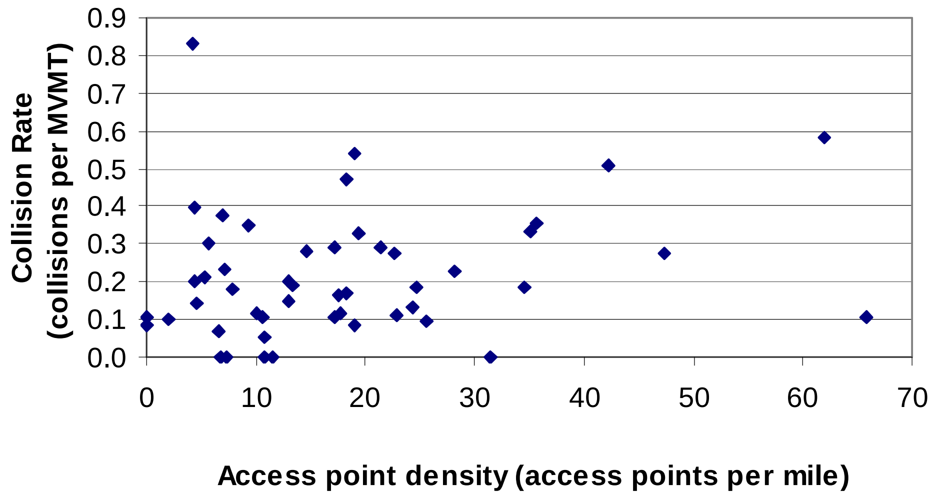


Figure 55. Relationship between Curb-Involved Collision Rate and Access Point Density

Figures 54 and 55 show weak relationships between the collision rates and access point density. To examine these relationships quantitatively, the team calculated the correlation coefficients of the two variables for total and curb-involved collisions. The correlation coefficients between the two variables for total and curb-involved collisions were about 0.40 and 0.21, respectively. Based on these values, it can be said that there are some positive but not strong correlations between the collision rates and access point density.

6.5 Collision Severity

Even when the collision rate of a segment is the same as that of another segment, the severities of collisions on those segments may be different. In this case, it can be said that one segment is less safe than the other and probably more deserving of remedial attention.

With this in mind, the team examined the equivalent property-damage only (EPDO) collision rates for both total and curb-involved collisions to investigate collision severity characteristics. In this study, we used the current NCDOT equivalency factors of 76.8 PDO collisions per fatal or A-level injury collision and 8.4 PDO collisions per B-level or C-level collision. Therefore, EPDO collision rates were calculated using the following equation:

$$\text{EPDO Collision Rate} = \frac{1{,}000{,}000 \times \{76.8(F + A) + 8.4(B + C) + P\}}{AADT \times 365 \times T \times L} \quad \text{(Equation 5)}$$

where,

F = number of fatal collisions,

A = number of A-level injury collisions,

B = number of B-level injury collisions,

C = number of C-level injury collisions,

P = number of property damage only collisions,

$AADT$ = average annual daily traffic (vehicles/day),

T = number of years the data spanned (years), and

L = segment length (miles).

Notice that unknown severity type collisions were not included in EPDO collision rates in this study. Fortunately, there were only 19 of these in our database, so this was not a serious distortion. The EPDO collision rates for each study site are presented in Appendix B. Table 33 shows summary EPDO collision rate data for total and curb-involved collisions at the study sites. The mean EPDO collision rates for total and curb-involved collisions were approximately 5.48 and 2.15 EPDO collisions per MVMT, respectively. For total collisions, the EPDO collision rate of 55 mph sites with TWLTLs was higher than that for 55 mph sites with non-traversable medians, while the collision rates of those categories shown in Table 24 revealed that the opposite was true for the overall collision rate.

Table 33. Summary EPDO Collision Rate Data (EPDO collisions per MVMT)

		45 mph			55 mph			Total
		NTM *	TWLTL*	Total	NTM *	TWLTL*	Total	
Total Collision	Minimum	0.565	0.000	0.000	0.707	0.313	0.313	0.000
	Average	3.926	7.736	5.967	3.732	5.273	4.833	5.481
	Maximum	15.601	24.623	24.623	6.614	12.949	12.949	24.623
Curb-involved Collision	Minimum	0.000	0.000	0.000	0.303	0.000	0.000	0.000
	Average	1.596	2.317	1.982	0.769	3.012	2.371	2.149
	Maximum	14.246	6.275	14.246	1.672	10.424	10.424	14.246

* NTM: Non-traversable median; TWLTL: Two-way left turn lane

The team conducted several *t*-tests to determine if there were some effects of speed limits and median types on EPDO collision rates at the study sites.

6.5.1 EPDO Collision Rates and Speed Limits

To test if the variances of the EPDO collision rates for 45 and 55 mph speed limit sites were different for both the total and curb-involved collisions, the team conducted *F*-tests using SAS. The results of the *F*-tests are shown in Table 34. These results showed that at the significance level of 0.05, the variances for 45 and 55 mph sites were significantly different for total collisions while the variances for 45 and 55 mph sites were not significantly different for curb-involved collisions.

Table 34. The results of the *F*-tests (EPDO Collision Rates and Speed Limits)

F-test	F-value	p-value
Between speed limits for total collisions	2.52	0.0367
Between speed limits for curb-involved collisions	1.21	0.6689

The team performed two-sample *t*-tests for both the total and curb-involved collisions to determine if the mean EPDO collision rates of 45 and 55 mph speed limit sites were significantly different using SAS. The same null and alternative hypotheses as shown in Table 28 were made for these *t*-tests. The same kinds of *t*-tests as those described above, i.e., unequal and equal variance independent *t*-tests with significance levels of 0.05, were again performed for total and curb-involved collisions, respectively. The results of these *t*-tests are shown in Table 35. The data did not reveal sufficient evidence to support the hypotheses that the mean EPDO collision rates for 45 and 55 mph speed limit sites were significantly different for either the total or the curb-involved collisions. This means that there is no statistically significant effect of speed limits on the EPDO collision rates for both total and curb-involved collisions of the study sites based on these *t*-test results.

