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The Effect of Fluorescent Yellow Warning Signs at Hazardous Locations

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ABSTRACT

Yellow warning signs are an important and abundant type of traffic control device. Improving warning signs could be a cost-effective countermeasure at hazardous locations, especially rural locations where approximately 61% of the Nation's traffic fatalities occur. The use of fluorescent yellow sheeting in place of standard yellow sheeting provides a method to increase the conspicuity of the traffic sign while conforming to the guidelines specified by the Manual of Uniform Traffic Control Devices. The 3M Corporation, and later other companies, developed a long-lasting fluorescent yellow retroreflective sign. Although the properties of the fluorescent yellow sheeting indicate that the conspicuity of the signs is much higher, the increased conspicuity ultimately must prompt a change in motorist behavior for highway safety to be improved. Therefore, the purpose was this research was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations. A before and after study used surrogate measures to evaluate the safety effectiveness of replacing existing yellow warning signs (engineer or high intensity grade) with fluorescent yellow warning signs (diamond grade) at seven hazardous locations. The results of this effort indicate that fluorescent yellow warning signs increased the safety at four of the seven sites by providing a more conspicuous warning to motorists. However, since surrogate measures were used, the actual collision savings are unknown.

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The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views and opinions of the STC, the NCDOT, the 3M Corporation, or North Carolina State University.

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CHAPTER I--INTRODUCTION

Background

In the United States in 1998, 41,471 people were killed in motor vehicle collisions on the nation's roadways. Traffic fatalities decreased by 1 percent from 1997 to 1998 for the nation as a whole. However, three of the seven southeastern states saw an increase in fatalities. In 1998, there were 1,002 fatalities in South Carolina, 1,596 fatalities in North Carolina, and 2,824 fatalities in Florida, increases of 11, 8, and 1 percent over 1997 fatalities, respectively. Alabama, Georgia, and Tennessee experienced a decrease in fatalities from 1997 to 1998. Kentucky experienced no change in traffic fatalities. In 1998, 61 percent of the fatalities in the United State's occurred on rural roadways. Of those collisions, 11,704 occurred in 55 mph posted speed limits *(1) (2)*.

In 1998, the Southeastern Transportation Center published a report of their findings of research initiated to study the collision patterns and potential countermeasures on secondary highways in the Southeast. As part of the study, they solicited the expert opinion of transportation and highway safety professionals in the Southeast. Improving traffic control devices was identified as a possible countermeasure with promise for reducing traffic collisions in a cost-effective manner *(3)*.

Yellow warning signs are an important and abundant type of traffic control device. Yellow warning signs inform the motorist to conditions on, or adjacent to, a highway or street that are potentially hazardous to traffic operations. Yellow warning signs may require the vehicle operator to drive with caution. The vehicle operator may need to reduce her speed or maneuver accordingly in the interest of safety. Yellow warning signs are commonly used to alert the operator to changes in the horizontal alignment, the presence of intersections, or the downstream presence of traffic control devices. However, as with all signs, in order for the yellow warning signs to be effective, the operator must detect them and the information on the warning sign must be conveyed.

The visibility of an object is the threshold at which the human eye detects it when the observer is searching for it. With traffic signs, the visibility of an object is the distance at which the sign can be differentiated from its surroundings. The contrast between the object and its background determines its visibility. The conspicuity of an object is also a function of the contrast between an object and its background *(4)*. However, conspicuity refers to the ease at which an object is discovered even if the observer is not actively searching for it. Relating this to traffic signs, a traffic sign is conspicuous if it is able to attract the driver's attention.

The conspicuity of a traffic sign is the key to the ease of its detection. If a motorist fails to detect a warning sign, the consequences could be extremely unfavorable. Exposure time is limited in the roadway environment by vehicle speeds. As the visual clutter, or noise, increases along the nation's roadsides, the importance of traffic sign conspicuity also increases.

Traffic engineers have tried various methods to make yellow warning signs more conspicuous. One method employed in North Carolina is the addition of fluorescent orange flags to the top of the sign. This is displayed in Figure 1-1. Although this may increase the conspicuity of the sign and sign post, it does not increase the conspicuity of the message that the sign is conveying. Additionally, the Manual of Uniform Traffic Control Devices reserves orange for construction signing *(5)*. The yellow warning signs equipped with the orange flags send a mixed message. The driver may wonder if they are about to enter a construction zone. The orange flags used also do not have the ability to retain their color over time. Some traffic engineers have replaced the cloth flags with small square pieces of orange sheeting. This is displayed in Figure 1-2. These signs are not only sending the mixed message with the orange and yellow colors together, but also the effective shape of the sign has been changed from the standard shape required by the MUTCD. These two methods also may create the impression that a sign without orange flags or squares of orange sheeting is of lesser importance.

Figure 1-1: Yellow Warning Sign Equipped with Orange Flag

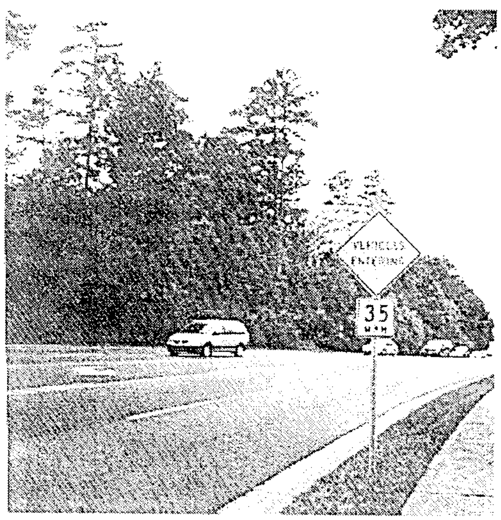


Figure 1-2: Yellow Warning Sign Equipped with Orange Sheeting

The use of fluorescent yellow sheeting provides a method to increase the conspicuity of the traffic sign while conforming to MUTCD guidelines. Fluorescent sheeting is different from ordinary sheeting because it not only reflects electromagnetic radiation, but it emits light. It absorbs near ultraviolet light and then re-emits the energy as longer wavelengths of visible light. This increases the luminance of the sign. The increased luminance in turn provides a greater contrast against the surroundings and hence, a more conspicuous sign *(6)*.

In the past, the rapid degradation of the fluorescent characteristic prevented its use in long-term traffic signing applications. Recently, the 3M Corporation, and later other companies, have developed a new class of long-lasting retroreflective sign sheeting that combines prismatic retroreflective optics with fluorescent colors. The resulting signs have an increased level of daytime conspicuity and the high level of nighttime retroreflectivity. Fluorescent orange retroreflective sheeting is currently used by many jurisdictions for work zone signing. The State of North Carolina uses fluorescent orange signs at the beginning of all work zones. Several studies have confirmed the success of fluorescent orange. Fluorescent-yellow green has been accepted by the Federal Highway Administration for use in pedestrian, bicycle, and school zone applications. Fluorescent yellow is the most recent color to be introduced. The expectation is that the fluorescent yellow sheeting can be used in yellow warning signs at hazardous locations to increase their conspicuity and the increased conspicuity will have a positive effect on highway safety. Although the increased conspicuity can be quantified in the laboratory with an eye tracking study or reaction time study, the effect of the fluorescent warning sign on motorist behavior in a real traffic situation is still unknown. Using fluorescent sheeting increases the cost of a yellow warning sign. Diamond grade fluorescent yellow sheeting costs approximately 15% more than diamond grade standard yellow sheeting. Therefore, the actual safety effect of the increased conspicuity to the driving public must be identified before highway agencies will make the investment.

Purpose and Scope

The purpose of this research was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations during daylight conditions. Although the properties of the fluorescent yellow sheeting indicate that the conspicuity of the signs is much higher, the increased conspicuity ultimately must prompt a change in motorist behavior for highway safety to be improved. Therefore, the effects of the fluorescent yellow warning signs on safety may be evaluated in a field study. This research was focused on the effects of fluorescent yellow warning signs on motorist behavior at hazardous highway locations during daylight conditions. Using collision data to identify locations with high collision frequencies, the research team identified hazardous highway locations. Because of resource limitations, the geographical limit of this project was Orange County, North Carolina. This project began in September 1999. Field evaluation began in December 1999, and was concluded in March 2000. The product of this research is a before-and-after safety evaluation of several hazardous locations with yellow warning signs in Orange County, North Carolina. The research team used indirect measures (i.e., not collision data) to test the effectiveness of replacing existing yellow warning signs with fluorescent yellow warning signs.

The research team used the results of this study to make recommendations to traffic engineers regarding the use of fluorescent yellow sheeting in place of ordinary yellow sheeting at hazardous locations. The research team also used the findings of the study and problems encountered during the study to make recommendations for future research.

Report Outline

The evaluation of fluorescent yellow warning signs began with a literature review regarding hazardous locations, human factors, collision surrogates, fluorescent materials research, and fluorescent materials field evaluation. Chapter Two contains a discussion of the applicable literature.

The selection of experimental sites is described in Chapter Three. The research team decided on the selection criteria that would be used to identify possible candidate sites. The North Carolina Department of Transportation (NCDOT) helped isolate possible sites. A brief background of the selected county and a description of the selected sites are included in Chapter Three.

Chapter Four describes the methodology used to evaluate each site. The measure of effectiveness at each location, the experiment design, and the data collection techniques are described in detail.

Chapter Five contains an analysis of the results at each site. Chapter Six contains a summary and conclusions based on the analysis of results. Recommendations for future research are presented.

CHAPTER II--LITERATURE REVIEW

The objective of this chapter is to provide a background to the research. The literature review identifies the purpose and basics on the use of yellow warning signs. Research on fluorescent signs is reviewed including human factors studies, laboratory evaluations, and field evaluations.

Yellow Warning Signs as Traffic Control Devices

Warning signs are used when it is necessary to warn traffic of existing or potential hazards on or adjacent to the highway. Typical locations or hazards that may warrant the use of warning signs are: changes in horizontal or vertical alignment, intersections, advance warning of control devices, converging traffic lanes, narrow roadways, changes in highway design, roadway surface conditions, railroad crossings, and hidden entrances onto the roadway. As summarized in *The Manual of Transportation Engineering Studies* (MTES) *(7)*, the Federal Highway Administration *(8)* recommends installing or improving warning signs as collision countermeasure for multiple situations. MTES also summarizes a United States Department of Transportation report *(9)* that cites the benefit to cost ratio of installing traffic signs as a safety improvement as 20.9 to 1. Many engineers use warning signs as countermeasures because they are very cost-effective solutions.

Placement of warning signs should provide time for the driver to perceive, identify, decide, and perform any necessary maneuvers. The Manual of Uniform Traffic Control (MUTCD) devices provides general guidelines for placement locations in relation to speed and condition of judgement required *(5)*.

As with all signs, the use of warning signs should be kept to a minimum. Unnecessary use of warning signs can breed disrespect for all signs. Warning signs should only be placed where they fulfill a need based on an engineering study. They are placed when they are needed to insure the safe and informed operation of traffic. Erecting warning signs is a relatively inexpensive safety measure. They are used when informing a motorist of a hazard more cost-effective than correcting the hazard *(5)*.

The Federal Highway Administration requires that generally all warning signs on the roadways shall be diamond-shaped with a black legend and border on a yellow background *(5)*. Yellow is the color selected from a group of twelve colors designated for use in highway signing to be used for warning signs. Yellow is defined for retroreflective sheeting for traffic control by ASTM D4956 *(10)*. Yellow is represented by the following chromaticity coordinates: (.498, .412), (.557, .442), (.479, .520), and (.438, .472). These are laboratory values under defined levels of lighting.

The size of the warning sign is specified in the MUTCD by its specifications. Oversized signs can be used where greater legibility or emphasis is needed. However, fabricating larger signs increases the costs. A hazard identification beacon may also be used to supplement an appropriate warning sign. This too increases the cost of the traffic control device without necessarily increasing its effectiveness. Hall studied the effectiveness of beacons at hazardous location on rural highways in New Mexico. The author recommends judicious use of hazard identification beacons at those sites that cannot be sufficiently improved using more traditional forms of passive corrective action *(11)*. However, others have found beacons effective at reducing speeds in school zones *(12, 13)*.

Many methods have been employed to study the effect of traffic signs on the road user. Driver surveys are a common method employed to evaluate if fluorescent signs were observed. Fisher *(14)* tested the effect of road traffic signs' information value on driver behavior. Research participants were unknowingly selected when the author indiscriminately "hitchhiked" a ride from them on a 9-km stretch of roadway leading to Johannesburg, South Africa. If the participants did not have passengers and reported unfamiliarity with the route, then the researcher engaged the participants in a discussion with the researcher about road signs that they had passed in one of two areas on the roadway. Fisher noted their answers and their vehicle speeds after leaving their vehicle at a designated spot. Of the participants questioned about the first of the two areas, only 36 subjects (56%) correctly recalled the sign when Fisher questioned them immediately after viewing it; 20 (55.6%) of which failed to reduce their speed accordingly. Of the participants questioned about the second of the two areas, 11 drivers (34%) adjusted their speed, including six drivers who failed to correctly report the sign. The researcher concludes that questioning the driver does not accurately assess measurement of the informational value of road traffic signs. Instead, he states that the true measure of effectiveness of a road sign is whether the motorist responds faster or more appropriately to the hazard.

Human Factors

Connors *(15)* investigated the effect of exposure duration on the luminance required to reach absolute, detection, chromatic, and correct-hue thresholds. In the first part of the experiment, three observers with normal color vision were presented stimuli at varying luminance and duration of exposure. The luminance necessary for threshold detection was measured as a function of exposure duration. In the second part of the experiment, the observer's task was to identify the hue of the stimulus when presented at different wavelengths, stimulus sizes, and exposure durations. The study found that in the higher luminance, a shorter duration was required for detection of the stimuli and detection of the correct hue thresholds.

Nagy and Sanchez *(16)* compared the effectiveness of luminance differences and chromatic differences to examine the usefulness of combining luminance and chromatic differences to code a target stimulus. They measured visual search time of three observers in a dark room. The stimuli the observers were searching for were small color disks. White distractor stimuli were also placed in the room. The target stimulus differed from the distractor stimuli in chromaticity or luminance or both chromaticity and luminance. Three separate experiments were conducted. The first experiment was designed to examine how search times varied as a function of display density when the target differed from the distractors only in luminance. The purpose of the second experiment was to determine how luminance differences compare with chromatic differences in affecting mean search time. The purpose of the last experiment was to determine whether there was an advantage for targets that differed from distractors in both luminance and chromaticity. The results showed that mean search time increased linearly with the number of distractors if the luminance difference between target and distractors was small but was roughly constant if the luminance difference was large. This is relevant to the traffic environment as the visual clutter on the roadside can be considered the distractors and the warning sign is the target.

Jenkins et al. *(16)* reviewed the daytime conspicuity of traffic control devices through a series of experiments. The complexity of the background, the size of the object, and its contrast with the immediate surroundings were all important variables for enhancing the daytime conspicuity. Another practical implication of their review is their conclusion that the present size of road signs is sufficient to ensure that they should be conspicuous. If they are not conspicuous, it is because their contrast is insufficient or there is a high degree of visual clutter. They urge traffic engineers to be aware of the importance of controlling sign contrast. However it should be noted that traffic engineers can control the size of the warning sign but may not be able to control the background clutter.

Fluorescent Yellow Materials Research

Much of the fluorescent materials research has involved spectral measurements taken in the laboratory under controlled lighting. Although the laboratory is a good starting point, the properties of the fluorescent material must also be measured in the field under actual driving conditions. Burns and Donahue *(18)* studied the photometric properties of yellow fluorescent-retroreflective signs using laboratory and field measurements. The signs used for the experiment included fluorescent and standard yellow retroreflective signs. Four of the five fluorescent signs had been exposed in the Arizona desert for varying durations from one to three years. In the laboratory, measurements of the photometric properties of each sample were taken including the coefficient of retroreflection over a range of observation angles, nighttime color, daytime color, and fluorescence. Field measurements were taken at the drivers eye position through the windshield of a vehicle during daytime and nighttime conditions in the field.

From this they concluded the following: laboratory testing of the colorimetric and photometric properties of fluorescent-retroreflective sheeting correlates well with field measurements of the same properties; the fluorescence luminance factor (Y_F) can be used to quantify and assess the durability of a sign's fluorescent properties; the fluorescence luminance factor correlates with high daytime sign luminance and high sign luminance contrast on the roadway; the nighttime photometric performance is similar to ordinary yellow sheeting of the same optical design; and field and laboratory measurements of the yellow fluorescent-retroreflective prismatic material indicate significant retention of colorimetric and photometric properties after accelerated and natural weathering. They also conclude that together with the results of other studies, the results of this study indicate a strong correlation between the high daytime and nighttime luminance properties of combined performance fluorescent-retroreflective signs and their visibility performance on the roadway and potential for improving road safety.

The laboratory and field measurements of the sign properties are related to the perception of the road users. Burns and Johnson *(6)* correlated the measured spectral radiance of fluorescent and non-fluorescent materials to the perceived visibility and conspicuity of the materials. Observers were asked to rate the brightness of a set of fluorescent and non-fluorescent targets. Photometric measurements were taken using a telespectroradiometer. The telespectroradiometer measures the sign luminance and the luminance of the area around the sign. With these two measures a ratio of the contrast of the sign to the background is found. The observer ratings and photometric measurements supported a direct correlation between the perceived brightness of the targets and target luminance contrast. Therefore, the photometric properties of fluorescent sheeting do contribute to exceptional visibility and conspicuity. The researchers also measured the photometric properties of fluorescent and non-fluorescent targets under natural daylight in the field. Standards for luminance and color of traffic signs are based on laboratory experiments. However, out in the field, the photometric properties are different than in the laboratory under artificial light. Measured under heavily overcast and rainy conditions, the luminance contrast of the fluorescent targets increases significantly relative to the non-fluorescent signs. The spectral radiance of each target was also measured. The spectral radiance of both the fluorescent and non-fluorescent targets degraded with decreasing daylight. However, the fluorescent targets degraded less than the non-fluorescent targets.

Fluorescent Field Evaluation

The true effect of a fluorescent sign on a driver can only be measured in the field. Jenssen et al. *(19)* evaluated the visual performance of fluorescent retroreflective traffic control devices through a human factors visibility study. Their study used a course viewed by participants in a railroad car to measure the distance at which subjects could detect and recognize shape, color, and the contents of fluorescent traffic signs versus non-fluorescent traffic signs. They used various signs employing fluorescent orange, fluorescent yellow, fluorescent yellow-green, and their non-fluorescent counterparts. They used two age groups, 18-25 year olds and 55-75 year olds, during daytime and some nighttime conditions. The fluorescent signs were detected before their non-fluorescent counterparts during daytime and nighttime conditions with an average difference of 53 m during the daytime and 31 m during the nighttime. This is statistically significant at the 99% level. As expected, this finding was especially true with the 55-75 age group. On average, the older age group detected the fluorescent signs 65 meters earlier than the non-fluorescent signs.

This research was taken further and studied in the actual driving environment as part of a comprehensive study of fluorescent retroreflective traffic control devices. Jenssen et al. *(19)* conducted a field evaluation of fluorescent traffic control devices. They conducted a series of studies of driver behavior in real traffic situations. At two test sites in Norway, they replaced existing enclosed lens or encapsulated lens retroreflective sheeting with fluorescent prismatic signs. The research team observed vehicle speed and lane position in a traffic engineering study, conducted roadside interviews at each site, and conducted a driver eye-scanning behavior study with a small number of subjects. One test site was a 4.4-km section of TransEuropean Roadway that had been identified as a high collision area. The section is a winding mountain road with many sharp curves. The signs were replaced in two phases on this section. First all of the existing encapsulated lens yellow sheeting chevrons were replaced with identical fluorescent yellow and black prismatic signs. Second, all regulatory and warning signs were replaced with fluorescent yellow-green signs. The original signs were made of white enclosed lens sheeting. This is not just a change in fluorescence, but also a change in color. The research team found a statistically significant (at the 99% level) reduction in light vehicle space mean speeds over the course in both after periods (2.3 km/hr for phase 1, 4.1 km/h for phase 2.) A reduction in centerline line crossings was also observed for the sharp left-hand curves in the section.

In an effort to determine the effectiveness of fluorescent yellow-green warning signs for pedestrian, bicycling, and school applications, the FHWA commissioned a nationwide program for their evaluation. In the largest field evaluation to date, Clark et al. *(16)* studied the effect of replacing yellow pedestrian warning signs with fluorescent strong yellow-green pedestrian warning signs in improving safety at midblock pedestrian crossing areas. The results of the effort indicated that the fluorescent strong yellow-green signs produced marginal improvements in perceived safety at the crossing sites when compared to standard pedestrian warning signs. The research showed significant increased slowing/stopping at three of the four treatment sites. However, the proportion of pedestrian/vehicle conflicts did not change significantly.

In another large field test reported to FHWA, Dhar and Woodin *(22)* conducted a similar before and after study and survey of the fluorescent strong yellow-green signs for pedestrian applications at three test sites in New York State. They monitored driver behavior and vehicle speed and conducted an impression survey of persons viewing the signs. Their results provided encouraging evidence of the benefit of the fluorescent signs over standard signs. Although they saw no change in vehicle speeds between the two periods, they did see an increase in the amount of drivers who slowed for pedestrians in the crosswalk. At one of the sites there was also a statistically significant reduction in the proportion of conflicts with pedestrians or bicyclists in the after period.

Besides pedestrian, bicycling, and school applications, fluorescent sheeting has also been field evaluated for construction signing applications. De Vos, Alferdinck, and Bakker *(23)* tested the effect of fluorescent yellow retroreflective signing in work zones on driver behavior by videotaping the approach to a construction zone on three consecutive days. Each day a different type of signing was installed on the approach: 1) non-fluorescent, high intensity grade signing, 2) fluorescent diamond grade signing, and

3) fluorescent diamond grade signing with a backing board. Driver speed behavior, interactions between vehicles, and lane changes were observed. On the day when the fluorescent sheeting was in place, the high speeds were reduced during dusk conditions. When the backing board was in place behind the posted speed signs, the average speed and excessive speeds were reduced at the entry of the work zone during daytime. With both the fluorescent signing and the fluorescent signing with a backing board, the researchers observed a decrease in potentially hazardous interactions between vehicles. The report fails to mention if any of these changes could be attributed to the drivers becoming more familiar with the construction zone on the third day as opposed to the first day. If the researchers had reported the study in the reverse order on the fourth, fifth, and sixth day, the findings of the study could have been strengthened. They also failed to mention how long the construction zone had been in place on the first day of the study.

In the United States, fluorescent orange is currently used for some construction signing applications. Hummer and Scheffler conducted a before and after with control study to compare fluorescent orange to standard orange work zone traffic signs *(24)*. They conducted the study at seven long-term work zones in North Carolina (four treatment and three control). All seven work zones had a left lane drop on a multilane highway. They observed traffic conflicts, the percentage of all traffic in the left lane, the percentage of trucks in the left lane, mean speeds, and speed variances at the beginning of the approach to the work zone, the taper, and a point midway between the beginning and the taper. They concluded that the fluorescent orange signs caused some, primarily positive, changes in driver behavior.

It has been suggested that fluorescent signs may adversely affect traffic safety by distracting the driver with such a conspicuous sign. However, no research to support this assertion is available.

Conclusions

In summary, fluorescent-retroreflective sign sheeting has been shown to increase sign luminance. The resulting affect is increased traffic sign conspicuity. Fluorescent orange and fluorescent yellow-green have shown in field evaluations to have a positive effect of highway safety. Fluorescent yellow materials research in the laboratory and outdoor human factors evaluations indicate that this latest color may have a similar positive effect on highway safety. However, a field evaluation in the actual driving environment is needed to measure the effect of the increased conspicuity on the behavior of the driver.

Chapter III--Site Characteristics

This chapter describes the criteria used to select experimental sites. It explains the process through which the sites were selected. It also provides a brief description of each experimental site.

Selection Criteria

The main criterion for an experimental site was that a site has shown through collision data that it was a hazardous location. For a site to have been considered a hazardous location for this study, it must have had more than five non-animal reported collisions in the three most recent years of available collision data. Additionally, those collisions must have been related to the information conveyed by the yellow warning sign. A site was defined as an intersection or a small, observable section of a roadway such as a curve or an approach to an intersection.

Experimental sites selected for this experiment must also have had existing yellow warning signs. The warning sign must have conveyed information to the motorist that was relevant at all times. For instance, a yellow warning sign that informed the motorist that "the bridge freezes before the roadway" was not relevant in July in North Carolina. Therefore, this type of sign was not included in this study. Relevant signs included signal ahead, stop ahead, yield ahead, curve, reverse curve, turn, reverse turn, side road, intersection ahead, arrow boards, and chevrons.

In addition, an experimental site must have had a behavior that could be observed with one or two data collectors and the available resources of the project. The site must have had a location where motorist behavior could be observed safely without endangering the motorist or the research team.

Experimental sites could not be under construction. The traffic conditions and signing practices of a construction zone would induce multiple threats to the validity of the experiment.

Site Selection

Orange County, North Carolina was selected as the area to conduct the experiment based on cooperating officials, abundance of rural roads, moderate to heavy traffic volumes, the proximity to the investigating university, and its medium size. Orange County is located in the Piedmont of North Carolina on the western edge of the metropolitan area known as the Research Triangle. The Research Triangle is comprised of Raleigh, Durham, Chapel Hill and many other small communities. The county is adjacent to the Triad region (Greensboro, Winston-Salem, and High Point). The population of Orange County in 1997 was 107,253 with a projected population of 112,436 for the year 2000. Chapel Hill, the largest city in Orange County, is the home of the University of North Carolina at Chapel Hill and has a (1997) population of 42,500. Carrboro, another town in Orange County, has a (1997) population of 15,000. Hillsborough, the county seat, has a (1997) population of 5,000. The land area of the county is 398.0 square miles, nineteen of which form Chapel Hill, 4.3 form Carrboro, and 4.3 form Hillsborough *(25)*.

As of November 1998, there were 80,346 vehicles registered in Orange County, 59,289 of which were passenger vehicles. Two major interstate highways, Interstate 40 and Interstate 85 intersect in the county just west of Hillsborough. Primary highways include NC 86, NC 57, NC 49, and NC 54. Together they consist of 127.5 miles of primary state-maintained highways. There is an additional 668 miles of state-maintained secondary, paved roads *(25)*.

In September of 1999, a request was made to the North Carolina Department of Transportation (NCDOT) for a list of hazardous locations in Orange County. The research team requested that the list be from fifty to one hundred sites of spots and sections that have a collision history that indicate that the location was hazardous to motorists. Although only ten sites were needed to conduct the experiment, more sites were requested so that the sites could be randomly drawn from a population of hazardous locations in the county. In October of 1999 a list of fifty-five locations was received from the NCDOT. Thirty-seven of these locations were intersections and eighteen were sections of roadway. The locations are listed in Appendix A as Table A-1 and Table A-2, respectively.

The research team visited each of the fifty-five sites in September for an initial field evaluation. Each site was evaluated to ensure that there were yellow warning signs at the location. Currently the NCDOT does not have a database of their traffic signs. Therefore, they were not able to screen the list of locations to ensure that all did in fact have yellow warning signs. Of the fifty-five sites, twenty-five intersections and four sections did not have warning signs and had to be removed from the population of eligible experimental sites. Another three sites, two intersections and one section, were removed because of on going road construction. One intersection and one section were removed because the research team was unable to locate the sites in the field.

There were nine intersections and twelve sections remaining. Upon further site investigation, five intersections were removed. The five intersections, Erwin and Dairy, Estes and Sewell School, Ephesus and Legion, Cardinal and Churton, and Churton and Mayo, are all large, highly visible intersections with multiple lanes and high volumes. Although the five intersections all had yellow advance warning signs, the signals were clearly visible well in advance of the intersection. Also, during the peak period, the demand on these signals was often greater than the capacity. Motorists must wait in long queues before reaching the intersection. Based on these intersection characteristics, the information provided by the yellow warning sign was redundant to the information conveyed by other features of the intersection.

The four remaining intersections and twelve sections are listed in Table A-3 and A-4 respectively in Appendix A. This list was sent to the NCDOT to request that a spot strip collision analysis be compiled for each of the sixteen sites. Collisions were requested for the three most recent years of available data. The spot strip analyses were delivered with 1996 through 1998 collisions.

The spot strip analyses were reviewed to ensure that there were more than five collisions in the three-year period. Collisions involving vehicles colliding with animals in the roadway were not considered. Five sections were excluded because they did not meet this criterion. One section was excluded because, although there were more than five non-animal collisions, the eight reported collisions were spread over a one-mile area without any concentration around a yellow warning sign. One intersection was excluded because the collisions were caused by the congestion at the signal and not by the curve ahead warning sign on one of the approaches. After this review, only three intersections and six sections remained.

Site Descriptions

Included here are brief descriptions of each section and intersection that were selected from the original list received by the NCDOT. As explained in subsequent chapters, ten experimental sites are selected from these six sections and three intersections. A pictorial description of each site that was used for the experiment is included in Appendix B.

Section A: NC 157 in the vicinity of secondary route 1575 (Walker Road)

NC 157 is a rural 2-lane paved road with grass shoulders on the Orange and Durham County line that runs northwest to southeast. Between Walker Road and the county line, there is a horizontal curve on a vertical crest. A low volume dirt road, Bromely Road, intersects NC 157 just north of the crest.

Driving northbound, a motorist would encounter a graphical curve sign (W1-4L) with a 35-m.p.h. auxiliary speed plaque, a side road ahead sign with a 35 m.p.h. auxiliary speed plaque, 3 chevrons, the intersection of Bromely Road on the right, 3 chevrons, and then the intersection of Walker Road on the left. Southbound, a driver would encounter Walker Road on the right, an advance curve sign with a 35 m.p.h. auxiliary speed plaque, a side road sign with a 35 m.p.h. auxiliary speed plaque, 3 chevrons, Bromely Road on the left, and 3 chevrons.

Section B: NC 49 in the vicinity of NC 86

NC 49 is a rural two-lane paved road with narrow grass shoulders and a tree line that is very close to the road. In the north part of the county, NC 49 ends at NC 86 at a 30 degree angle with double stop signs (i.e. on left and right sides of lane, with left side stop sign positioned on a small concrete median) for northbound traffic on NC 49. For the northbound traffic on NC 49, there is a stop ahead graphical sign (W3-1a).

Intersection C: NC 54 and Secondary Route 1102 (Dobson's Crossroads)

Site C is located four miles west of the town of Carrboro at the intersection of NC 54 and secondary route 1102. NC 54 west of Carrboro is a rural, two-lane, paved road with ample clear zones. The speed limit is 55 mph, but the open, flat conditions facilitate higher operating speeds. South of the intersection, secondary route 1102 becomes Butler Road. Dobson's Crossroads is stop-controlled at the intersection, while NC 54 is uncontrolled. There are turn bays on NC 54 at the intersection. On eastbound and westbound NC 54, there are intersection ahead signs before the intersection. The signs do not have advisory speed plaques.

Intersection D: NC 57 and NC 86

Just north of Hillsborough, southbound NC 57 ends at a signalized intersection with NC 86. NC 86 is a north-south road. NC 57 is also a north-south road. Southbound NC 57 curves to the west immediately before approaching the signal. The signal is the low point of the area. All approaches slope down to the intersection. The eastbound approach has very minimal volume. It is a driveway to a gas station for state and county vehicles such as police cars and maintenance trucks. There are two signal ahead signs (W3-3) on NC 86, one northbound and one southbound. On south/westbound NC 57 there is a signal ahead sign, a right turn ahead sign (W1-1R), and a large arrow sign (W1-6).

Section E: US 70 Bypass in the vicinity of Secondary Route 1561 (Lawrence)

This section of road is to the east of Hillsborough. US 70 splits into Business US 70 and Bypass US 70 one mile east of this section. Bypass US 70 is 2-lane, paved road with a 55 m.p.h. speed limit. Lawrence Road is a north-south road that crosses Bypass US 70. Lawrence Road dead ends one mile north of the intersection but still contributes some traffic to the intersection. The intersection is signalized. On Bypass US 70 there are signal ahead signs from both approaches. The southbound approach of Lawrence Road has a double signal ahead sign.

Section F: Secondary Route 1710 (Old NC 10) in the vicinity of Secondary Route 1723 (New Hope Church Road)

Old NC 10 is an east-west road south east of Hillsborough. It is a paved, 2-lane road with ample grass shoulders. There is a very severe curve on Old NC 10 under a grade-separated railroad crossing. There is a reverse turn sign (W1-3R) with a 25-mph speed advisory sign for both westbound and eastbound traffic on Old NC 10. There are also six chevrons in each direction.

Intersection G: Secondary Route 1006 (Orange Grove Rd.) and Secondary Route 1192 (Mayo Street)

This intersection is within the city limits of Hillsborough although it isn't an urban intersection. Mayo Street ends at Orange Grove Road. Both are two lane roads with 35 m.p.h. speed limits. Mayo Street is stop controlled for left-turning traffic and yield-controlled for right turning traffic. Orange Grove Road is uncontrolled. The two roads intersect on a slight horizontal and crest vertical curve. There are curve ahead signs (W1-4R) on both approaches on Orange Grove. For the southbound Orange Grove approach there is also a side road sign (W2-2). There is a stop ahead sign on westbound Mayo Street.

Section H: Secondary Route 1009 (Old NC 86 Road) in the vicinity of Secondary Route 1129 (Davis Road)

SR 1009 is a paved, 2-lane road with minimal shoulders south of Hillsborough. There is a curve just north of the intersection of SR 1009 and Davis Road. There is a curve ahead sign on northbound SR 1009 but no sign on the southbound approach. There are no chevrons in the curve. The speed limit is 45 m.p.h.

Section I: Secondary Route 1777 (Homestead Road) in the vicinity of Secondary Route 1729 (Rogers Road)

The area is semi-rural. Homestead Road is a two-lane, paved, east-west road. SR 1729 is north-south road that ends at Homestead Road. The southbound approach of SR 1729 is stop-controlled at Homestead Road. Homestead Road is uncontrolled. The intersection is in a sag vertical curve. There are side road signs (W2-2) for both eastbound and westbound on Homestead Road.

Summary

The research team intended to randomly select the experimental locations but was not able to do so because only nine locations met the criteria. However, the locations selected for the experiment were based on clear and consistent criteria established by the research team. The selected locations are the basis for the next chapter, Evaluation Methodology.

CHAPTER IV--EVALUATION METHODOLOGY

The objective of this chapter is to discuss the methodology that was employed in evaluating the fluorescent yellow warning signs. The chapter is arranged in the order in which the evaluation process occurred. The data collection processes for the different measures of effectiveness are discussed.