Table 35. The Results of the *t*-tests (EPDO Collision Rates and Speed Limits)

t-test	Variances	t-value	p-value	Result
Between speed limits for total collisions	Unequal	0.88	0.3852	Accepted the null hypothesis
Between speed limits for curb-involved collisions	Equal	-0.47	0.6407	Accepted the null hypothesis

6.5.2 EPDO Collision Rates and Median Types

The team also conducted *F*-tests to test if the variances of the EPDO collision rates for non-traversable and TWLTL median sites were different for both the total and curb-involved collisions using SAS. The results of the *F*-tests are shown in Table 36. The variances for non-traversable and TWLTL median sites were almost significantly different at the 0.05 level for total collisions while the variances for 45 and 55 mph sites were not significantly different at the same level for curb-involved collisions.

Table 36. The results of the *F*-tests (EPDO Collision Rates and Median Types)

F-test	F-value	p-value
Between median types for total collisions	2.45	0.0501
Between median types for curb-involved collisions	1.56	0.2803

The team conducted two-sample *t*-tests with significance levels of 0.05 to determine if the mean EPDO collision rates of the study sites with two different types of median were significantly different for both total and curb-involved collisions using SAS. The null and alternative hypotheses were the same as shown previously in Table 31. Table 37 shows the results of these *t*-tests. The data did not provide sufficient evidence to support the hypotheses that the mean EPDO collision rates of the sites with non-traversable and TWLTL median types were significantly different for either the total or the curb-involved collisions. In other words, there is no statistically significant effect of median type on the EPDO collision rates for both the total and the curb-involved collisions at the study sites based on these *t*-test results.

Table 37. The Results of the *t*-tests (EPDO Collision Rates and Median Types)

t-test	Variances	t-value	p-value	Result
Between median types for total collisions	Equal	-1.95	0.0574	Accepted the null hypothesis
Between median types for curb-involved collisions	Equal	-1.62	0.1117	Accepted the null hypothesis

6.5.3 EPDO Collision Rates and Access Point Density

Figure 56 and 57 shows scatter plots representing the relationships between EPDO collision rates and access point densities of the study sites for total and curb-involved collisions, respectively.

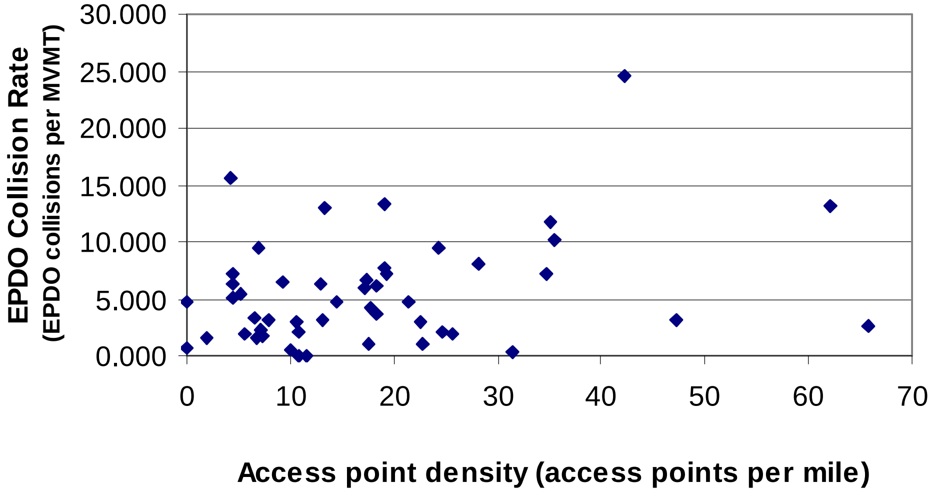


Figure 56. Relationship between EPDO Collision Rate for Total Collisions and Access Point Density

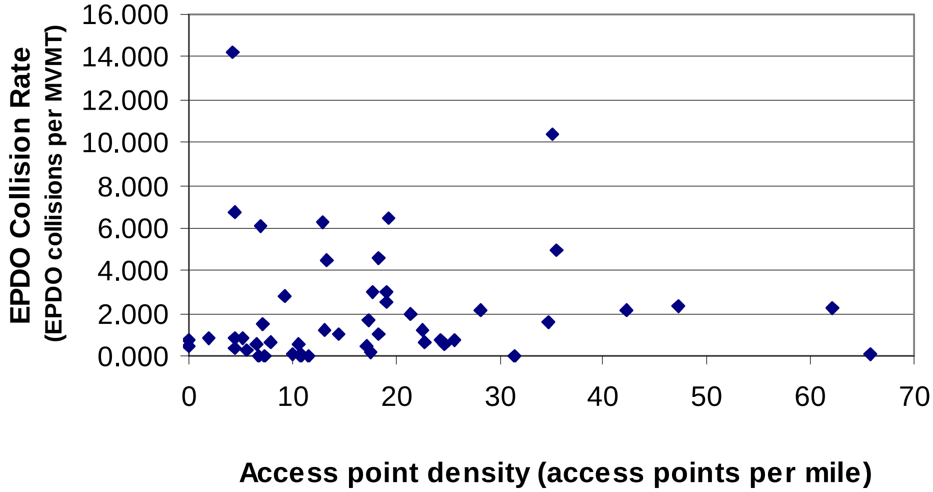


Figure 57. Relationship between EPDO Collision Rate for Curb-Involved Collisions and Access Point Density

As before, the team calculated the correlation coefficients between the two variables for the total and curb-involved collisions. The correlation coefficients between the EPDO collision rate and access point density for the total and curb-involved collisions were about 0.30 and 0.02, respectively. It appears that there was some positive but not strong correlation between EPDO collision rate and access point densities for total collisions but not much of a relationship in the case of curb-involved collisions.