Collision Analysis

The research team requested the collision history for the three most recent years of available data for each experimental location from the North Carolina Department of Transportation. Collisions reported from 1996 through 1998 were described in a spot strip analysis for each location. Spot strip analyses report the milepost where the collision occurred, the collision date and time, the type of collision, the amount of property damage in dollars, any injuries that resulted, the pavement condition, the light condition, fixed objects that were struck, the type of vehicles involved, whether alcohol was involved, the approximate speed of involved vehicles, the direction the vehicle or vehicles were traveling, and the maneuver of the vehicle or vehicles when the collision occurred. The report also includes a summary of the data. A strip diagram of intersecting roads and features along the section is included with the section reports but not with the intersection reports.

There are some inherent problems with police reported crash data. In general, the accuracy of the crash data is dependent on the training and expertise of the police officer collecting the information and the difficulty of collecting the information. The location of the collision is referenced by the reporting officer and then assigned a milepost when the data are input in the office.

The reporting threshold for collisions in North Carolina in 1996 through 1998 was $1000. That is, in order for a collision to be recorded in the collision files for the state, it had to have incurred at least $1000 of damage to the vehicle or vehicles involved.

The KABCO injury scale is used on the North Carolina police reports. The investigating officer determines the level of injury. The most severe category is 'fatal' (K); the next most severe category is 'incapacitating injury' (A); the next most severe category is 'non-incapacitating injury' (B); and the least severe category is 'possible injury' (C). The last category is 'no injury' (O).

All reported collisions from 1996, 1997, and 1998 for each site were delivered in a stop strip analysis. A spot strip analysis for a section reports collisions within a defined segment. Spot strip analyses for intersections include all reported collisions occurring within 999 feet of the intersection on any of the approaches. A section analysis was requested for site A, B, E, F, H, and I. An intersection analysis was requested for site C, D, and G.

Based on the collision analysis of the six sections and three intersections, experimental sites were identified. Although the preliminary field evaluations were used to identify possible experimental locations, the collision analyses were needed to identify distinct sites within each section or at each intersection. A site is an observable location such as a portion of a curve or an approach to an intersection.

Section A

Collisions occurring on NC 157 from the Durham County line to 0.70 miles north of the county line were reported in the spot strip analysis. Sixteen collisions were reported in this section in the three-year period from 1996 through 1998 including two class B injuries and seven class C injuries. Eleven of the sixteen collisions occurred in a tenth of a mile section from milepost 0.10 to milepost 0.20. This tenth of a mile section is an S-curve. All nine injuries occurred in this section. The collisions in this section are numbers four through fourteen in the spot strip analysis. They are briefly summarized in Table 4-1.

Travelers on NC 157 are heading southeast or northwest. The collision report only has four choices for direction: north, east, south, or west. Therefore, collisions of vehicles heading southeast are coded as south or east and collisions of vehicles heading northwest are coded as north or west. Nine of the eleven collisions in the tenth of a mile section are single vehicle run off the road collisions. In seven of those collisions, vehicles were heading southeast.

Table 4-1: Collisions 4 through 14 at Section A

Collision Number	Milepost	Collision Type	Vehicle	Direction of travel
4	0.10	Ran Off Road Left	Passenger vehicle	W
5	0.10	Ran Off Road Right	Pickup truck	E
6	0.10	Ran Off Road Right	Passenger vehicle	E
7	0.13	Ran Off Road Left	Passenger vehicle	S
8	0.14	Angle	Station wagon	E
			Station wagon	N
9	0.14	Rearend	Passenger vehicle	N
			2 Axle truck	N
10	0.14	Ran Off Road Right	Passenger vehicle	E
11	0.14	Ran Off Road Right	Pickup truck	S
12	0.16	Ran Off Road Left	Passenger vehicle	S
13	0.18	Ran Off Road Left	Passenger vehicle	S
14	0.19	Ran Off Road Right	Passenger vehicle	N

Although this study focuses on daylight, dawn, and dusk conditions, eight of the above eleven conditions were coded on the police report as occurring during 'dark' light conditions. Additionally, data were only collected for this study during dry pavement conditions, nine of the eleven conditions were coded as occurring on 'icy' or 'wet' pavement conditions.

Section B

The spot strip analysis for section B contains reported collisions occurring on NC 49 in a 0.63 mile section starting 0.5 miles south of the intersection with NC 86 and extending to the county line. Eight collisions were reported in the three-year period from 1996 through 1998; three class C injuries occurred in those collisions. Half of the collisions had the light condition coded as 'day' and half as 'dark'. Three of the collisions occurred when the pavement was wet, five when the pavement was dry. Seven of the eight collisions occurred at the NC 86 junction. Six of those collisions involved northbound vehicles striking vehicles on NC 86 or fixed objects. Reportedly, five of those northbound vehicles did not observe the stop sign.

Intersection C

The spot strip analysis for intersection C contains reported collisions occurring within 999 feet of the intersection of NC 54 and SR 1102/SR 1951 (Dobson's Crossroads/Butler Road). Sixteen collisions were reported in the three-year period from 1996 through 1998 including two class B injuries and five class C injuries. Five of those collisions were coded as 'dark' light conditions. All but one were coded as 'dry' pavement conditions. Seven of the sixteen collisions were rear ends, four were collisions with animals, three were left turn cross traffic collisions, one was an angle collision, and one was a single vehicle ran off road collision. Eleven of the sixteen collisions involved westbound vehicles on NC 54.

Intersection D

The spot strip analysis for intersection D contains reported collisions occurring within 999 feet of the intersection of NC 57 and NC 86 on any of the approaches. Seventeen collisions were reported in the three-year period from 1996 through 1998 including one class A injury and six class C injuries. Only four of the collisions were coded as occurring during 'dark' lighting conditions. All but four were coded as 'dry' pavement conditions. Eleven of the collisions were rear end collisions, three were left-turn-across-traffic collisions, one was a left turn collision for the same direction, and one was an angle collision. Seven of the rear end collisions involved vehicles heading southbound. Four of the rear end collisions involved vehicles heading northbound.

Section E

The spot strip analysis for section E contains reported collisions occurring on a one-mile section of US 70 Bypass in the vicinity of SR 1561 (Lawrence Road). Twenty-three collisions were reported in the three-year period from 1996 through 1998 including three class B injuries and five class C injuries. Eleven of the twenty-three collisions occurred at the intersection with SR 1561/1709. These are referred to as collision 9 through 19 in the spot strip analysis. All eleven of those collisions were coded as occurring during 'day' light conditions and 'dry' pavement conditions. Six of the eleven were angle collisions and two were rear end collisions.

Section F

The spot strip analysis for section F contains reported collisions occurring on a one-mile section of SR 1710 in the vicinity of SR 1723. Eleven collisions were reported in the three-year period from 1996 through 1998 including two class B injuries and two class C injuries. Three of the four injuries occurred at the same spot. SR 1723 takes a reverse turn to the right as it dips under a railroad overpass. Three collisions occurred at this spot resulting in the two class B injuries and one of the class C injuries. All three of the collisions were single vehicle run off the road collisions involving passenger vehicles traveling westbound during 'day' or 'dusk' light conditions. One was coded as occurring on 'wet' pavement conditions.

Interviews with local residents corroborated that run off the road collisions were occurring at this spot. However, the residents indicated that the magnitude of collisions was much greater than reported in the collision files. According to those residents, single vehicle run off the road collisions often go unreported at this spot.

Intersection G

The spot strip analysis for intersection G contains reported collisions occurring within 999 feet of the intersection of SR 1006 (Orange Grove Road) and SR 1192 (Mayo Street). Twenty-seven collisions were reported in the three-year period from 1996 through 1998 including one class A injury, four class B injuries, and seven class C injuries. Twenty of the collisions were coded as occurring during 'day' light conditions. Nineteen of the collisions were coded as occurring on 'dry' pavement. There were six rear end collisions, six left turn and cross traffic collisions, five right turn and cross traffic collisions, five ran off the road collisions, four left turn and same road collisions, and one angle collision.

Section H

The spot strip analysis for section H contains reported collisions occurring on a one mile section of SR 1009 (Old NC 86) in the vicinity of SR 1129 (Davis Road).

Thirty collisions were reported in the three-year period from 1996 to 1998 including seven class B injuries and nine class C injuries. Ten of the collisions occurred within a 0.02-mile section at the junction of SR 1009 and Interstate 40. Although this is a large concentration of collisions, there are not any warning signs that would facilitate this spot being selected for the experiment. At another spot along the section, eight collisions were reported within a tenth of a mile. They occurred at a curve on the roadway with one advance curve warning sign for northbound traffic. The eight collisions included one class B and two class C injuries. These are referenced as collisions fifteen through twenty-two in the spot strip analysis. Three of the eight collisions were coded as occurring during 'dark' light conditions. Four of the eight collisions were coded as occurring on dangerous pavement conditions such as 'snow', 'icy', and 'wet'. Six of the eight collisions are single vehicle run off the road collisions. In five of these collisions, the vehicles were traveling northbound, the direction equipped with the yellow warning sign.

Section I

The spot strip analysis for section I contains reported collisions occurring on a one mile section of SR 1777 (Homestead Road) in the vicinity of SR 1729 (Rogers Road). Twenty-one collisions were reported in the three-year period from 1996 to 1998 including one class A injury, four class B injuries, and seven class C injuries. The total estimated property damage was $96,200. Seven of the twenty-one collisions occurred in a 0.02-mile spot at the intersection of Rogers Road, all of which occurred during daylight conditions. These are referenced as collision number 10 through 16 in the spot strip analysis. The majority of those collisions occurred on dry pavement. Five of these collisions were rear end collisions, four eastbound and one westbound.

Experiment Design

A before-and-after experiment is a paired comparison of measurements taken at the same location twice: once before a change and once after a change. The *Manual of Transportation Engineering Studies* identifies the before-and-after experiment as an attractive experiment design because: it allows a comparison to be performed without having to consider variations between locations, it can be performed during improvement programs, it requires measurements at fewer locations than other experiment designs, and it is easily understood by engineers and non-technical readers. The *Manual* also identifies seven drawbacks to a before-and-after experiment design: the experiment may require a longer time between the decision to conduct an experiment and the achievement of a conclusion than other types of experiments, it may be difficult to design while treatments are being implemented, units may not react instantaneously to a treatment or may exhibit unusual behaviors that bias the experiment, units may react in an unstable or random fashion, other factors may cause the changes in the measure of effectiveness other than the treatment (history), the measure of effectiveness may mature or change over time (maturation), and regression to the mean may occur. *(7)*

Parker published recommendations for field evaluations of fluorescent strong yellow green pedestrian signs on motorist behavior in the Federal Highway Administration (FHWA) publication "Guidelines for Evaluating Fluorescent Strong Yellow Green Crossing Signs" *(26)*. Parker recommends using a before and after study with comparison site experimental design with five experimental and two control sites.

The guidelines do not suggest using a simple before and after study because the experimental sites may produce unreliable or misleading results due to unknown or uncontrolled factors. Parker also recommend replacing all existing signs with new standard crossing signs one month prior to data collection to avoid any confounding factors created by the use of an old standard sign. However, the increase in cost and duration of the project from the sign replacement is not mentioned. Parker also recommends collecting the after data one month following the fluorescent sign installation.

The experimental method employed for this evaluation was a simple before-and-after design. Comparison sites were not used because sites with yellow warning signs are not all similar in traffic control and geometry. Comparison sites must be similar to the experimental sites in order to be effective. In this experiment, the experimental sites include curves, 2-way stop-controlled intersections, signalized intersections, and stop-controlled t-intersections. If comparison sites had been used, it would have increased the number of sites needed. Additionally, adequate comparison sites would have been hard to locate. Comparison sites are used in before and after experiments to account for extraneous factors such as changes in driver characteristics, new legislation, or other factors which may influence the results. The short duration of this project and the number of experimental sites mitigated these concerns. No major changes occurred during the project that would influence the results: no new traffic legislation was passed, relevant volumes did not change significantly, seasonal variations were limited, and the sites had no noticeable changes in the driving environment.

The experimental units selected were hazardous locations in Orange County with yellow warning signs. It was the original intention of the research team to randomly select the experimental sites from a pool of candidate sites. The candidate pool received from the NCDOT was greatly reduced because many sites did not meet the site criteria established by the research team. Therefore the sites were not randomly selected. However, there was no bias due to deliberate site selection either. The nine experimental sites were the only locations that met the criteria of the study from the fifty-five sites that were originally candidates.

The treatment applied to the test units was a change in the color of the warning signs from yellow to fluorescent yellow. The new signs were identical in size and message to the existing signs. The fluorescent yellow signs were fabricated on diamond grade retroreflective sign sheeting. The existing yellow signs were on various types of sheeting used by the Department of Transportation including engineer grade and high intensity grade sheeting.

The ultimate measure of effectiveness of a yellow warning sign is the number of collisions it prevents. However, an experiment that studies the collision effects of fluorescent yellow sheeting would be too long and costly for this study. Therefore indirect measures or collision surrogates were used for this study. This reduced the duration of the experiment to four months. The short experiment duration reduced the likelihood of bias due to history or maturation. Another threat to the validity of the study was reduced by allowing a minimum of a three-week warm-up period between the before and after period to allow drivers to overcome any novelty or "shock" affects the experimental signs might have. Regression to the mean is not a substantial threat to the validity of the study since collisions were used to select the study sites but indirect measures were used to conduct the experiment.

The sample size collected at each experimental site varied by the type of measure collected and the time needed to collect the sample. Approximately the same size of sample was collected in the after period as was collected in the before period.

Data were collected during daylight hours under conditions of fair to good weather. Data were only collected when the pavement was dry and clear to reduce any changes in condition from the before period to the after period. The before data collection began in mid-December. The deciduous trees no longer had their leaves at that time. So as not to have any differences in the background of the signs between the two time periods, the research team attempted to collect the after data before the deciduous trees regained their leaves. However, the last week of data collection occurred when some of the foliage had returned.

Measures of Effectiveness

The observed behavior, or measure of effectiveness (MOE), selected at each location was based on the collision history of the site, the traffic control devices at the site, the available resources of the data collector, and the available observation locations. The best measures of effectiveness are the ones that use the available staff, equipment, and budgeted time and are able to gather an adequate sample size. Hostetter and Lunenfeld *(27)* identified the following four things that a measure of effectiveness must be: 1) directly related to the project's objective, i.e., valid; 2) stable and repeatable, i.e., reliable; 3) amenable to data collection—given a particular equipment/personnel situation, i.e., feasible; and 4) of value in diagnosing a problem, i.e., meaningful.

A single measure of effectiveness could not be chosen to evaluate all sites. The warning signs at the sites convey different information to the driver based on the type of hazard at the site. The measure of effectiveness selected must be related to that information. Hostetter and Lunenfeld *(27)* suggest that a basic way to identify candidate measures for both diagnosing and as evaluation MOE's is to analyze driver performance requirements.

The same data collector was employed at each site for the before and after periods The research team limited data collection to one data collector if possible. One site necessitated the assistance of an additional data collector.

Site A

Collision studies indicate that horizontal curves experience a one and a half to four times greater collision rate than tangent sections *(28)*. Based on single vehicle run off the road collisions being the predominant type of collision occurring at this site, the research team selected centerline and edgeline encroachments in the curve as the measure of effectiveness. Hostetter and Lunenfeld *(27)* identify encroachments as a possible MOE when evaluating a horizontal curve. They define an encroachment as a deviation from a prescribed path in a lane, intersection, or interchange as described by the existing pavement markings. An encroachment occurs when a wheel or wheels of an encroaching vehicle touches or goes across a lane line, centerline, edgeline, or other feature *(27)*. Many researchers have used centerline and edgeline encroachments to evaluate curves including Jennings and Demetsky *(29)*, Terhune and Parker *(30)*, and Glennon, Newman, and Leisch *(31)*.

The majority of the collisions involved vehicles heading southeast towards Durham County. Based on the direction in which the collisions were occurring and the availability of an observation location, the research team decided to observe southeast-bound vehicles heading towards Durham County.

Site B

The only yellow warning sign at Site B is a stop ahead sign on the northbound approach of NC 49. The majority of collisions occurring at this intersection involved vehicles failing to observe the stop sign. If a driver failed to see the stop ahead sign but did see the stop sign, the driver would have less reaction time to slow his or her vehicle and observe the stop sign. The driver's brake application would begin later for the stop sign. Some drivers may not fully observe the stop sign or fail to observe the stop sign at all.

Hostetter and Lunenfeld recommend brake light indications and sign compliance as possible MOE's for warning signs *(27)*. The research team selected two MOE's at this site: stop sign observance (compliance) and brake application.

Site C

At this stop-controlled intersection for the minor approach, the only yellow warning signs are intersection ahead signs on the major approach, NC 54. Based on the control of the intersection and the various types of collisions that were occurring there, the research team selected traffic conflicts as the MOE.

The *Manual of Transportation Engineering Studies (7)* identifies traffic conflicts studies as a supplement to traffic collision studies in estimating the traffic collision potential at an intersection or other location. Traffic conflict studies observe and record the interactions between vehicles or road users when one or more vehicles or road users take evasive action to avoid a collision. The *Manual* identifies the small investment of time and other resources as a benefit of a traffic conflict study. It recommends traffic conflict studies as a way to evaluate the effectiveness of a safety-related countermeasure before the traffic collision data are available. It also notes that a before-and-after study with traffic conflicts may not need control sites to overcome the history and maturation threats to experiment validity.

Migletz, Glauz, and Bauer *(32)* studied the relationship between traffic conflicts and collisions by analyzing 41 intersections in Kansas City, Missouri. The purpose of their study was to identify expected and abnormal conflict rates for various circumstances. They concluded that overall traffic conflicts of certain types are good surrogates for collisions. Although there are twelve basic conflict types, not all are common at signalized intersections. Same direction and opposing left turn conflicts are common. Cross traffic conflicts are rare and occur only if a motorist violates the red signal phase. At unsignalized intersections, they found that cross traffic conflicts are the prevalent type.