6.6 Three-Factor ANOVA Tests

The analyses described in the last two sections were for the relationships between collision rates and single factors like speed limit. In other words, the team compared the responses (collision rates and EPDO collision rates) at different levels (45 and 55 mph speed limits) of a single factor (speed limit) to test the effect of that single factor on collision rates.

In addition to the effects of each single factor, the research team was also interested in the possible interaction effects between the factors because the factors might combine to affect the expected responses. To conduct this kind of factorial analysis, a so-called multi-way ANOVA is appropriate. In this section, the procedure and results for the three-factor ANOVA we conducted on the collision data are presented.

6.6.1 Characteristics of the data

The appropriate analysis method depends on the characteristics of the data to be analyzed. First, the team determined the independent and dependent variables. The independent variables - that is, measured responses - were the collision rates or EPDO collision rates of the total and curb-involved collisions. The dependent variables - that is, the factors - were speed limit, median type, and access point density. The levels of each factor used in this study are as follows:

- Speed limit: 45 mph and 55 mph (two levels),
- Median type: non-traversable median and TWLTL (two levels), and
- Access point density: high and low (two levels).

Access point density was recorded as a continuous variable, but we categorized into two levels for this analysis. The categorizing threshold value of 15 access points per mile per both sides was selected for reasons as noted earlier in the section on the analysis of the relationship between speeds and access point density.

Table 38 shows the numbers of observations in each subclass of the collision data. As shown in this table the numbers of observations in each subclass of the data were unequal, that is, there were unbalanced data. In this case the analysis is more complicated than in the case of equal observation numbers in each subclass, for several reasons, and statistical software is appropriate for the required calculations (*Rao, 1998*).

Table 38. The Numbers of Observations in Each Subclass of the Collision Data

<table>
<tr><th rowspan="2">Access point density</th><th rowspan="2">Speed limit</th><th colspan="2">Median type</th><th rowspan="2" colspan="2">Total</th></tr>
<tr><th>Non-traversable median</th><th>TWLTL</th></tr>
<tr><td rowspan="2">Low</td><td>45 mph</td><td>9</td><td>6</td><td>15</td><td rowspan="2">25</td></tr>
<tr><td>55 mph</td><td>5</td><td>5</td><td>10</td></tr>
<tr><td rowspan="2">High</td><td>45 mph</td><td>4</td><td>9</td><td>13</td><td rowspan="2">24</td></tr>
<tr><td>55 mph</td><td>1</td><td>10</td><td>11</td></tr>
<tr><td colspan="2">Total</td><td>19</td><td>30</td><td colspan="2">49</td></tr>
</table>

6.6.2 Three-Factor ANOVA Using SAS

The team used the GLM procedure of the statistical program package SAS to perform the unbalanced three-way ($2 \times 2 \times 2$) ANOVA. One of the major tasks in analyzing the collision data with multi-factors is to estimate the expected responses for each level of a given factor. The GLM procedure of SAS uses so-called least squares means (LS-means) for this task, especially in case of unbalanced data.

In case of unbalanced data, marginal sample means (that is, arithmetic means that are familiar and well-known) are not useful. Marginal means are the right method for analyzing one-way and balanced data, but usually adjusted means (LS-means) are used in unbalanced factorial ANOVA (*SAS Institute Inc., 1999*). The LS-means were used in place of adjusted means by SAS in this case.

The GLM procedure of SAS produces two types of sums of squares, Type I and Type III. Type I sums of squares for the factors in a model are the extra regression sums of squares resulting from adding the factors sequentially to the model in order. For instance, Type I sums of squares for the second factor is the extra regression sum of squares obtained by adding the second factor to a model that contains the first factor. On the other hand, Type III sums of squares for a factor are the extra regression sums of squares obtained by adding that particular factor to a model containing the other factors (*Rao, 1998*). Type I and Type III sums of squares are typically unequal in the unbalanced case. In the unbalanced case, Type III sums of squares are used to test the significance of the factorial effects because they test a function of the underlying parameters which is independent of the number of observations per level combination (*SAS Institute Inc., 1999*).

In a three-way factorial analysis, the factorial effects are usually classified into three types as follows (*Rao, 1998*):

1. Main effects - There are three main effects.
2. First-order interaction effects – The effects of interactions between two factors.
3. Second-order interaction effects – The effect of the interaction between the three factors. This can also be thought of as an interaction between a main effect and a first-order interaction.

The first step in analyzing the factorial effects is to examine if the second-order interaction between the three factors exist. If the second-order interaction effect is significant, the next step is to analyze the first-order interactions at each level of the third factor. If the first-order interaction between two factors at a level of the third factor is significant, the next step is to check the simple effects of the two factors at the level of the third factor. For instance, if the interaction between factors A and B is significant, the effects of the different levels of the factor A must be compared separately at each level of the factor B. If the first-order interaction between two factors at a level of the third factor is not significant, on the other hand, the next successive step is to analyze the main effects of the two factors at the level of the third factor.

If the second-order interaction between the three factors is not significant, the next step is to examine the first-order interactions between each of the three pairs of factors. The step after that is the same as the case of the significant second-order interaction described in the preceding paragraph.