Site D

There are two distinct experimental locations at this signalized intersection. The major approaches, NC 86 both northbound and southbound, are equipped with signal ahead signs. The majority of the collisions involved vehicles on these approaches. This site is referred to as Site D1. Based on the various types of intersection-related collisions occurring, the research team selected both conflicts and events (primarily signal violations) as the MOE's at this site. Hostetter and Lunenfeld recommend traffic conflicts as a suitable MOE for evaluating signalized intersections. They also identify compliance as an MOE for evaluating warning signs *(27)*.

The southbound NC 57 approach to the signal turns to the west immediately before the intersection. This site is referred to as Site D2. A small building blocks the motorists' view of the signal until just before the intersection. The signal ahead sign on NC 57 informs the motorist that he or she must slow down as they approach the signal because they are unable to see the signal indication. There is also a curve ahead sign and an arrow board. Based on the geometry of the signal and the applicable signs, the research team selected rear end conflicts, emergency stops, and signal violations as the measures of effectiveness. The Insurance Institute for Highway Safety estimates that 260,000 collisions a year are caused by signal violations *(33)*. According to the North Carolina motor vehicle code, signal violations occur when vehicles enter the intersection during the red signal phase. An emergency stop occurs when a motorist must quickly decelerate to avoid violating a signal. Characteristics such as the diving nose of the vehicle or squealing tires classify an emergency stop.

Site E

This signalized intersection is equipped with signal ahead signs on the major approaches, US 70. The southbound minor approach also has signal ahead signs although the volume on the dead end road is very low. Based on the various types of collisions occurring at this signalized intersection and the traffic control present, the research team selected conflicts as the MOE.

Site F

The collisions at this location are concentrated at a severe curve under a railroad overpass. Motorists are warned of the curve by a yellow reverse turn ahead sign. The reverse turn ahead sign is equipped with a 25 m.p.h. auxiliary speed plaque. Motorists who fail to prepare to enter the curve may be unable to negotiate the curve. Motorists should reduce their speed before entering this curve. Hostetter and Lunenfeld identified spot speeds and encroachments as valid measures of effectiveness for evaluating horizontal curves *(27)*. Therefore, the research team selected two measures of effectiveness at this location: vehicle speed immediately before entering the curve and centerline and edgeline encroachments in the curve.

Site G

Similar to Site C, this intersection is stop-controlled for the minor approach and uncontrolled for the major approach. There are yellow intersection ahead warning signs on Orange Grove Road. Based on the control of the intersection and the various types of collisions that were occurring there, the research team selected traffic conflicts as the MOE at the intersection.

Site H

At this site, a density of the collisions occurred at a curve just north of the intersection of Davis Road. The majority of the single vehicle run off the road collisions occurring at this curve were heading northbound. Although centerline and edgeline encroachment would be a logical measure of effectiveness at this site, the research team was unable to locate a safe observation location to observe this behavior. Shinar et al. used approach speeds to a curve to evaluate innovative changes in advance warning signs *(34)*. Lyles also used speed to evaluate the effect of curve warning signs in a rural two-lane situation *(35)*. Therefore, vehicle speeds immediately before entering the curve were chosen as the measure of effectiveness.

Site I

Similar to Site C and Site G, this intersection is stop-controlled for the minor approach and uncontrolled for the major approach. There are yellow intersection ahead warning signs on the major approach, Homestead Road. Based on the control of the intersection and the various types of collisions that were occurring there, the research team initially selected traffic conflicts as the MOE at the intersection. As described later, the research team eventually changed the measure of effectiveness to vehicle speed at this location. Five of the collisions occurring at this site were rear end collisions.

Data Collection Methodology

Speed Measurement

Vehicle speed was the selected measure of effectiveness at some sites. Only non-platooned, or free-flowing, vehicles were targeted. A platoon of vehicles is a group of vehicles traveling together. Individual vehicles are not free to chose their own speed but instead must travel at the speed of the platoon. Non-platooned or free-flowing vehicles are vehicles whose speed is unencumbered by other vehicles.

A point was selected in the field at each location from which to monitor speeds. Before each period of data collection the distance from the traffic control device to the point at which the speeds were monitored was measured using a surveyor's wheel. The point was then marked on the roadway using white chalk or small orange flags, similar to flags used to mark underground utilities. This was done to ensure that the speeds were recorded from the same location each time.

Speed measurements were collected using a radar gun. Data collected in December, January, and the beginning of February were collected using a Model K-15 hand-held stationary radar gun. The radar gun was borrowed from the North Carolina Department of Transportation. In February, 2000, the research team gained access to a North Carolina State University radar gun. Subsequent to February 15, 2000, data were collected using a Falcon hand-held traffic radar unit.

Both radar guns were calibrated before every use. A circuit test, an internal calibration test, and an external calibration with a tuning fork were performed before each hour of data collection began. All tests were performed in accordance with the manufacturer's recommendations for proper operation.

Both radar guns are stationary radar guns. The operator must be positioned in a stationary location to accurately measure vehicle speeds. Radar guns operate on the Doppler Principle using electromagnetic waves. Therefore, the radar only measures velocity in a direct line, toward or away from the transmitter. The research team positioned themselves in locations for all data collection so as to minimize angle error.

Vehicle speeds were monitored according to the proper methodology described in the operator's manuals for the radar guns. Vehicles were targeted only if other vehicles were not in the radar beam. Vehicles that were larger, closer, or much faster than the selected target can block the radar from monitoring the speed of the selected target. Target vehicles were visually observed and their speeds were estimated for comparison with the display reading. The Doppler audio pitch was also used to corroborate the display reading. The tone needed to be clear and strong. Interference is indicated by scratchy or garbled tones from the Doppler audio *(36, 37)*.

Centerline and Edgeline Encroachment

When vehicles drive through curves, they are expected to stay within their lane. Encroaching on the centerline or the edgeline can be hazardous to the safety of other motorists and the encroaching driver. Centerline encroachments can result in head-on collisions with opposing traffic. Edgeline encroachments can result in single vehicle run off the road collisions.

Centerline and edgeline encroachments were observed at Site A and Site F. Both sites are curves. Site H is also a curve; however, there was no safe location from which to collect encroachment data, so only speed data were recorded at Site H.

Centerline and edgeline encroachments were observed from the shoulder of the roadway. The data collector positioned herself in a location so that she could watch vehicles as they traversed a section of the curve. The same vantage point was used during the before and after periods. Only non-platooned vehicles were observed. Vehicles were coded into one of five possible categories: stayed in lane, minor white edgeline encroachment, major white edgeline encroachment, minor yellow centerline encroachment, or major yellow centerline encroachment. A minor encroachment was coded if all or part of the vehicle's tire drove on edgeline or centerline. A major encroachment was recorded if the vehicle's entire tire went beyond the edgeline or centerline and was completely on the shoulder or in the opposing lane, respectively. A copy of the data sheet used is included in Appendix C.

Stop Sign Observance and Stopping Behavior

Stop sign observance and stopping behavior was observed at the intersection of NC 49 and NC 86, Site B. Vehicles approaching NC 86 northbound on NC 49 were observed as they approached the one-way stop controlled intersection. Traffic on NC 86 is uncontrolled. The data collector was positioned 400 feet in advance of the stop sign. A line of trees provided cover from the view of the approaching drivers. As vehicles approached the stop sign their brake applications were observed first and then their compliance or non-compliance with the stop sign.

Orange flags, similar to the flags used to mark the underground utilities, were placed 100, 200, 300, and 386 feet back from the stop sign. These were used to measure the distance from the stop sign where the motorists applied their brakes. The farthest back the data collector could see brake application was 386 feet. There were thus six categories of brake application: under 100', 100-200', 200-300', 300-386', over 386', and indeterminate. Vehicles were coded as indeterminate if the data collector was unable to discern when the brakes were first applied. Often this occurred because of glare from the sun or dirt covering the vehicle's brake lights. Platooned vehicles were excluded from data collection. If a queue was present at the stop sign, all vehicles approaching the stop were also excluded because the presence of the queue provided the motorist with information in addition to the yellow warning sign and the stop sign.

Stop sign observance was evaluated in accordance with the procedure outlined by the *Manual of Transportation Engineering Studies (7)*. The data collector recorded one of four movements for each non-platooned vehicle: fully stopped, practically stopped, stopped by traffic, or non-stopping. A *full stop* is defined as a "complete cessation of movement, however brief." A vehicle was considered practically stopped if it was traveling below three miles per hour. In the field this was estimated. This behavior is commonly referred to as a "rolling stop." Above three miles per hour was considered non-stopping. A vehicle was considered stopped by traffic if the motorist was required to stop because of conflict with cross traffic.

Intersection Study of Conflicts and Events

Traffic conflicts were observed at Site C, D1, D2, E, G, and I. Traffic events in addition to traffic conflicts were observed at Site D1, D2, and E. Traffic conflict and event data were collected in accordance with the methodology described in the *Manual of Transportation Engineering Studies (7).* Traffic conflicts are defined as interactions between two or more vehicles or road users when one or more vehicles or road users take evasive action, such as braking or weaving, to avoid a collision. Events for this study were signal violations and emergency decelerations without the presence of another vehicle. These emergency decelerations occur when motorists decelerate quickly to avoid violating the signal. Conflicts and events were observed from a safe, hidden location away from the intersection. The data collector positioned herself between one of the warning signs and the intersection. The same vantage point was used during both periods of data collection. Conflicts and events were recorded on the data sheet shown as in Appendix C.

Vehicular Volume

At the sites where conflicts or conflicts and events were measured, the traffic volume was collected to provide a comparative proportion for the conflicts and events. Because the data were collected by only one researcher, a complete turning movement count of each intersection during each data period was not possible. Instead, the research team collected the volume of the movements on the approaches with the warning signs.

Volumes were collected during every other fifteen-minute interval. The research team interpolated the data to obtain a full hour count.

Data Collection

Preliminary Field Review

The research team conducted a field review at each site to evaluate the existing signs. All applicable signs were measured and quantified. The results of this review were used to request the fabrication of fluorescent signs to replace the existing signs in the after period. Each sign was inspected to ensure that its condition was good. The research team recorded the installation date if indicated on the back of the sign.

The research team also used this opportunity to secure any permission necessary for the use of the observation locations at each site.

Sign Replacement Needs

After the preliminary field review a list of the signs needing replacement (shown in Table 4-2) was sent to the NCDOT and to Corrections Enterprises who fabricated the signs.

Before Data Collection Period

The before period of data collection was started on December 15, 1999. Data collection was suspended around the holiday season in December and the beginning of January, 2000. Towards the end of January, data collection was suspended again due to a large snowstorm that affected the roadways in the area. The majority of the before data were collected during February of 2000.

The research team collected data during daylight hours between twilight periods. The conflict and event studies, which are volume dependent, were conducted during the

AM or PM peak periods. In Orange County, the AM peak period is from seven o'clock to nine o'clock. The PM peak period is from four o'clock to six o'clock. During the months of December and January the PM peak collection was ended earlier than six o'clock to avoid collecting data beyond twilight. In order to minimize the number of days spent collecting data, data were collected during the off-peak at sites that were not volume-dependent. The sites where conflicts or conflicts and events were the measure of effectiveness were considered volume dependent sites. Therefore, during the low light conditions around dusk or dawn data were collected at the volume dependent sites.

Table 4-2: Sign Replacement Needs

Site	Description	Designation	Direction	Quantity	Size
A	35 mph Advisory	W13-1	SB	2	24"X24"
A	Reverse Curve	W1-4L	SB	1	36"X36"
A	Chevrons	W1-8	SB	6	18"X24"
B	Stop Ahead Sign	W3-1a	NB	1	36"X36"
C	Cross Road Sign	W2-1	EB	1	36"X36"
C	Cross Road Sign	W2-1	WB	1	36"X36"
D1	Signal Ahead Sign	W3-3	NB	1	36"X36"
D1	Signal Ahead Sign	W3-3	SB	1	36"X36"
D2	Turn Sign	W1-1R	SB	1	36"X36"
D2	Signal Ahead Sign	W3-3	SB	1	36"X36"
D2	Large Arrow Sign	W1-6	SB/WB	1	48"X24"
E	Signal Ahead Sign	W3-3	WB	1	36"X36"
E	Signal Ahead Sign	W3-3	EB	1	36"X36"
F	Reverse Turn	W1-3R	WB	1	30"X30"
F	Advisory Speed	W13-1	WB	1	18"X18"
F	Chevrons	W1-8	WB	5	24"X30"
G	Reverse Curve	W1-4R	NE	1	30"X30"
G	Side Road	W2-2	NE	1	30"X30"
G	Reverse Curve	W1-4R	SW	1	30"X30"
G	Side Road	W2-2	SW	1	30"X30"
H	Reverse Curve	W1-4R	NB	1	30"X30"
I	Side Road	W2-2	EB	1	30"X30"
I	Side Road	W2-2	WB	1	30"X30"

Data were collected only when the pavement was dry and clear of impediments such as snow or ice. Data were not collected at a site if there were any temporal variations in the site or surrounding area that day. For instance, at Site H orange cones were in place for a week to provide some protection to construction workers who were working on a property close to the roadway. During that week all data collection was suspended at Site H. When the construction was done, the site returned to the same condition as it began, and data collection resumed.

It was initially estimated that five hours of data collection would be needed at each site during each period (before and after) in order to gain a meaningful sample. Three sites--Site C, Site E, and Site G--had to be dropped from the experiment because the time investment needed to gain a meaningful sample was beyond the available resources of this project. Similarly, the measure of effectiveness at Site D2 and Site I had to be changed in order to collect a meaningful sample in the allotted time.

Site C

A conflict study was initiated at this intersection. The data collector recorded conflicts for four hours of before data collection, two hours during the AM peak and two hours during the PM peak. No conflicts occurred during the four hours of data collection. Based on the absence of conflicts during the four-hour period, the research team decided the investment of time needed to collect a meaningful sample size at this intersection was well beyond the resources allocated to this project. This site was excluded from the experiment.

Site E

A conflict and event study was initiated at this signalized intersection. After four hours of before data collection, 2 hours in the AM peak and 2 hours in the PM peak, only one event and no conflicts were observed. Based on the absence of conflicts and a single event during the four-hour period, the research team decided the investment of time needed to collect a meaningful sample size at this intersection was well beyond the resources allocated to this project. Additionally, after speaking with local residents and enforcement officers, the research team discovered that the signal at the intersection was installed less than one year ago. Therefore, the collision history that made the intersection a candidate site was based on a different type of control than was now present. This site was excluded from the experiment.

Site G

A conflict study was initiated at this intersection. After eight hours of before data collection, two AM peak hours and six PM peak hours, only three conflicts were observed. As with the other two sites, this site was excluded from the experiment because of the large resource allocation needed to collect a meaningful sample.

Site D2

Originally, the measures of effectiveness at this site were conflicts and events with an emphasis on rear end conflicts and signal violations. However, after four hours of data collection, no conflicts were observed. The volume on this intersection approach is very low compared to the major approaches to the intersection. In order to avoid excluding the site from the experiment, the measure of effectiveness was changed to non-platooned vehicle speeds approaching the intersection. Vehicle speed is a valid measure of effectiveness at this intersection approach because the signal and its indication are not visible until immediately before the intersection. Therefore, motorists would need to reduce their vehicles' speeds in order to prepare for the intersection.

Site I

Originally, the measure of effectiveness at this uncontrolled intersection was conflicts with an emphasis on rear-end conflicts. However, after four hours of data collection the data collector observed no conflicts from either of the major approaches. The measure of effectiveness was changed to non-platooned vehicle speeds. Although not optimal, this is a valid measure of effectiveness because the collisions that were occurring at this intersection were mainly rear-end collisions.

The Remaining Sites

The amount of data collected at the remaining seven sites was based on the estimated sample size needed to make meaningful statistical inferences between the before and after periods. The hours of data collection and sample size collected in described for each site in Table 4-3.

Table 4-3: Summary of Before Period Data Collection Hours and Sample Size

Site	Hours	Measure of Effectiveness	Sample Size
A	3	Centerline and Edgeline Encroachment	144 Vehicles
B	6	Stop Sign Observance and Stopping Behavior	187 Vehicles
D1	10.5	Conflicts	12 Conflicts
		Events	14 Events
D2	4	Vehicle Speeds Southbound	135 Vehicles
F	4	Vehicle Speeds Westbound	86 Vehicles
	4	Centerline and Edgeline Encroachment	111 Vehicles
H	3	Vehicle Speeds Northbound	83 Vehicles
I	1.5	Vehicle Speeds Eastbound	60 Vehicles
	1.5	Vehicle Speeds Westbound	63 Vehicles

Spectrometry and Retroreflectivity Measurements of Existing Signs

Spectrometry and retroreflectivity measurements were sampled from both the yellow existing signs and the fluorescent yellow experimental signs. The measurements were taken with the assistance of David Burns of the 3M Corporation. Mr. Burns provided both the equipment and the expertise to collect the measurements. Luminance and chromaticity measurements were collected using a PR 650 manufactured by PhotoResearch. Retroreflectivity measurements were collected using a Retrosign Retroreflectrometer manufactured by Delta Light and Optics.

Some spectrometry readings are relative to the ambient light at the time the readings are taken. Therefore, when the yellow existing signs were measured, the data researchers brought a square piece of fluorescent yellow sheeting in the field from which to take comparative measurements from. In the field, the researchers collected the retroreflectivity, luminance, and chromaticity of the existing signs. The researchers then placed the fluorescent yellow sheeting next to the existing sign and collected luminance and chromaticity measurements in the same lighting conditions.

Table 4-4 displays the sign installation date, luminance, and chromaticity measurements at some of the existing signs at each site. Measurements were not taken on every sign, but on a representative sample of the signs at each site. For instance, at Site F, measurements were taken on the curve ahead sign, the auxiliary speed template, and on two of the six chevrons. All the existing signs were engineer grade except for the chevrons at Site F and the large arrow at Site D2 which were high intensity grade. Retroreflectivity measurements and luminance measurements of the surrounding backgrounds at some of the signs were also collected. These values are included in Appendix D.

Table 4-4: Sign Installation, Luminance and Chromaticity Measurements Collected in the Before Period

Site	Sign	Installation	Area on Sign	Existing Sign			Fluorescent Yellow Sample		
				Luminance (cd/m^2)	Chromaticity X	Chromaticity Y	Luminance (cd/m^2)	Chromaticity X	Chromaticity Y
A	Curve Ahead	Jan. 98	Yellow background	1027	0.462	0.426	1353	0.536	0.443
			Black legend	169	0.315	0.327			
	Speed template	Jan. 98	Yellow background	939	0.476	0.438			
B	Stop Ahead	No date	Yellow background	621	0.45	0.441	1078	0.52	0.462
			Red Legend	156	0.514	0.315			
			Black legend	96.9	0.283	0.299			
D1	Signal Ahead	Feb. 97	Yellow background	11000	0.481	0.451	Values overloaded machine		
			Red Legend	3943	0.528	0.337			
			Green Legend	2197	0.209	0.414			
D2	Signal Ahead	Feb. 97	Yellow background	1399	0.454	0.422	2285	0.514	0.432
			Red Legend	583	0.477	0.319			
			Green Legend	491	0.234	0.375			
			Black legend	214	0.284	0.295			
F	Curve Ahead	Oct. 95	Yellow background	5696	0.464	0.453	9806	0.532	0.458
			Black legend	652	0.32	0.333			
	Speed template	Oct. 95	Yellow background	6344	0.503	0.463			
	Chevron 1	Mar. 98	Yellow background	2619	0.528	0.457	7992	0.535	0.459
			Black legend	194	0.308	0.325			
	Chevron 2	Mar. 98	Yellow background	5308	0.521	0.46			
			Black legend	445	0.312	0.33			
H	Curve Ahead	Oct. 95	Yellow background	6511	0.493	0.46	9524	0.529	0.458
			Black legend	728	0.299	0.318			
I	Intersection Ahead	Oct. 95	Yellow background	810	0.508	0.442	1323	0.54	0.436
			Black legend	104	0.337	0.35			

Sign Installation

The fluorescent yellow replacement signs were fabricated by Corrections Enterprises. Corrections Enterprises is a division of the North Carolina Prison System and is responsible for fabricating all signs used by the North Carolina Department of Transportation. The signs were fabricated on fluorescent yellow, diamond grade sheeting provided by the 3M Corporation. The signs were shipped to the area office for review by the Area 2 Accident Investigation Engineer, Scott Collier, on February 22, 2000. After the review the signs were sent to the Division 7, Orange County Maintenance Yard. On March 7, 2000, the fluorescent yellow signs were installed in Orange County. Sign erectors from the Orange County Maintenance Yard installed the signs. The Division 7 Assistant Traffic Engineer, Mike Stout, and the data collector accompanied one of the two crews that installed the signs. At the end of the installation, the data collector inspected the signs installed by the other crew to ensure that they were installed at the correct locations.

Six chevrons intended to replace the existing oversize chevrons at Site A were not useable because they were smaller than the chevrons at the site. This was due to a measurement error by the data collector. However, the reverse curve ahead sign for the site was the correct sign. Only the reverse curve ahead sign was replaced and the original chevrons remained intact.

One sign, a reverse turn ahead for Site F, was not received with the original order. A replacement sign was fabricated. The sign was installed on April 4, 2000.

After Data Collection Period

The after period of data collection began on March 28, 2000. This allowed for a warm-up period of at least three weeks. Although Parker recommends a four-week warm-up period *(26)*, a three-week period was used because of the time constraints of the study. At site F data collection was not started until April 19, 2000 to allow for a two-week warm-up period after the April 4 installation of the reverse turn ahead sign. This was shorter than the desired warm-up period of three weeks. However, it was necessary to ensure that the data collection was completed in the desired time frame.

In order to take advantage of daylight savings time, AM data collection at Site D1 did not begin until after April 2, 2000. During the before period, the sun was rising during the AM peak. However, by early March when the after period began, the sun was rising before the AM peak began. When daylight saving time began, clocks were set forward by one hour. Therefore the sun rose during the AM peak as it had in the before period. This allowed the light conditions to be similar between the before and after period in the AM peak at Site D1. However, because the days were longer, the PM period became farther removed from similar light conditions in the before and after period.

As in the before period, data were collected only when the pavement was dry and clear of impediments such as snow or ice. Data were not collected at a site if there were any variations in the site or surrounding area that day.

For the volume independent data collection, the time of day when the after data were collected was approximately the same as in the before period. There were some minor variations in this. Rain shortened the number of available days. In order to collect all the data before the deciduous trees regained their leaves, some variations in the exact time of data collection in the after period were necessary.

Approximately the same amount of observations were collected in the after period as in the before period. The hours of data collection and sample size collected is described for each site in Table 4-5.

Table 4-5: Summary of After Period Data Collection Hours and Sample Size

Site	Hours	Measure of Effectiveness	Sample Size
A	4	Centerline and Edgeline Encroachment	202 Vehicles
B	7	Stop Sign Observance and Stopping Behavior	230 Vehicles
D1	11	Conflicts	8 Conflicts
		Events	6 Events
D2	5	Vehicle Speeds Southbound	123 Vehicles
F	3.5	Vehicle Speeds Westbound	88 Vehicles
	3	Centerline and Edgeline Encroachment	115 Vehicles
H	3	Vehicle Speeds Northbound	83 Vehicles
I	1.5	Vehicle Speeds Eastbound	60 Vehicles
	1.5	Vehicle Speeds Westbound	63 Vehicles

Background on Statistical Analyses Employed

Z-Test for Proportions

The Z-test for proportions was used at Site A, Site B, Site D1, and Site F. To test if changes between the before and after period were statistically significant, the research team performed a Z-test for proportions as recommended by Parker *(26)*. This is a common statistical test often employed when comparing between two samples when the number of observations in each sample is above thirty *(38)*. The assumption in using this test is that the variance in the before period and the variance in the after period are equal.

The Z-test is a comparison between the before period and after periods of the proportion of vehicles that behaved in one way as opposed to those that did not. For example, at Site A, the research team compared the proportion of vehicles that stayed in their lane in a curve in the before period to the proportion of the vehicles that stayed in their lane in the after period. The denominator of the proportion is not the total volume of vehicles that traveled through the curve during the data collection period. Instead, it is the number of vehicles that were observed. Vehicles traveling in platoons were not included as observations. For example at Site A again, during the after period, the volume through the test section of roadway was 262 vehicles. However, sixty of those vehicles were traveling in platoons. Therefore, the proportion used in the Z-test to represent the proportion that stayed in their lane is 134/202, not 134/262. This distinction can make a large difference in the result of the Z-test.

Although Parker recommends using a two-tailed test, a one tailed test was employed. According to Johnson *(38)*, a two-tailed test is only employed if the null hypothesis is rejected for values of the test statistic falling into either tail of its sampling distribution. For the null hypotheses tested in this experiment, the hypothesis will only be rejected if the calculated Z statistic falls into one tail of the sampling distribution. Therefore, the one-sided test is appropriate.

T-Test for Significance in Differences

Significance testing was used at Site D2, F, H, and I to determine whether the differences in speeds between the before and after periods of sample data were statistically significant or merely due to chance variations that result from sampling. The t-test was employed as recommended in *The Manual of Transportation Engineering Studies (7)*. The t-test is valid when the sample size is greater than thirty *(38)*. Similar to

Parker's recommendations for the Z-test, the *Manual* recommends using a two-tailed test. However, the research team used a one-tailed test based on Johnson's *(38)* definition.

F-Test for Comparison of Standard Deviations of Speed Samples

The standard deviation of a speed sample is one statistic used to describe the dispersion of the sample. The F-test is a statistical test employed to determine if a change in the standard deviation between two samples is significant *(38)*. Although it can be determined if changes in the standard deviation are significant, the effect of those changes on highway safety must be identified for the statistic to be relevant.

Managing Speed (39), a Transportation Research Board special report that reviewed current practices for setting and enforcing speed limits, discussed the hypothesis that it is a higher speed deviation, not a higher mean speed, that increases the probability of a collision. The benchmark study for this hypothesis was conducted by Solomon in 1964 *(40)*. Solomon compared average speed with the police reported travel speeds of crash-involved vehicles of free-flowing traffic on two and four lane, non-limited access rural highways. Crash-involved vehicles were over-represented in the high and low speed areas of the traffic speed distribution. A U-shaped distribution between deviation from average speed and crash involvement was found. Studies that are relevant to this research (i.e. studies not focused on limited access highways) that supported Solomon's findings included Munden *(41)* and Harkey et al. *(42)*. The pertinent criticism of these findings are the dependence on police reported speeds which can be unreliable and the inclusion of turning vehicles as low speed vehicles. When West and Dunn *(43)* removed crashes involving turning vehicles, the U-shaped relationship was considerably weakened. Cowley *(44)* disaggregated Solomon's study by crash type and only found the overrepresentation present for one crash type—nighttime head-on collisions. A recent study by Fildes *(45)* of urban arterials and two lane rural roads found no evidence of the U-shaped relationship.

The special report concludes that empirical data provide evidence that both high mean speed and speed dispersion are associated with crash involvement. Based on these conclusions, a significant decrease in the standard deviation between the before and after periods is considered evidence that the safety of the site may have increased with the use of fluorescent yellow warning signs, although the magnitude of the change is not known. Conversely, if the standard deviation significantly increases, there is evidence that the safety of the site may have decreased.

Summary of Methodology

The methodology employed was a solid methodology, grounded in tradition and the recommendations of the traffic safety profession. The experiment design accounted for several known threats to the validity of before and after studies.

The field evaluation of the fluorescent yellow warning signs was completed within the desired time frame. However, the number of experimental sites was reduced from ten sites to seven sites. Based on preliminary estimates, the sample collected at each of the remaining sites was large enough to provide a meaningful comparison. The work presented in this chapter is the basis for the next chapter, Analysis of Results.

CHAPTER V--ANALYSIS OF RESULTS

In evaluating fluorescent yellow warning signs, the research team collected data as described in the previous chapter. The following sections describe the results of a comparison between the before and after period for each of the seven experimental sites. For a complete compilation of each individual observation, the reader should consult the detailed summary of each data collecting period contained in Appendix D.

The same measure of effectiveness was not used at each site. Accordingly, the statistical analysis performed for each site's results is different. The statistical analysis performed at each site was chosen based on the sample size, the bin size, and the measure of effectiveness.

Site A

Results

The research team collected centerline and edgeline encroachments of southbound vehicles at a portion of the curve on NC 157 southeast of Walker Road. They collected data in the before period on February 17, 2000 from 10:15 to 12:15 and from 2:15 to 3:15 PM. During the three hours of before data collection, 141 samples were observed. They collected data in the after period on April 6, 2000 from 9:30 to 11:30 AM and from 2:00 to 4:00 PM. During the four hours of after data collection, 202 samples were observed. A summary of the before and after period data is in Table 5-1. The total volume traveling through the curve was also collected during the before and after periods.

Table 5-1: Summary of Before Period and After Period Data at Site A

Centerline and Edgeline Encroachments at Site A				
	Before		After	
	Amount	Percentages	Amount	Percentages
Stayed in Lane	90	63.8	134	66.3
Minor Yellow Encroachment	4	2.8	8	4.0
Major Yellow Encroachment	0	0.0	0	0.0
Minor White Encroachment	42	29.8	54	26.7
Major White Encroachment	5	3.5	6	3.0
Total	141	100.0	202	100.0

Z-test Analysis

As discussed earlier, it is desirable for vehicles to stay in their lane when driving through a curve. The percentage of vehicles that stayed in their lane increased by two and a half percent with the fluorescent yellow warning signs in place. To test if this change between the before and after period was statistically significant, the research team performed a Z-test for proportions.

Two distinct hypotheses can be tested for the results of site A. For the first hypothesis, the Z-test was used to compare the proportion of vehicles that stayed in their lane in the before period to the proportion of the vehicles that stayed in their lane in the after period. For the second hypothesis, the Z-test was used to compare the proportion of vehicles that encroached on the white edgeline in the before period to the proportion of the vehicles that encroached on the white edgeline in the after period. A hypothesis regarding the yellow centerline encroachments could not be tested because the observed sample was too small for the Z test to be accurate. The hypotheses that were tested were as follows:

Null hypothesis number 1: The proportion of vehicles that stayed in their lane in the after period is less than or equal to the proportion of vehicles in the before period. ($P_A \leq P_B$)

Null hypothesis number 2: The proportion of vehicles that encroached on the white edgeline in the after period is greater than or equal to the proportion in the before period. ($P_A \geq P_B$)

The results of the two hypothesis tests and their calculated Z statistics are presented in Table 5-2. The Z-test was performed at the 90, 95, and 99 percent significance level. If a Z-test rejects the null hypothesis at the 90, 95, or 99 percent level, the chance that the null hypothesis was rejected when in fact it was correct is 10, 5, and 1 percent respectively. This is the alpha error. For both hypothesis tests, the research team failed to reject the null hypothesis at the 90 percent level. Based on the measure of effectiveness selected by the research team, there was no significant increase in traffic safety at this location between the before period and the after period.

Table 5-2: Results of the Hypothesis Testing for Site A

Null Hypothesis	Change in Percentage	Calculated Z statistic	Accept or Reject the Null Hypothesis at Significance:		
			90% (Z=1.28)	95% (Z=1.645)	99% (Z=2.33)
Number 1: Staying in Lane	+2.5%	.473	Accept	Accept	Accept
Number 2: White Encroachment	- 3.6%	.714	Accept	Accept	Accept

Site B

The research team collected stop sign observance and stopping behavior at this site on the NC 49 approach to the intersection. They collected data in the before period on December 16, 1999 from 12:40 to 3:00; February 4, 2000 from 10:45 to 12:45; and again on February 4 from 2:30 to 3:30. During the five and one-half hour of data collection in the before period, 187 samples were observed. They collected data in the after period on March 28, 2000 from 10:30 to 2:30; April 4, 2000 from 1:00 to 2:00; and on April 11, 2000 from 10:00 to 12:00. During the seven hours of after data collection, 230 samples were observed.

The research team collected two measures of effectiveness at this site, stop sign observance and stopping behavior. Although they were observed together, they are analyzed separately.

Analysis of Stopping Behavior

In the before period, 123 of the 187 samples had relevant stop sign observations. In the after period, 143 of the 230 samples had relevant stop sign observations. Of the four possible stop sign observance categories, 'stopped by traffic' was not relevant to the analysis. A comparison of the relevant categories between the before and after periods is presented as Table 5-3.

Table 5-3: Comparison of Stop Sign Observance between the Before and After Periods

	Before		After		Change in Percentage
	Amount	Percentage	Amount	Percentage	
Voluntary Full Stop	78	63.4	92	64.3	+0.9
Practically Stopped	30	24.4	46	32.2	+7.8
Non-Stopping	15	12.2	5	3.5	-8.7
Total	123	100	143	100	

The research team tested two distinct hypotheses of stop sign observance. For the first hypothesis, the Z-test compared the proportion of vehicles that came to a voluntary full stop in the before period to the proportion of the vehicles that came to a voluntary full stop in the after period. For the second hypothesis, the Z-test compared the proportion of non-stopping vehicles in the before period to the proportion of the non-stopping vehicles in the after period. The null hypotheses that were as follows:

Null hypothesis number 1: The proportion of vehicles that made a complete, voluntary stop in the after period is less than or equal to the proportion in the before period.

Null hypothesis number 2: The proportion of vehicles that did not stop in the after period is greater than or equal to the proportion in the before period.

The results of the two hypothesis tests and their calculated Z statistics are presented in Table 5-4. For the first hypothesis, the research team failed to reject the null hypothesis at the 90 percent significance level. For the second hypothesis test, the research team rejected the null hypothesis and accepted the alternative at the 99% significance level. Based on the measure of effectiveness selected by the research team, there was a significant increase in traffic safety at this location between the before period and the after period caused by a reduction of the number of vehicles that were non-stopping. A statistically significant reduction of non-stopping vehicles has practical significance on traffic safety. Every vehicle that violates a stop sign has the potential to cause a collision. This change could also have been caused by externalities such as recent or upstream enforcement activities.

Table 5-4: Results of Hypothesis Testing at Site B on Stop Sign Observance

Null Hypothesis	Change in Percentage from Before to After	Calculated Z statistic	Accept or Reject the Null Hypothesis at Significance:		
			90% (Z=1.28)	95% (Z=1.645)	99% (Z=2.33)
Number 1: Voluntary Stop Proportion	+0.9%	0.156	Accept	Accept	Accept
Number 2: Non-Stopping Proportion	-8.7%	2.68	Reject	Reject	Reject

Analysis of Stopping Distance

In the before period, 150 of the 187 samples had relevant stopping distance observations. In the after period, 175 of the 230 samples had relevant stopping distance observations. Some of the categories were combined for analysis because of low sample sizes in the individual categories. A comparison of the resulting categories between the before and after period is presented as Table 5-5.