Twenty-four SAS runs with significance levels of 0.05 were performed to analyze the factorial effects for total and curb-involved collisions for the following six conditions:

1. Overall collision rates,
2. EPDO collision rates,
3. Dry road condition,
4. Not-dry road condition,
5. Daylight condition,
6. Dark condition,

6.6.3 Results of the ANOVA

Total Collisions

The team conducted a three-way ANOVA using the SAS GLM procedure to analyze the factorial effects on collision rates including all collisions that occurred in the study sites. The output of the SAS GLM procedure is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0944	0.22	0.6396
MedianType	0.0022	0.01	0.9430
SpeedLimit*MedianType	0.2423	0.57	0.4540
AccessPointDensity	1.3585	3.20	0.0809
SpeedLimit*AccessPointDensity	0.6439	1.52	0.2249
MedianType*AccessPointDensity	0.0000	0.00	0.9927
SpeedLimit*MedianType*AccessPointDensity	1.2542	2.96	0.0930

The sum of squares for testing the second-order interaction between the three factors was 1.2542, which was not significant (p=0.0930). Similarly, all the first-order interactions and main effects were not significant. That is, for all collisions that occurred at the study sites during the three years from 2001 to 2003, the expected collision rates were not significantly different for the two speed limits, two median types, and two access point density levels, and any combination of those factors.

The team also conducted a three-way ANOVA for overall collision rate using curb-involved collisions. The output of the SAS GLM procedure to analyze the factorial effects for the collision data is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0105	0.34	0.5617
MedianType	0.0077	0.25	0.6186
SpeedLimit*MedianType	0.0034	0.11	0.7411
AccessPointDensity	0.0239	0.78	0.3819
SpeedLimit*AccessPointDensity	0.0021	0.07	0.7927
MedianType*AccessPointDensity	0.0011	0.04	0.8518
SpeedLimit*MedianType*AccessPointDensity	0.0287	0.94	0.3381

Again, all the factorial effects were not significant. In other words, overall collision rates using curb-involved collisions were not significantly different regardless of the speed limits, median types, access point density, and any combination of those three factors.

EPDO Collision Rate for Total Collisions

The team conducted similar analyses for the EPDO collision rate data using total collisions. The output of the SAS GLM procedure is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.4012	0.02	0.8852
MedianType	29.4603	1.55	0.2204
SpeedLimit*MedianType	9.9215	0.52	0.4743
AccessPointDensity	25.2044	1.33	0.2564
SpeedLimit*AccessPointDensity	15.4885	0.81	0.3721
MedianType*AccessPointDensity	0.0002	0.00	0.9973
SpeedLimit*MedianType*AccessPointDensity	70.3821	3.70	0.0614

Again, there was no significant factorial effect at the 0.05 level. Based on this result, it can be said that the data do not provide sufficient evidence in support of the hypothesis that the expected EPDO collision rate using total collisions is different for the two speed limits, two median types, two access point density levels, or any combination of those factors.

The output of the SAS GLM procedure to analyze the factorial effects for EPDO collision rates using curb-involved collisions is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.3719	0.04	0.8374
MedianType	15.2488	1.75	0.1934
SpeedLimit*MedianType	2.0309	0.23	0.6320
AccessPointDensity	0.0643	0.01	0.9320
SpeedLimit*AccessPointDensity	1.4097	0.16	0.6898
MedianType*AccessPointDensity	0.2936	0.03	0.8553
SpeedLimit*MedianType*AccessPointDensity	2.2177	0.25	0.6168

Like the other ANOVA results presented to this point, this result also revealed that the EPDO collision rates using curb-involved collisions were not significantly different regardless of the speed limit, median type, access point density, or any combination of those factors.

Dry Conditions

The team conducted three-way ANOVA procedures using SAS GLM to examine the factorial effects for collisions that occurred in dry road conditions. Separate SAS GLM procedures were run for total and curb-involved collisions. The outputs of these SAS runs are as follows:

1. Total collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.1364	0.61	0.4388
MedianType	0.0187	0.08	0.7738
SpeedLimi*MedianType	0.0127	0.06	0.8125
AccessPointDensity	0.5384	2.41	0.1280
SpeedLimi*AccessPoin	0.4444	1.99	0.1657
MedianTyp*AccessPoin	0.0003	0.00	0.9707
SpeedL*Median*Access	0.4752	2.13	0.1521

2. Curb-involved collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0004	0.03	0.8631
MedianType	0.0190	1.35	0.2522
SpeedLimit*MedianType	0.0003	0.02	0.8860
AccessPointDensity	0.0060	0.42	0.5187
SpeedLimit*AccessPointDensity	0.0021	0.15	0.7048
MedianType*AccessPointDensity	0.0010	0.07	0.7919
SpeedLimit*MedianType*AccessPointDensity	0.0004	0.03	0.8613

There were no significant factorial effects in either case. That is, the collision rates were not significantly different for the two speed limits, two median types, two access point density levels, or any combination of those factors.

Not Dry Conditions

Another three-way ANOVA was conducted to examine the factorial effects for collision rates including all collisions that occurred when road conditions were not dry (as defined in the footnotes of Table 22). The output of this analysis is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0035	0.08	0.7773
MedianType	0.0107	0.25	0.6230
SpeedLimit*MedianType	0.1446	3.32	0.0756
AccessPointDensity	0.1981	4.55	0.0389
SpeedLimit*AccessPointDensity	0.0182	0.42	0.5212
MedianType*AccessPointDensity	0.0001	0.00	0.9668
SpeedLimit*MedianType*AccessPointDensity	0.1835	4.22	0.0464

This analysis provided a result different from the results presented so far, in that the second-order interaction between the three factors was significant at the 0.05 level (p=0.0464). In view of the significance of the second-order interaction, the team conducted additional two-way ANOVAs to analyze the first order interactions between two factors at each level of the third factor. The outputs of these analyses are as follows:

1. Two-way ANOVA for speed limit and median type at low access point density:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0298	2.07	0.1652
MedianType	0.0071	0.49	0.4917
SpeedLimit*MedianType	0.0018	0.13	0.7255