Table 5-5: Comparison of Stopping Distance at Site B in the Before and After Periods

Stopping Distance	Before		After		Change in Percentage
	Amount	Percentage	Amount	Percentage	
Over 386'	65	43.3	92	52.6	+ 9.3
300-386'	60	40	65	37.1	- 2.9
Under 300'	25	16.7	18	10.3	- 6.4
Total	150	100	175	100	

The research team tested two hypotheses concerning the stopping distance results using the Z statistic. The null hypotheses tested were as follows:

> Null hypothesis number 1: The proportion of vehicles that began applying their brakes over 386' before the stop sign in the after period was less than or equal to the proportion in the before period.
>
> Null hypothesis number 2: The proportion of vehicles that began applying their brakes under 300' before the stop sign in the after period was greater than or equal to proportion in the before period.

The results of the two hypothesis tests and their calculated Z statistics are presented in Table 5-6. For both hypothesis tests, the research team rejected the null hypothesis at the 95% significance level and accepted the alternate hypothesis. Based on the measure of effectiveness selected by the research team, there was a significant increase in traffic safety at this location between the before period and the after period represented in the braking behavior of the motorists. The increased advance preparation for the intersection indicates that the motorist is more aware of the approaching intersection. However, this surrogate measure is not as strongly correlated to traffic safety at this location as stop sign observance.

Table 5-6: Results of Hypothesis Testing at Site B on Stopping Distance

Null Hypothesis	Change in Percentage	Calculated Z statistic	Accept or Reject the Null Hypothesis at Significance:		
			90% (Z=1.28)	95% (Z=1.645)	99% (Z=2.33)
Number 1: Proportion over 386'	+9.3%	1.66	Reject	Reject	Accept
Number 2: Proportion under 300'	-6.4%	1.69	Reject	Reject	Accept

Site D1

Results

The research team collected data at this location in the before period on December 15, 1999 from 4:00-5:30 PM; on December 16, 1999 from 7:00-9:00 AM and then again from 4:00-5:30 PM; on January 21, 2000 from 4:00-5:57 PM; on February 3, 2000 from 7:30-9:00 AM; and on February 16, 2000 from 4:00-6:00 PM. The research team collected data in the after period on March 28, 2000 from 4:00-6:00 PM; March 30 from 4:00-6:00 PM; April 4 from 4:00-5:00 PM; April 11 from 7:00-9:00 AM and from 4:00-6:00 PM; and on April 19 from 7:00-9:00 AM.

The research team collected both events and conflicts at the northbound approach to the intersection. Two different types of events occurred: red light violations and single vehicle emergency decelerations to avoid violating the signal. The distribution of events is presented in Table 5-7. Five different types of conflicts occurred at the intersection: rear-end conflicts as a result of northbound vehicles turning left immediately after the intersection into a junkyard, slows in the queue causing emergency decelerations, hesitations on green causing emergency decelerations, vehicles stopping for the red signal and causing emergency decelerations from other vehicles, and left turn conflicts with through vehicles. The distribution of conflicts is presented in Table 5-8.

Table 5-7: Comparison of Events between the Before and After Period at Site D1

Event	Before	After
Red light violation	10	5
Emergency deceleration	4	1
Total	14	6

Table 5-8: Comparison of Conflicts between the Before and After Period at Site D1

Conflict	Before	After
Junkyard emergency deceleration	4	3
Slow queue emergency deceleration	2	1
Hesitation emergency deceleration	4	2
Stopped emergency deceleration	1	0
Left turn conflict	1	2
Total	12	8

The volumes for the major movements at the intersection are included in Appendix D. The northbound through volumes were used as the denominator of the proportions for conflicts and events. This volume was used because all of the conflicts and events involved only vehicles on the northbound approach with the exception of the left turn conflicts which involved northbound vehicles interacting with southbound vehicles. The northbound volume in the before period was 4,047 vehicles. The northbound volume in the after period was 4,533.

The data were also compared by combining conflicts and events into one category called total events. Conflicts are specific types of events which involve two vehicles. Therefore, they can be grouped together with events involving one vehicle. In the before period, there were 26 total events. In the after period, there were 14 total events.

Z-test Analysis

The research team tested three hypotheses regarding the results at this site. They used the Z statistic to accept or reject the null hypotheses. The null hypotheses that were tested were as follows:

Null hypothesis number 1: The proportion of vehicles that were involved in a traffic conflict in the after period was greater than or equal to the proportion in the before period.

Null hypothesis number 2: The proportion of vehicles that were involved in a single vehicle event in the after period was greater than or equal to proportion in the before period.

Null hypothesis number 3: The proportion of vehicles that were involved in a total event, both conflicts and single vehicle events, in the after period was greater than or equal to proportion in the before period.

The results of the three hypothesis tests and their calculated Z statistics are presented in Table 5-9. For the first hypothesis tests, the research team accepted the null hypothesis at the all levels. Therefore, there was no statistically significant change in the amount of conflicts between the before period and the after period. For the second hypothesis test, the research rejected the null hypothesis at the 95% significance level and accepted the alternative hypothesis that the number of traffic events decreased significantly between the before and after periods. The decrease in junkyard emergency decelerations may have been caused by a decrease in the volume turning into the junkyard. However, the data collector did not collect this volume. For the third hypothesis test, the research rejected the null hypothesis at the 95% significance level and accepted the alternative hypothesis that the number of total traffic events, conflicts and single vehicle events, decreased significantly between the before and after periods.

Based on the measure of effectiveness selected by the research team, there was a significant increase in traffic safety at this location between the before period and the after period. However, traffic conflicts are a better surrogate of the safety of the intersection and they did not change significantly. Traffic conflicts are near collisions. Events do not involve another vehicle. However, because some signal violations have the potential to cause collisions, the reduction in signal violations does indicate some practical increase in traffic safety.

Table 5-9: Results of Hypothesis Testing at Site D1 on Traffic Conflicts and Events

Null Hypothesis	Difference from Before to After	Calculated Z-Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90% (Z=1.28)	95% (Z=1.65)	99% (Z=2.33)
Number 1: Conflicts	- 0.12%	1.15	Accept	Accept	Accept
Number 2: Single-vehicle events	- 0.21%	2.05	Reject	Reject	Accept
Number 3: Total events	-0.33%	2.26	Reject	Reject	Accept

Site D2

The research team collected speeds as vehicles approached the intersection of NC 57 and NC 86. They collected data in the before period on February 16, 2000 from 8:00 to 11:00 and on March 6, 2000 from 1:00 to 2:00. During the four hours of data collection in the before period, 135 speed samples were collected. Although the data collected for the before period was collected in two different time periods, the mean of the two speed samples was not significantly different at the 95% level and therefore could be combined together for analysis.

The research team collected data in the after period on April 12, 2000 from 8:00 to 11:00 and on April 19 from 9:00 to 10:00 and from 5:00 to 6:00. During the five hours of after data collection, 123 speed samples were collected. Although the data collected for the after period was collected in two different time periods, a t-test analysis reveals that the mean of the three speed samples was not significantly different at the 95% level and therefore could be combined together for analysis.

A summary of the speed data collection in the before and after period is presented in Table 5-10. The mean vehicle speed, standard deviation, 50th percentile speed, and 85th percentile speed for both periods are shown and compared.

Table 5-10: Comparison of Descriptive Statistics at Site D2 in M.P.H.

	Before Period	After Period	Change
Mean Speed	42.6	41.2	-1.4
Standard Deviation	4.8	5.5	+0.7
50th %tile Speed	43	42	-1
85th %tile Speed	47	46	-1

The data are represented graphically as a histogram in Figure 5-1 and as cumulative distribution curves in Figure 5-2. The histogram displays frequency data for both the before and after period. The cumulative distribution curve displays the cumulative percentages of data at each interval. For example, the point at the coordinates (40, 0.45) would represent that 45 percent of the speed values were at or below 40 m.p.h.

Analysis of Vehicle Speed Data

The research team tested four hypotheses regarding the results at this site. They used the t-statistic to accept or reject the first, second, and third null hypotheses; and the f-statistic to test the fourth null hypothesis. The null hypotheses that were tested were as follows:

Null hypothesis number 1: The mean speed of the vehicles in the after period was greater than or equal to the mean speed of the vehicles in the before period.

Null hypothesis number 2: The 50^{th} percentile speed of the vehicles in the after period was greater than or equal to the 50^{th} percentile speed of the vehicles in the before period.

Null hypothesis number 3: The 85^{th} percentile speed of the vehicles in the after period was greater than or equal to the 85^{th} percentile speed of the vehicles in the before period.

Null hypothesis number 4: The standard deviation of the speeds in the after period was greater than or equal to the standard deviation of the speeds in the before period.

The results of the four hypothesis tests and their calculated t and f- statistics are presented in Table 5-11. The mean speed was reduced in the after period by 1.4 miles/hour. The calculated value of *t* was 2.17. The t-test validates that this reduction in the mean speed is significant at the 95% level. Although this reduction is a significant change between the two periods, it is a small decrease in the mean speed and may not impact the safety of the site. Similar reductions in the 50^{th} percentile (median) and 85^{th}

Figure 5-1: Comparison of Speed Distribution at Site D2

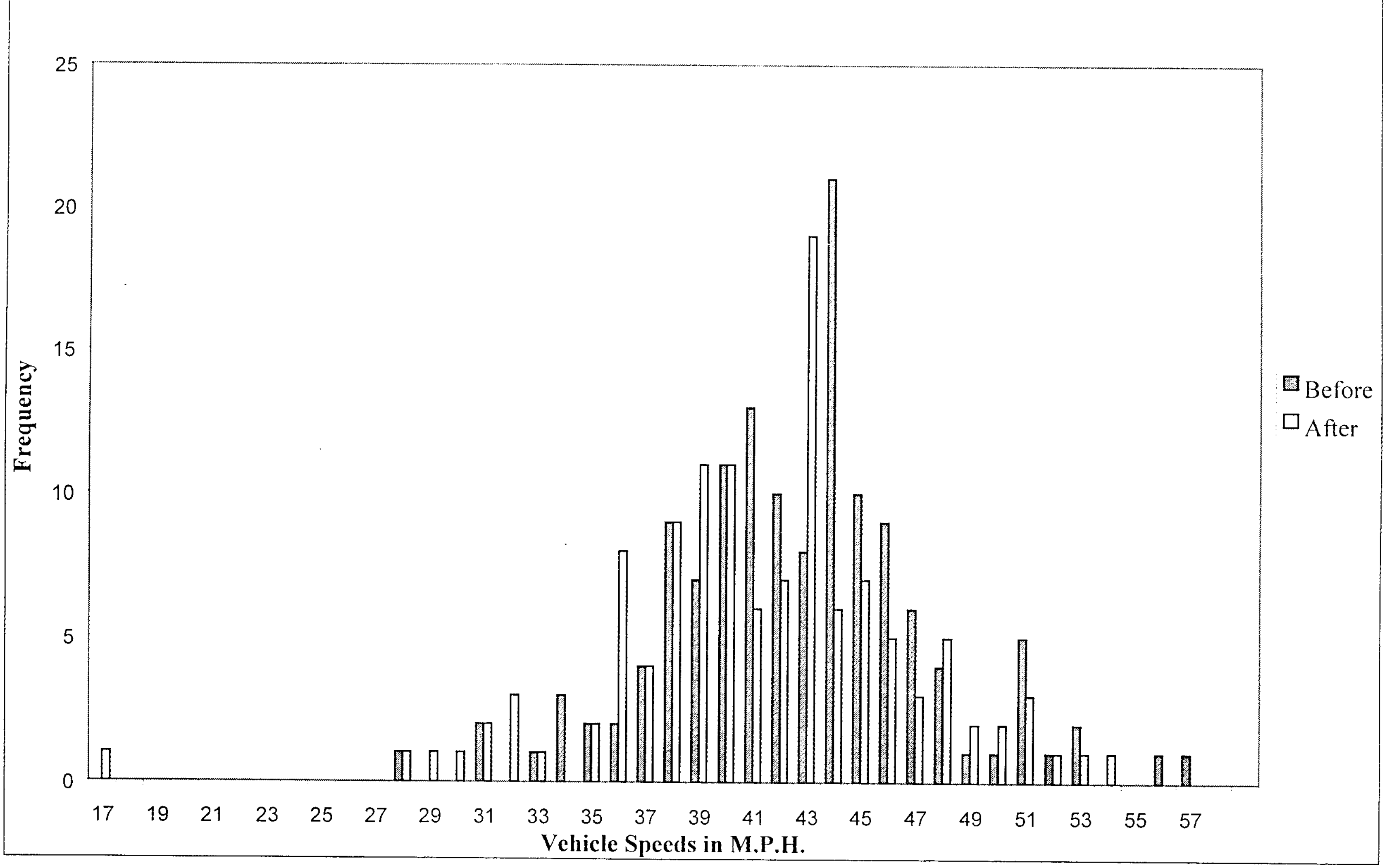
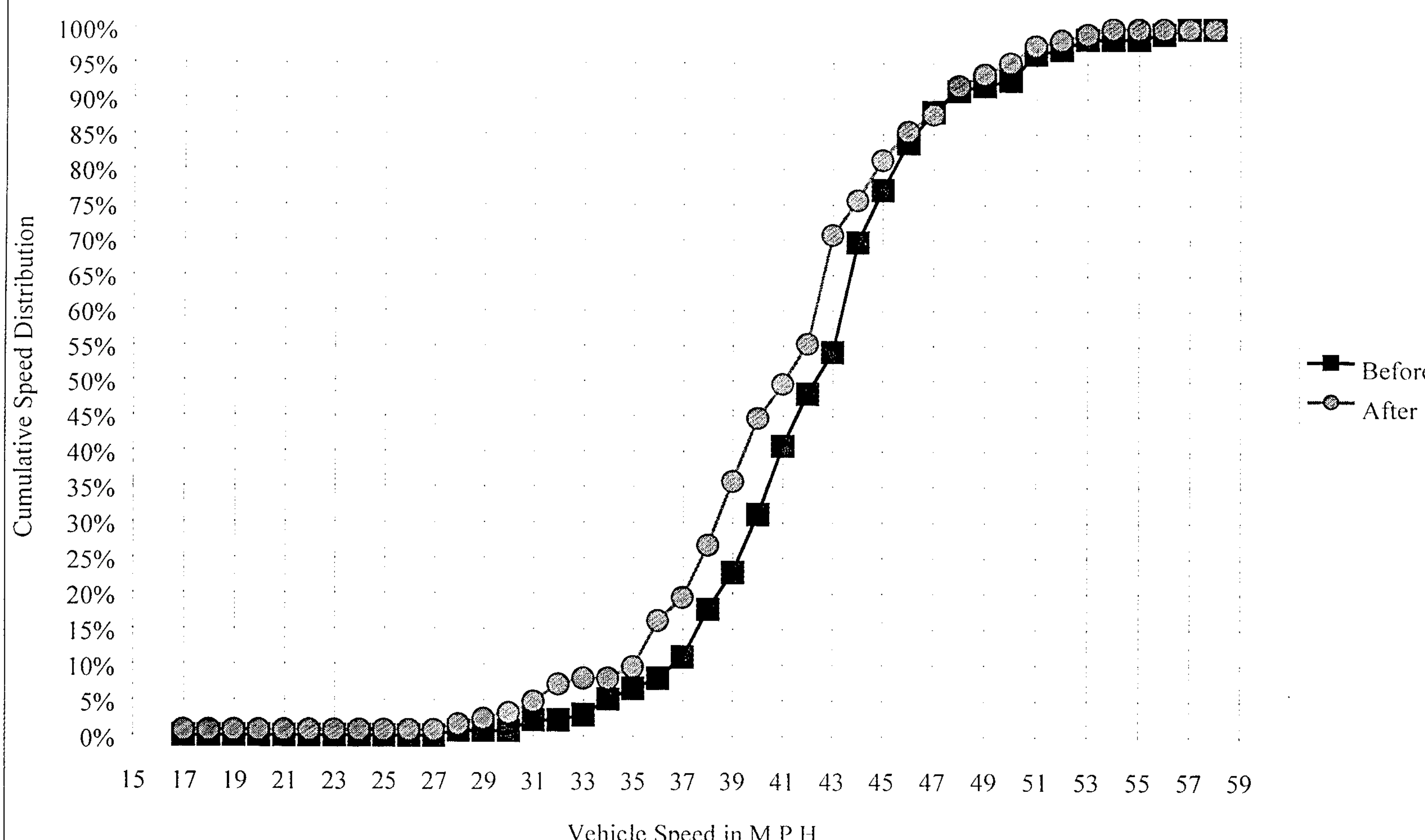


Figure 5-2: Cumulative Speed Distribution at Site D2



percentile speed were also significant at the 90% level. The standard deviation of the sample increased. The F-test was used to determine if the increase was significant. The increase was significant at the 90% level. The results at this site are inconclusive on whether the safety was impacted.