2. Two-way ANOVA for speed limit and median type at high access point density:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0021	0.03	0.8682
MedianType	0.0046	0.06	0.8058
SpeedLimit*MedianType	0.2393	3.23	0.0873

3. Two-way ANOVA for median type and access point density at 45 mph speed limit:

Source	Type III SS	F Value	Pr > F
MedianType	0.0642	1.05	0.3165
AccessPointDensity	0.2816	4.59	0.0425
MedianType*AccessPointDensity	0.1474	2.40	0.1342

4. Two-way ANOVA for median type and access point density at 55 mph speed limit:

Source	Type III SS	F Value	Pr > F
MedianType	0.0834	4.55	0.0477
AccessPointDensity	0.0343	1.87	0.1889
MedianType*AccessPointDensity	0.0681	3.72	0.0706

5. Two-way ANOVA for speed limit and access point density at non-traversable median type:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0662	5.20	0.0376
AccessPointDensity	0.0705	5.55	0.0326
SpeedLimit*AccessPoin	0.0295	2.32	0.1487

6. Two-way ANOVA for speed limit and access point density for TWLTL median type:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0953	1.56	0.2234
AccessPointDensity	0.1762	2.88	0.1018
SpeedLimit*AccessPointDensity	0.2936	4.79	0.0377

As seen in the first and second results above, there was no significant factorial effect of speed limit and median type at either level of access point density. However, as seen in the third result, at the 45 mph speed limit level there was a significant difference between the expected collision rates at the two access point density levels. As the fourth result shows, at the 55 mph speed limit level there was a significant difference between the expected collision rates at the two median types. The fifth result above revealed the fact that there were some speed limit and access point density effects on the expected collision rates at the non-traversable median type. From the sixth result, it can be said that there was interaction between speed limit and access point density for the TWLTL median type. All of these statistical analysis results mean that for not-dry total collisions, there are some significant factorial effects on collision rates in various conditions.

For the curb-involved collisions which occurred in road conditions that were not dry, the three-way ANOVA output is as follows:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0133	2.08	0.1570
MedianType	0.0034	0.53	0.4728
SpeedLimit*MedianType	0.0069	1.08	0.3058
AccessPointDensity	0.0073	1.14	0.2924
SpeedLimit*AccessPointDensity	0.0001	0.01	0.9294
MedianType*AccessPointDensity	0.0000	0.01	0.9373
SpeedLimit*MedianType*AccessPointDensity	0.0333	5.23	0.0275

The not-dry curb-involved analysis provided similar results to that for not-dry total collisions. That is, the second-order interaction between the three factors was significant at the 0.05 level (p=0.0275). Again, the team conducted several two-way ANOVAs to analyze the first order interactions between two factors at each level of the third factor. The outputs of these analyses are provided below.

1. Two-way ANOVA for speed limit and median type at low access point density:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0092	1.36	0.2565
MedianType	0.0033	0.48	0.4958
SpeedLimit*MedianType	0.0079	1.16	0.2936

2. Two-way ANOVA for speed limit and median type at high access point density:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0055	0.92	0.3500
MedianType	0.0010	0.16	0.6908
SpeedLimit*MedianType	0.0258	4.32	0.0508

3. Two-way ANOVA for median type and access point density at 45 mph speed limit:

Source	Type III SS	F Value	Pr > F
MedianType	0.0005	0.06	0.8089
AccessPointDensity	0.0051	0.58	0.4518
MedianType*AccessPointDensity	0.0299	3.43	0.0765

4. Two-way ANOVA for median type and access point density at 55 mph speed limit:

Source	Type III SS	F Value	Pr > F
MedianType	0.0071	2.29	0.1483
AccessPointDensity	0.0030	0.99	0.3344
MedianType*AccessPoin	0.0111	3.60	0.0749

5. Two-way ANOVA for speed limit and access point density at non-traversable median type:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0134	1.64	0.2196
AccessPointDensity	0.0021	0.26	0.6172
SpeedLimit*AccessPointDensity	0.0123	1.51	0.2385

6. Two-way ANOVA for speed limit and access point density with TWLTL:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0010	0.18	0.6742
AccessPointDensity	0.0077	1.45	0.2393
SpeedLimit*AccessPointDensity	0.0285	5.33	0.0291

In this case (curb-involved collisions that occurred in not-dry road conditions), there was no significant factorial effect except for the significant first-order interaction between speed limit and access point density at the TWLTL median type as seen in the sixth set of results. That is, for the curb-involved collisions that occurred in not dry conditions, the effects of the different speed limits are not same at each level of the access point density.

Daylight Condition

The outputs of the SAS GLM procedures for the analyses of the factorial effects on the total and curb-involved collision rates for collisions that occurred in daylight appear below.

1. Total collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0478	0.22	0.6413
MedianType	0.0126	0.06	0.8107
SpeedLimit*MedianType	0.0911	0.42	0.5208
AccessPointDensity	0.8996	4.14	0.0483
SpeedLimit*AccessPointDensity	0.2516	1.16	0.2880
MedianType*AccessPointDensity	0.0003	0.00	0.9713
SpeedLimit*MedianType*AccessPointDensity	0.6948	3.20	0.0810

2. Curb-involved collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0188	1.88	0.1774
MedianType	0.0003	0.03	0.8696
SpeedLimit*MedianType	0.0001	0.01	0.9303
AccessPointDensity	0.0128	1.28	0.2636
SpeedLimit*AccessPointDensity	0.0025	0.25	0.6181
MedianType*AccessPointDensity	0.0002	0.02	0.8885
SpeedLimit*MedianType*AccessPointDensity	0.0064	0.64	0.4286

For total collisions in daylight conditions, the main effect of access point density was significant at the 0.05 level (p=0.0483). That is, the data do not provide sufficient evidence in support of the hypothesis that the expected collision rates are the same for the two access point densities. The LS-means for high access point density were higher than those for low access point density for the 45 mph with NTM, 45 mph with TWLTL, and 55 mph with NTM sites. For the curb-involved collisions in daylight conditions, however, no significant factorial effect was found.

Dark Conditions The team conducted ANOVAs to examine the factorial effects on total and curb-involved collision rates that occurred in dark conditions (as defined in the footnotes of Table 22). The outputs appear below.

1. Total collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0049	0.12	0.7314
MedianType	0.0354	0.87	0.3565
SpeedLimit*MedianType	0.0401	0.98	0.3269
AccessPointDensity	0.0355	0.87	0.3558
SpeedLimit*AccessPointDensity	0.0599	1.47	0.2320
MedianType*AccessPointDensity	0.0006	0.01	0.9040
SpeedLimit*MedianType*AccessPointDensity	0.0948	2.33	0.1348

2. Curb-involved collisions:

Source	Type III SS	F Value	Pr > F
SpeedLimit	0.0027	0.32	0.5737
MedianType	0.0040	0.47	0.4954
SpeedLimit*MedianType	0.0012	0.14	0.7136
AccessPointDensity	0.0017	0.20	0.6574
SpeedLimit*AccessPointDensity	0.0000	0.00	0.9874
MedianType*AccessPointDensity	0.0002	0.03	0.8694
SpeedLimit*MedianType*AccessPointDensity	0.0069	0.81	0.3723

As seen in these results, there was no significant factorial effects for either total or curb-involved collision rates for collisions that occurred in dark conditions.

6.7 Summary

From the collision data analyses, the following major results were derived:

1. There was no significant effect of speed limit or median type on the overall collision rate for either total or curb-involved collisions based on two-sample *t*-tests.
2. There was no significant effect of speed limit or median type on the EPDO collision rate for either total or curb-involved collisions based on two-sample *t*-tests.
3. Based on the correlation coefficient analyses, it can be said that there were some positive but not strong correlations between the total collision rates or EPDO collision rates and access point densities for both the total and curb-involved collisions.
4. From the three-way ANOVA results we found that the data do not provide sufficient evidence to support the hypothesis that the overall and EPDO collision rates are different due to the two speed limits, the two median types, the two access point density levels, or any combination of those three factors for both total and curb-involved collisions.
5. There were some significant factorial effects on collision rates for some collisions that occurred in roadway conditions that were not dry and in daylight conditions, but these were relatively obscure cases.

In short, speed limit does not seem to make an important difference in the collision rates or EPDO collision rates we observed for the roads we examined.

7. CONCLUSIONS and RECOMMENDATIONS

Previous literature looked at the performance of various curbs in three types of analyses: crash tests, computer simulations, and collision data analyses. Crash test and simulation findings indicated that curbs placed along higher speed roadways (> 45 mph) had potential to cause vehicles to become airborne hitting secondary objects, roll over, or sometimes redirect the vehicle into the traveled-way. Limited collision data analysis findings usually reported higher numbers of collisions along roadways using curb and gutter than those without.

Studies were also conducted on the use of curb and gutter with traffic barriers and effects of posted speed on operating speeds. Placing curbs with a vertical or nearly vertical face too far away from a traffic barrier, such as guardrail, may produce undesirable results causing the vehicle to vault over or on top of the guardrail. Another interesting piece of literature pertained to establishing posted speed limits along roadways and the effect this has on operating speeds. These studies showed that, although posted speeds are usually set to improve overall safety along roadway segments, it was not a guarantee that operating speeds or collisions decreased with lower speed limits.

NCDOT's basic guidelines for typical utilization of curb and gutter were summarized to help understand current policy. The four most common curb and gutter combinations are each used for different reasons or conditions. The 2'-6" and 1'-6" curbs and gutters are primarily for roads posted ≤ 45 mph, expressway gutter is primarily for roads posted > 45 mph, and 8” by 12” or 18” curb is primarily for channelization and right-of-way protection. The most commonly used of these four combinations is the 2’-6” and 1’-6” curb and gutter along the outer pavement and shoulders, respectively.

Designing roadways without the use of curb and gutter has become challenging in instances where roadways warrant posted speeds in excess of 45 mph. Preliminary designs are often revisited by following public hearings and readjustments are made. Use of curb and gutter often negates or lessens many of the problems brought up during these hearings. However, speeds along many of the corridors have to be decreased when using curb and gutter because AASHTO guidelines vaguely indicate that there is additional collision risk. Thus roads that in all other respects would typically be posted at 55 mph are decreased to 45 mph, sometimes adding to public outrage.

AASHTO guidelines on the use of curb and gutter along corridors with posted speeds greater than 45 mph are vague. There is no clear guidance on what conditions could potentially warrant curb and gutter installations along higher speed corridors. Case studies were conducted in attempt to understand the conditions under which curb and gutter was used along high speed roadways with 55 mph posted speeds in North Carolina, as well as to look at the characteristics of more typical cross-sections along 45 mph posted corridors. The feedback from field personnel we received seemed to indicate various features that are associated with the use of curb and gutter along high speed roadways posted at 55 mph. Two of the more prominent aspects of these roadways are very low access point densities and extreme right-of-way restrictions.

As noted earlier, crash test research is fairly clear about the use of curbs along higher speed roadways. However, evidence from collision data is much less convincing.

Two separate analyses were completed as a part of this research effort in order to help solidify knowledge of these effects along these types of roadways in North Carolina. The analyses conducted included speed and collision studies. The sites were randomly-chosen segments with 45 and 55 posted speed limits with either traversable or non-traversable median types. The primary purpose of these studies was to answer the question, "Does a 45 mph speed limit on a four-lane road with a 2'-6" curb and gutter really cause motorists to drive differently, thus increasing or decreasing the frequency and severity of collisions in comparison to a 55 mph speed limit?" The findings reported below for roads posted at 55 mph probably also apply to roads posted at 50 mph under similar circumstances.