Table 5-11: Results of Hypothesis Testing at Site D2 on Vehicle Speeds

Null Hypothesis	Difference from Before to After	Calculated Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90%	95%	99%
Number 1: Mean Speed	-1.4	t=2.17	Reject	Reject	Accept
Number 2: 50th Percentile	-1	t=1.55	Reject	Accept	Accept
Number 3: 85th Percentile	-1	t=1.55	Reject	Accept	Accept
Number 4: Standard Deviation	+0.7	f=1.31	Reject	Accept	Accept

Site F

Results

Two measures of effectiveness were used at this curve. The research team collected centerline and edgeline encroachments in the before period on February 16, 2000 from 12:00 to 3:00 and on March 3, 2000 from 4:00 to 5:00. During the four hours of data collection in the before period, 111 samples were observed. The research team collected data in the after period on April 19, 2000 from 1:30 to 3:30 and from 4:00 to 5:00. During the three hours of after data collection, 115 samples were observed. A summary of the results is presented as Table 5-12.

Table 5-12: Summary of Before and After Centerline and Edgeline at Site F

	Before		After	
	Amount	Percentage	Amount	Percentage
Stayed in Lane	64	57.7	78	67.8
Minor Yellow encroachment	9	8.1	1	0.9
Major Yellow Encroachment	1	0.9	0	0.0
Minor White Encroachment	35	31.5	34	29.6
Major White Encroachment	2	1.8	2	1.7
Total	111	100	115	100

The research team collected vehicle speeds immediately before vehicles entered the curve. They collected data in the before period on December 21, 1999 from 12:30 to 2:00 and on February 9, 2000 from 9:15 to 10:15 and from 12:30 to 2:00. During the four hours of data collection in the before period, 86 speed samples were collected. The t-test confirmed the differences between the mean speeds of the three before period data collection samples were not significant at the 95% level. They collected data in the after period on April 18, 2000 12:00 to 1:30 and on April 19 from 11:15 to 1:15. During the 3.5 hours of after data collection, 88 speed samples were collected. The t-test confirmed that differences between the mean speeds of the two samples of after period data collection were not significant at the 95% level.

A summary of the speed data collection in the before and after period is presented in Table 5-13. The mean vehicle speed, standard deviation, 50th percentile speed, and 85th percentile speed for both periods are shown.

Table 5-13: Comparison of Descriptive Speed Statistics at Site F in M.P.H.

	Before Period	After Period	Change
Mean Speed	36.6	34.6	- 2.0
Standard Deviation	4	4.4	+ 0.4
50th %tile Speed	36	34	- 2.0
85th %tile Speed	41	39	- 2.0

The data are presented graphically as a histogram in Figure 5-3 and as cumulative distribution curves in Figure 5-4. The histogram displays frequency data for both the before and after period. The cumulative distribution curve displays the cumulative percentages of data at each interval.

Figure 5-3:Comparison of Speed Distribution at Site F

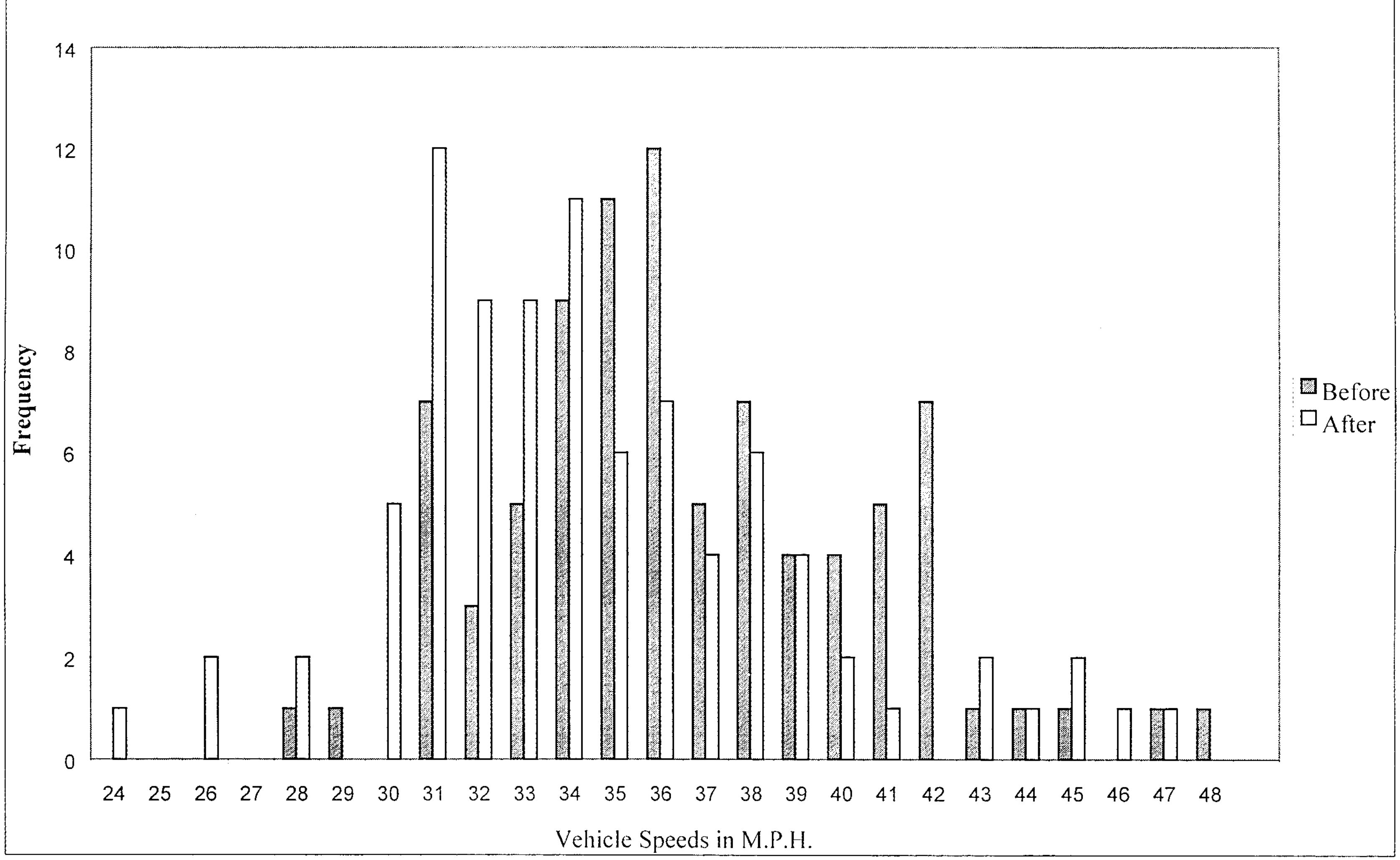
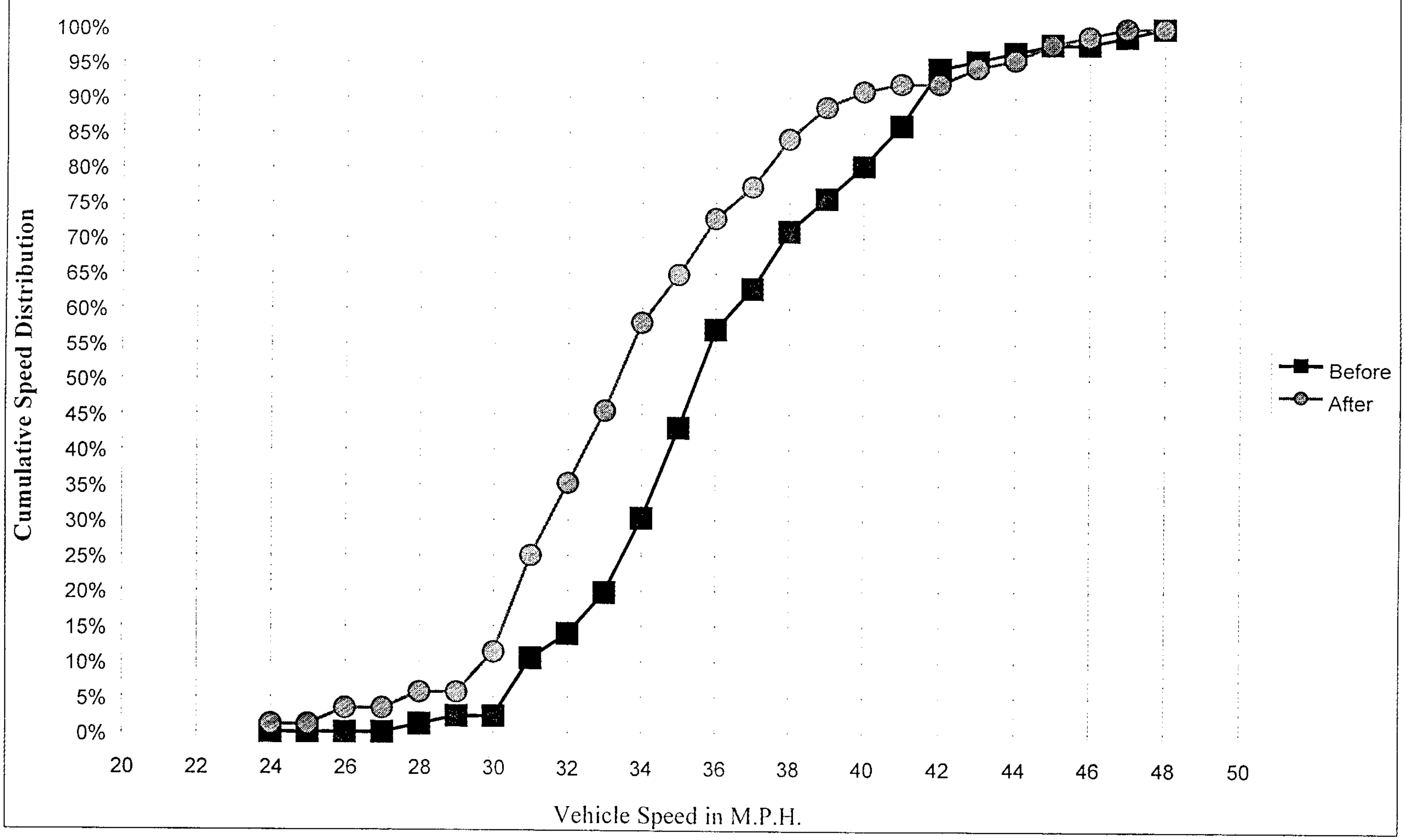


Figure 5-4: Cumulative Speed Distribution at Site F



Analysis of Centerline and Edgeline Encroachment Data: Z-test Analysis

The percentage of vehicles that stayed in their lane increased by 10.1 percent with the fluorescent yellow warning signs in place. Similar to the analysis at Site A, the researcher performed a Z-test for proportions to test if this change between the before and after period was statistically significant. The null hypotheses that were tested follow:

> Null hypothesis number 1: The proportion of vehicles that stayed in their lane in the after period is less than or equal to the proportion of vehicles in the before period. ($P_A \leq P_B$)
>
> Null hypothesis number 2: The proportion of vehicles that encroached on the white edgeline in the after period is greater than or equal to the proportion in the before period. ($P_A \geq P_B$)
>
> Null hypothesis number 3: The proportion of vehicles that encroached on the yellow centerline in the after period is greater than or equal to the proportion in the before period. ($P_A \geq P_B$)

The results of the three hypothesis tests and their calculated Z statistics are presented in Table 5-14. The first hypothesis was rejected at the 90% significant level and the alternative hypothesis was accepted. The second hypothesis, that the proportion of white edgeline encroachments did not change between the before and after periods, was accepted. The third hypothesis was rejected at the 99% significance level and the alternative hypothesis was accepted. Therefore, there is a statistically significant reduction in the amount of vehicles that encroached on the yellow centerline between the before and after periods. Based on the measure of effectiveness selected by the research team, there was a significant increase in traffic safety at this location between the before period and the after period.

Table 5-14: Results of Hypothesis Testing at Site F

Null Hypothesis	Difference from Before to After	Calculated Z statistic	Accept or Reject the Null Hypothesis at Significance:		
			90% (Z=1.28)	95% (Z=1.645)	99% (Z=2.33)
Number 1	+10.1%	1.58	Reject	Accept	Accept
Number 2	-5.1%	0.78	Accept	Accept	Accept
Number 3	-12.2%	2.93	Reject	Reject	Reject

Analysis of Vehicle Speed Data

The research team tested four hypotheses regarding the results at this site. They used the t-statistic to test the first, second, and third null hypotheses; and the f-statistic to test the fourth null hypothesis. The null hypotheses that were tested were as follows:

Null hypothesis number 1: The mean speed of the vehicles in the after period was greater than or equal to the mean speed of the vehicles in the before period.

Null hypothesis number 2: The 50th percentile speed of the vehicles in the after period was greater than or equal to the 50th percentile speed of the vehicles in the before period.

Null hypothesis number 3: The 85th percentile speed of the vehicles in the after period was greater than or equal to the 85th percentile speed of the vehicles in the before period.

Null hypothesis number 4: The standard deviation of the speeds in the after period was greater than or equal to the standard deviation of the speeds in the before period.

Table 5-15 displays the results of the four hypothesis tests. The null hypotheses regarding the mean, 50th percentile, and 85th percentile speeds were rejected at the 99% level. From Table 5-13, the reader can observe that the mean speed was reduced in the after period by 2.0 miles/hour and Figure 5-4 shows a sizable shift in the cumulative distribution. The t-test validates that this reduction in the mean speed is significant at the 99% level. Practically, although this reduction is significant, it is a small decrease in the mean speed and may not impact the safety of the site very much. Similar reductions in the 50th percentile (median) and 85th percentile speed were also significant at the 99% level.

Table 5-15: Results of Hypothesis Testing at Site D2 on Vehicle Speeds

Null Hypothesis	Difference from Before to After	Calculated Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90%	95%	99%
Number 1: Mean Speed	- 2.0	t=3.14	Reject	Reject	Reject
Number 2: 50th Percentile	- 2.0	t=3.14	Reject	Reject	Reject
Number 3: 85th Percentile	- 2.0	t=3.14	Reject	Reject	Reject
Number 4: Standard Deviation	+ 0.4	f=1.21	Accept	Accept	Accept

The standard deviation of the sample increased. The F-test was used to determine if the increase was significant. The null hypothesis was accepted at the 90% level. Therefore, the increase was not significant at the 90% level.

Site H

Results

The research team collected vehicle speeds immediately before vehicles entered the curve. They collected data in the before period on December 21, 1999 from 9:00 to 11:00 and on February 28, 2000 from 2:15 to 3:15. During the three hours of data collection in the before period, 83 speed samples were collected. The t-test confirmed the differences between the mean speeds of the three before period data collection samples were not significant at the 95% level and therefore the samples were combined together.

The research team collected data in the after period on April 11, 2000 from 1:00 to 3:00 p.m. and on April 19 from 10:15 to 10:45 a.m. During the three hours of after data collection, 83 speed samples were collected. The research team performed a t-test to compare the two after period samples. The t-test confirmed that differences between the mean speeds of the two samples of after period data collection were not significant at the 95% level and therefore the samples were combined together for analysis.

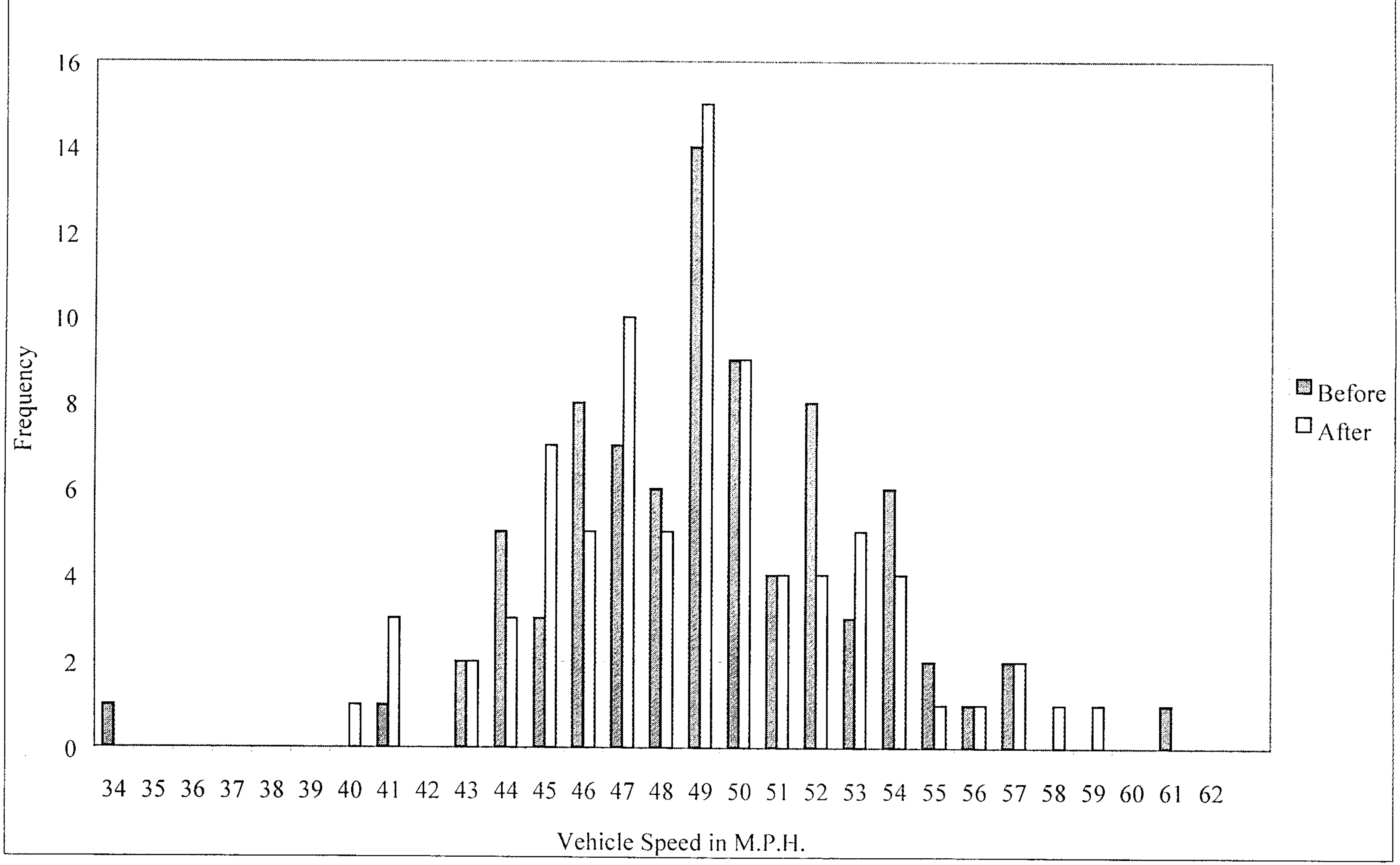
A descriptive summary and comparison of the speed data collection in the before and after period is presented in Table 5-16. The mean vehicle speed, standard deviation, 50^{th} percentile speed, and 85^{th} percentile speed for both the before and after periods are shown.