Speed data were collected along each of the randomly-selected corridor sites. Based on skewness and kurtosis tests, we concluded that the speed data were normally distributed. The mean speeds for posted 55 mph sites were right around 55 mph, while 45 mph sites were approximately 49 mph. *T*-tests revealed that the mean speeds for both median types were significantly different for 45 and 55 mph sites. The 85th percentile speeds for 45 mph sites were 54-55 mph, while those posted at 55 mph were 60-62 mph. Lastly, the mean speeds of sites defined as having low access point density were about 1 mph higher than those with high access point density for 45 and 55 mph sites.

Collision data for each of the corridors were collected for each corridor in our study and analyzed using two data sets: total and curb-involved collisions. Statistical analyses showed that there was no statistically significant effect of posted speed limits or median types on collision rates for each of the data sets based on *t*-tests. Correlation coefficients showed positive, but not strong correlations between the collision rates or

EPDO collisions rates, and access point densities. Based on *t*-tests, there was also no statistically significant effect of speed limit or median type on EPDO collision rates. From three-way ANOVA results using SAS GLM procedures, we found that the data do not provide sufficient evidence to support the hypothesis that the expected collision rate and EPDO collision rate are different for the two speed limits, the two median types, the two access point density levels, or any of their interactions for both total and curb-involved collisions. There were some significant factorial effects on collision rates for some collisions that occurred in roadway conditions that were not dry and in daylight conditions, but these were relatively obscure cases.

To summarize, the research team found that, for a random sample of suburban four-lane highways with curbs in North Carolina, relative to segments posted at 45 mph, segments posted at 55 mph had a:

- Significantly higher mean speed and 85th percentile speed, by 6-7 mph,
- Significantly higher variance about the mean speed,
- Lower mean overall collision rate, by about 0.27 collisions per MVMT,
- Higher mean curb-involved collision rate, by about 0.02 collisions per MVMT,
- Significantly lower variance about the mean for overall and curb-involved collision rates,
- Lower mean EPDO collision rate for total collisions, by about 1.1 EPDO collisions per MVMT, and
- Higher mean EPDO collision rate for curb-involved collisions, by about 0.4 EPDO collisions per MVMT.

Overall, speed limit does not seem to make an important difference (a statistically significant difference) in the collision rates or severities for the roads the team examined. When there was a difference in collision rate or severity, it was usually the 55 mph segments that had the lower rates. The higher speed limit made a difference in the mean speeds and speed variances observed, but the differences were not that large. The mean speed for segments posted at 55 mph was still right around 55 mph.

Considering all of the findings, the researchers recommend that the NCDOT continue to exercise sound engineering judgment in determining speed limits on four-lane roadways with curbs on a selective, case-by-case basis. There were not major differences in the geometric features between the 45 mph and 55 mph posted sites in our sample. However, there were subtle or slight differences that likely contributed to the fact that the collision rates were not much different despite the higher mean speeds and speed variances at the 55 mph sites. The NCDOT and other agencies should therefore continue to consider a wide range of factors before posting a road with curbs above 45 mph, including low access point density, few roadside objects, and generous curve dimensions. If curb and gutter is installed in locations where the characteristics for safe higher speed operation are not present, NCDOT should continue its practice of lowering its posted speed limits to no more than 45 mph.

To help determine a proper speed limit for a new or existing road section with curbs where higher speeds may be justified, the team suggests a list of things to consider based on Federal Highway Administration (FHWA)'s Manual on Uniform Traffic Control Devices (MUTCD) 2003 edition (*FHWA, 2003*) and North Carolina's "Guidelines for the Establishment of Restrictive Speed Limits" (May 15, 1995):

1) The 85th Percentile Speed of prevailing and free-flowing traffic in the area under study

2) Overall design speed, and nature of any violations of the design speed by specific roadway elements

3) Classification and strategic purpose of facility

4) Conditions and type of roadway surface

5) Roadway type, width, and number of traffic lanes

6) Shoulder width, condition, and type

7) Horizontal and vertical alignment and sight distance of the roadway

8) Roadside development: amount, type, and proximity to the travel way

9) Parking practices and pedestrian activity

10) Composition of the traffic using the roadway

11) Numbers and types of intersections, including interchanges and private driveways and roads

12) Crash experience, including frequency, severity, and rate for at least a 36-month period if available

13) Statutory limits for the area under study

14) Section length and speed limits on adjacent links

15) Lane density, level of service, and ADT

16) Directional peak hour volume

17) Peak hour factor

18) Seasonal traffic and condition variations

19) Presence of or lack of median barrier and median type and width

20) Clear zone, roadside recovery area, and lateral clearances

21) Acceleration and deceleration lane lengths

22) Pending development or highway construction

Note that items 1, 4, and 12 are not applicable to a new road section.

The team recommends that future research should attempt to include a larger sample size, especially with respect to sites with posted speeds of 55 mph and non-traversable medians. Of course, valid regression models for suburban multilane arterials explaining speeds and collision frequencies as a function of a number of independent variables including curb presence and road conditions like drainage could answer a number of interesting planning and design questions such as that posed in this report. The effort to build such models should be a priority. A similar effort as made in this paper in other states would also be revealing to see how far these results could be generalized.

REFERENCES

1. AASHTO, "A Policy on Geometric Design of Highways and Streets", American Association of State Highway and Transportation Officials, Washington, D.C., 2004.

2. AASHTO, "Roadside Design Guide", American Association of State Highway and Transportation Officials, Washington, D.C., 2002.

3. Agent, K.R., Pigman, J.G., and Weber, J.M., "Evaluation of Speed Limits in Kentucky," *Transportation Research Record 1640*, Transportation Research Board, Washington, D.C., 1998.

4. Beaton, J.L., and Peterson, H., "A Report on Dynamic Testing of Various Design of Highway Bridge Curbing – Roadway Barrier Curb Investigation, California Division of Highways, 1953.

5. Bennett, Jay. NCDOT Roadway Design Unit. Email and phone conversations, April-June 2005.

6. Binkowski, S.E., Maleck, T.L., Taylor, W.C., and Czewski, T.S., "Evaluation of Michigan 70-mph Speed Limit," *Transportation Research Record 1640,* Transportation Research Board, Washington, D.C., 1998.

7. Bligh, R.P., Mak, K.K., "Crashworthiness of Roadside Features Across Vehicle Platforms," *Transportation Research Record 1690*, Transportation Research Board, Washington, D.C., 1999.

8. Carter, H., and Szplett, D., "A Local Government's Experience with Planning and Implementing an Access Management Plan," ITE, Washington D.C., 1999.

9. Council, F.M., et al., "Safe Geometric Design for Minicars," FHWA *Report No. FHWA-RD-87-047*, 1987.

10. Cross-Section Typicals. NCDOT Roadway Design Unit. Received by email from Jay Bennett, April 2005.

11. Daughtry III, Haywood. NCDOT Regional Traffic Engineer, Divisions 1, 2, and 4. Email and phone conversations, 2005.

12. Dunlap, D.F., "Barrier-Curb Redirection Effectiveness," Highway Research Record No. 460, 1973, pp. 1-10.

13. Dunlap, D.F., “Curb-Guardrail Vaulting Evaluation,” Highway Research Record No. 460, 1973, pp. 10-20.

14. Fambro, D.B., Nowlin, R.L., Warren, S.P., Lienau, K., Mounce, J.M., Bligh, R.P., Mak, K.K., and Ross, H.E., “Geometric Design Guidelines for Suburban High-Speed Curb and Gutter Roadways,” *Report Number 1347-1F*, Texas Transportation Institute, 1995.

15. Faulkner, Gary. NCDOT, retired. Email and phone conversations, Fall 2004.

16. FHWA, “Manual on Uniform Traffic Control Devices for Streets and Highways”, Federal Highway Administration, Washington, D.C., 2003

17. Fitzpatrick, K., et al., “Design Speed, Operating Speed, and Posted Speed Practices,” *NCHRP Report 504*, Transportation Research Board, Washington, D.C., 2003.

18. Highway Design Branch. Cross-Sections of Smith Avenue in Shallotte, North Carolina, U-3462. Received by email from Jay Bennett, April 2005.

19. Holloway, J.C., et al., “Performance Evaluation of NDOR Mountable Curbs,” Final Report, Nebraska Department of Roads, Lincoln, 1994.

20. Lienau, K., “Safety Effect of Barrier Curb on High-Speed Suburban Multilane Highways” *Research Report 4690-6*, Texas Transportation Institute, 1996.

21. Nalecz, A.G., Lu, Z.Y., d'Entremont, K.L., “Effects of Light Truck and Roadside Characteristics on Rollover. Technical Summary - Final rept.,” DOT-HS-808 414, Missouri Univ.-Columbia.; National Highway Traffic Safety Administration, Washington, DC., 1994.

22. Olson, R.M., at al., “Effect of Curb Geometry and Location on Vehicle Behavior,” *NCHRP Report 150*, Transportation Research Board, Washington, D.C., 1974.

23. Owens, G., “Developing Street Standards That Allow Flexibility,” Transportation Research Circular, Washington D.C., 1999.

24. Parker, Jr., M. R., “Effects of Raising and Lowering Speed Limits on Selected Roadway Sections.” Final Report, FHWA *Report No*. FHWA-RD-92-084, Federal Highway Administration, Washington, D.C., 1997.

25. Raju, S., Souleyrette, R., and Maze, T.H., “Impact of 65-mph Speed Limit on Iowa’s Rural Interstate Highways: Integrated Bayesian Forecasting And Dynamic Modeling Approach,” *Transportation Research Record 1640*, Transportation Research Board, Washington, D.C., 1998.

26. Rao, P.V., “Statistical Research Methods in the Life Sciences,” Duxbury Press, 1998.

27. Renski, H., A. J. Khattak, and F. M. Council, “Effect of Speed Limit Increases on Crash Injury Severity: Analysis of Single-Vehicle Crashes on North Carolina Interstate Highways,” *Transportation Research Record 1665*, Transportation Research Board, Washington, D.C., 1999.

28. “Roadway Standard Drawings”, NCDOT Highway Design Branch, January 2002.

29. Ross, H.E., Jr, and Post, E.R., “Dynamic Behavior of an Automobile Traversing Selected Curbs and Medians,” *Research Report 140-6*, Texas Transportation Institute and Texas Highway Department, 1975.

30. Ross, H.E., Jr, Perera, H.S., Sicking, D.L., and Bligh, R.P., “Roadside Safety Design for Small Vehicles,” *NCHRP Report 318*, Transportation Research Board, Washington, D.C., 1989.

31. SAS Institute Inc., “SAS/STAT User’s Guide (online documents),” SAS OnlineDoc, <http://v8doc.sas.com/sashtml/stat/index.htm>, SAS Institute Inc., Cary, NC, 1999.

32. Texas Department of Transportation, Roadway Design Manual, Design Division, Roadway Design Section, Austin, 2002.

33. Transportation Research Board, Highway Capacity Manual, Special Report 209, Transportation Research Board, Washington, D.C., 2000.

34. Transportation Research Board, “Managing Speed: A Review of Current Practice for Setting and Enforcing Speed Limits,” Special Report 254, Transportation Research Board, Washington, D.C., 1998.

35. Zar, J. H. Biostatistical Analysis. Pearson Education, 1999.