Table 5-16: Comparison of Descriptive Speed Statistics at Site H in M.P.H.

	Before Period	After Period	Change
Mean Speed	49.2	48.9	- 0.3
Standard Deviation	4	3.9	- 0.1
50th %tile Speed	49	49	No change
85th %tile Speed	53	53	No change

The data are represented graphically as a histogram in Figure 5-5 and graphically as cumulative distribution curves in Figure 5-6. The histogram displays frequency data for both the before and after periods. The cumulative distribution curve displays the cumulative percentages of data at each interval for both the before and after periods.

Figure 5-5:Comparison of Speed Distribution at Site H



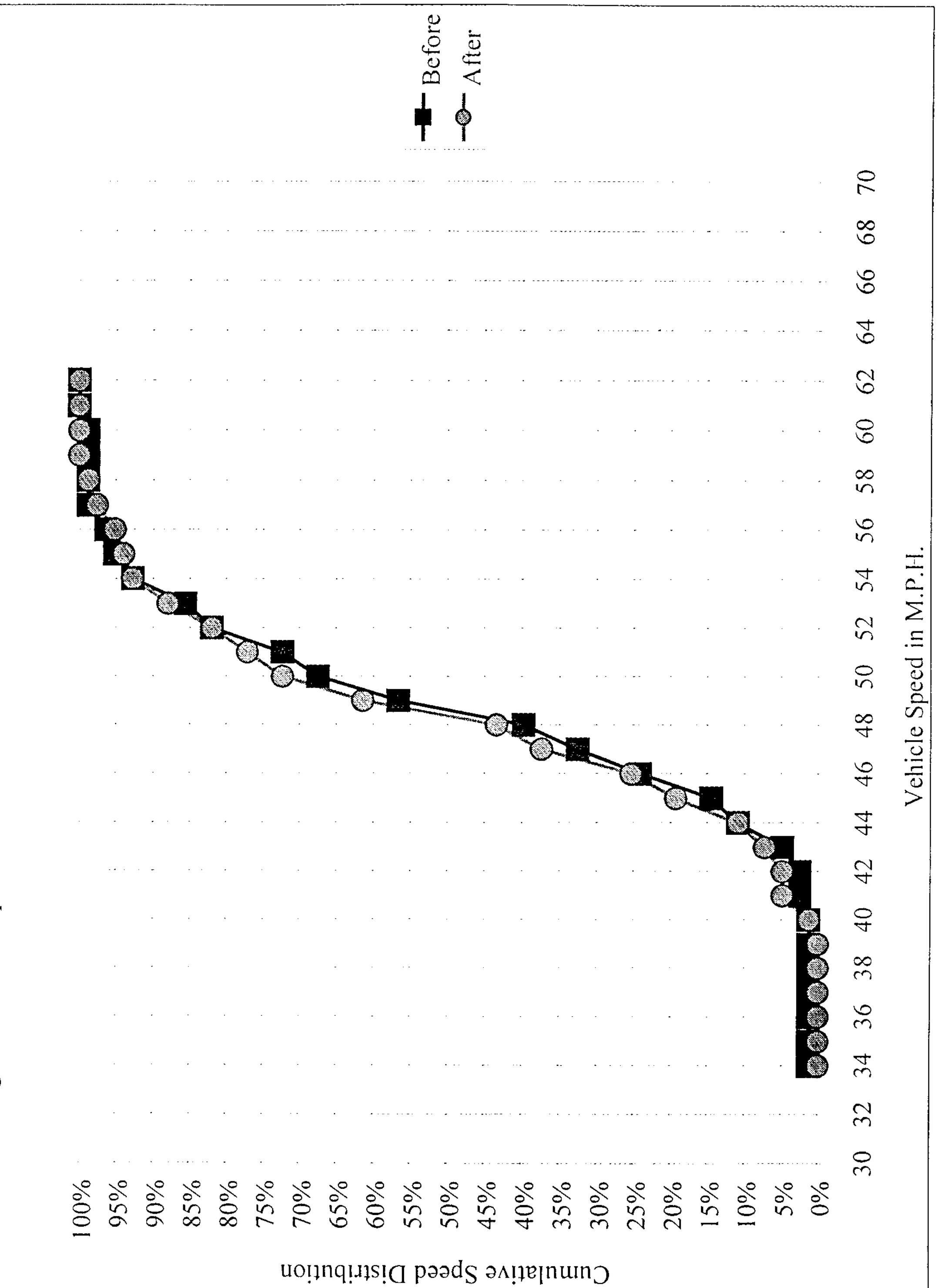


Figure 5-6: Comparison of Cumulative Distribution at Site H

Analysis of Vehicle Speed Data

The research team tested two hypotheses regarding the results at this site. They used the t-statistic to test the first null hypotheses and the f-statistic to test the second null hypothesis. The null hypotheses that were tested were as follows:

> Null hypothesis number 1: The mean speed of the vehicles in the after period was greater than or equal to the mean speed of the vehicles in the before period.
> Null hypothesis number 2: The standard deviation of the speeds in the after period was greater than or equal to the standard deviation of the speeds in the before period.

Between the before and after period, the mean speed changed very slightly. The 50th percentile and 85th percentile speeds did not change at all. Therefore, no hypotheses were tested regarding the 50th and 85th percentile speeds. Table 5-17 displays the results of the hypothesis tests. The test for significance between the before period and after period mean speed yielded a calculated *t* value of 0.49. The t-test validates that this reduction in the mean speed is not significant at the 90% level and the research team accepted the first null hypothesis.

Table 5-17: Results of Hypothesis Tests at Site H

Null Hypothesis	Difference from Before to After	Calculated Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90%	95%	99%
Number 1: Mean Speed	- 0.3	t=0.49	Accept	Accept	Accept
Number 2: Standard Deviation	- 0.1	f=1.05	Accept	Accept	Accept

The standard deviation of the sample increased. The F-test was used to determine if the increase was significant. The increase was not significant at the 90% level and the research team accepted the second null hypothesis.

Based on the measure of effectiveness selected at this site, the fluorescent yellow signs did not impact the safety of the location.

Site I

Results

The research team collected vehicle speeds at Site I as the vehicles approached the intersection on the eastbound and westbound approaches. They collected data in the before period for the eastbound direction on February 6, 2000 from 10:00 to 11:30. They collected data in the after period for the eastbound direction on April 18, 2000 from 9:00 to 10:30. During both the before period and the after period, sixty samples were collected. A summary of the eastbound speed data collection in the before and after period is presented in Table 5-18. The mean vehicle speed, standard deviation, 50^{th} percentile speed, and 85^{th} percentile speed for both periods are shown.

Table 5-18: Comparison of Descriptive Speed Statistics EB at Site I in M.P.H.

	Before Period	After Period	Change
Mean Speed	47.6	45.6	-2.0
Standard Deviation	5.5	4.4	-1.1
50th %tile Speed	48	45	-3.0
85th %tile Speed	53	50.2	-2.8

The research team collected data in the before period for the westbound direction on February 6 from 12:30 to 2:30. They collected data in the after period in the westbound direction on April 12 from 12:30 to 2:30. During the both the before period and the after period, 63 samples were collected. A summary of the westbound speed data collection in the before and after period is presented in Table 5-19.

Table 5-19: Comparison of Descriptive Speed Statistics WB at Site I in M.P.H.

	Before Period	After Period	Change
Mean Speed	46.3	45.8	-0.5
Standard Deviation	4.5	4.1	-0.4
50th %tile Speed	46	46	0
85th %tile Speed	50.9	50	-0.9

The data are represented graphically as a histogram in Figure 5-7 and Figure 5-8 and as cumulative distribution curves in Figure 5-9 and Figure 5-10. The histogram displays frequency data for both the before and after period. The cumulative distribution curve displays the cumulative percentages of data at each interval.

Analysis of Vehicle Speed Data

The research team tested seven hypotheses regarding the results at this site; four hypothesis in the eastbound direction and three in the westbound direction. They used the t-statistic to test the hypotheses regarding the mean, 50th percentile, and 85th percentile speeds. They used the f-statistic to test the hypotheses regarding the standard deviations. The null hypotheses that were tested for the eastbound direction were as follows:

Null hypothesis 1: The mean speed of the eastbound vehicles in the after period was greater than or equal to the mean speed of the eastbound vehicles in the before period.

Null hypothesis 2: The 50th percentile speed of the eastbound vehicles in the after period was greater than or equal to the 50th percentile speed of the eastbound vehicles in the before period.

Null hypothesis 3: The 85th percentile speed of the eastbound vehicles in the after period was greater than or equal to the 85th percentile speed of the eastbound vehicles in the before period.

Null hypothesis 4: The standard deviation of the speeds in the after period was greater than or equal to the standard deviation of the speeds in the before period.

Figure 5-7: Comparison of Eastbound Speed Distribution at Site I

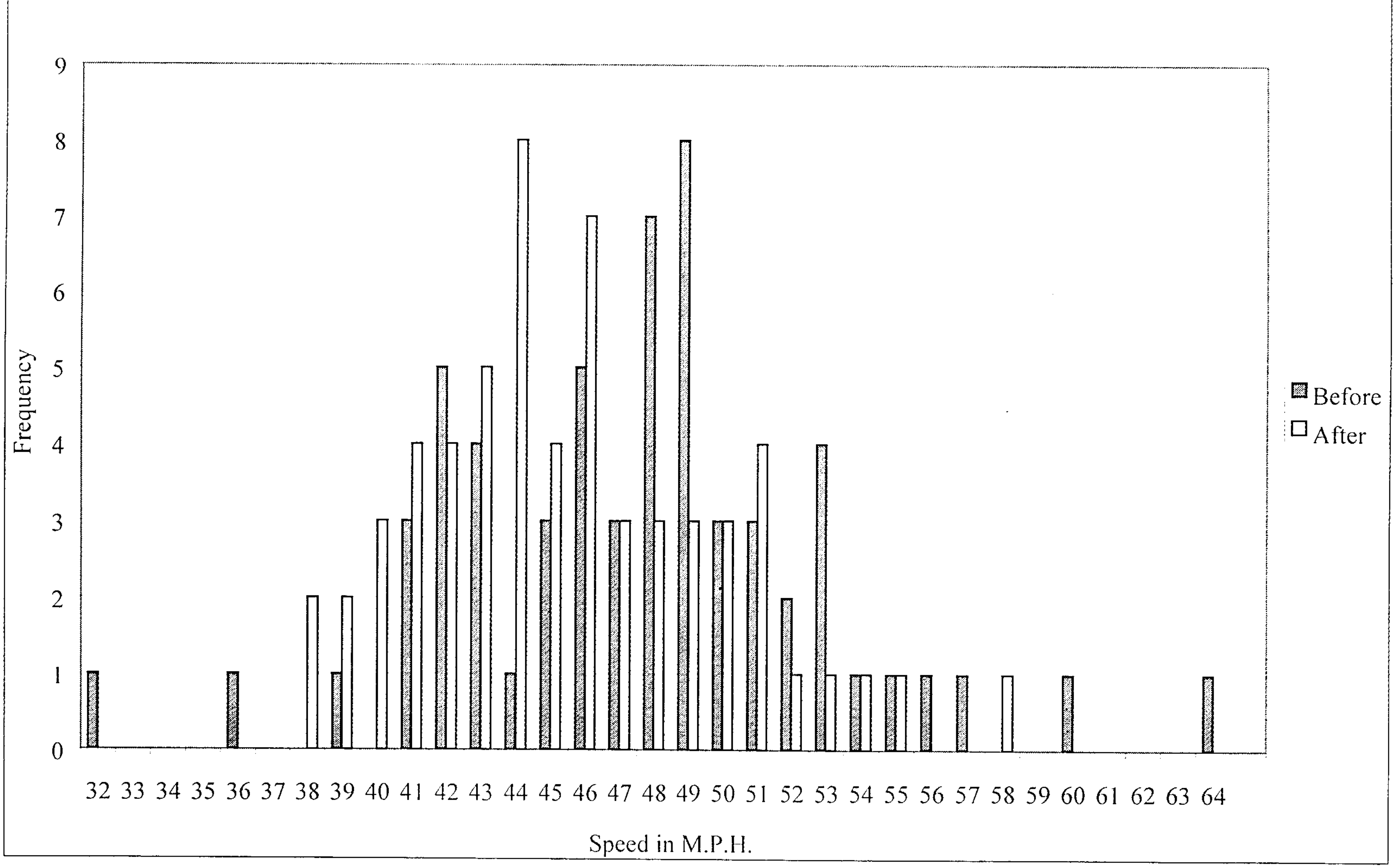


Figure 5-8: Comparison of Cumulative Distribution at Site I Eastbound

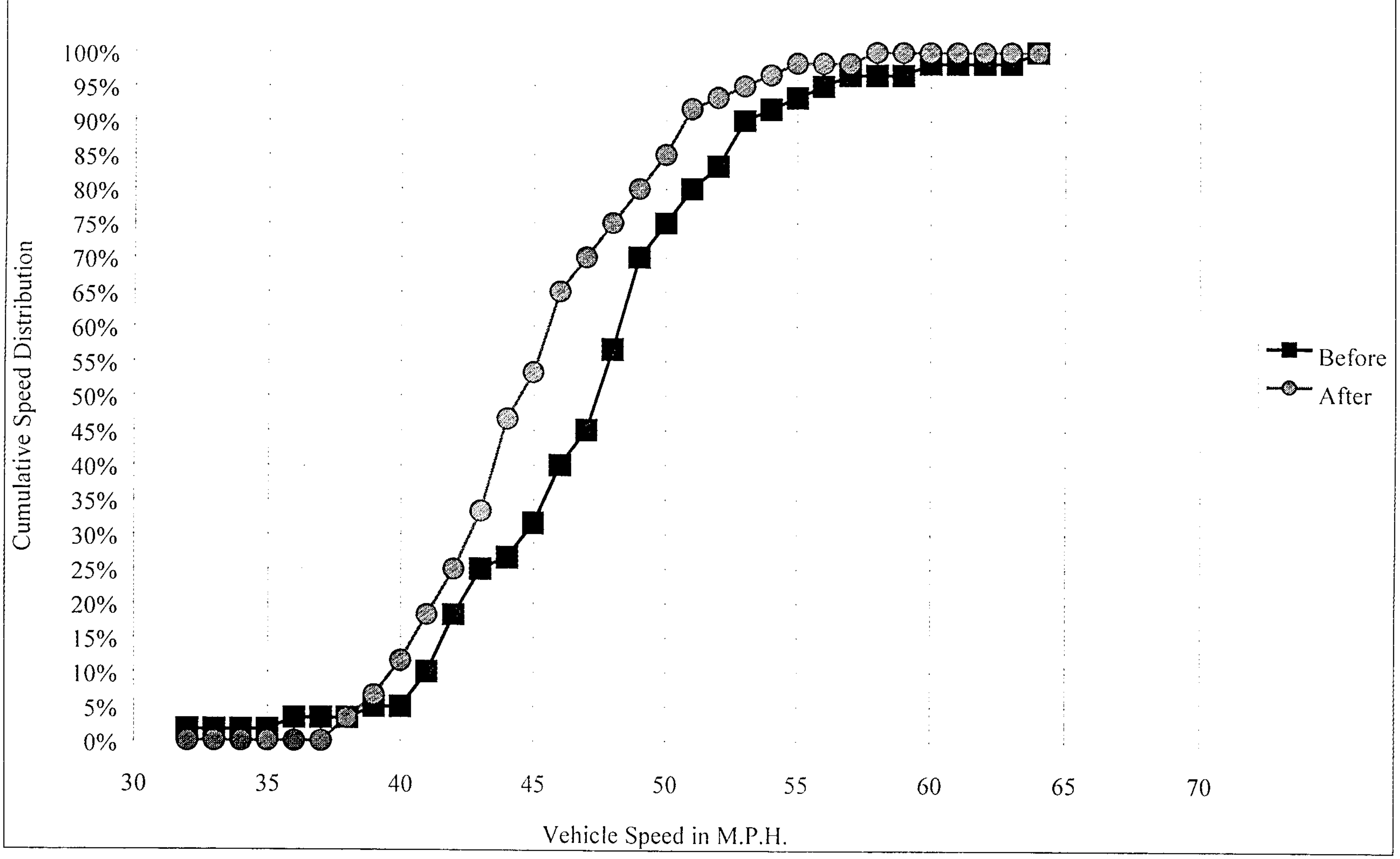


Figure 5-9: Comparison of Westbound Speed Distribution at Site I

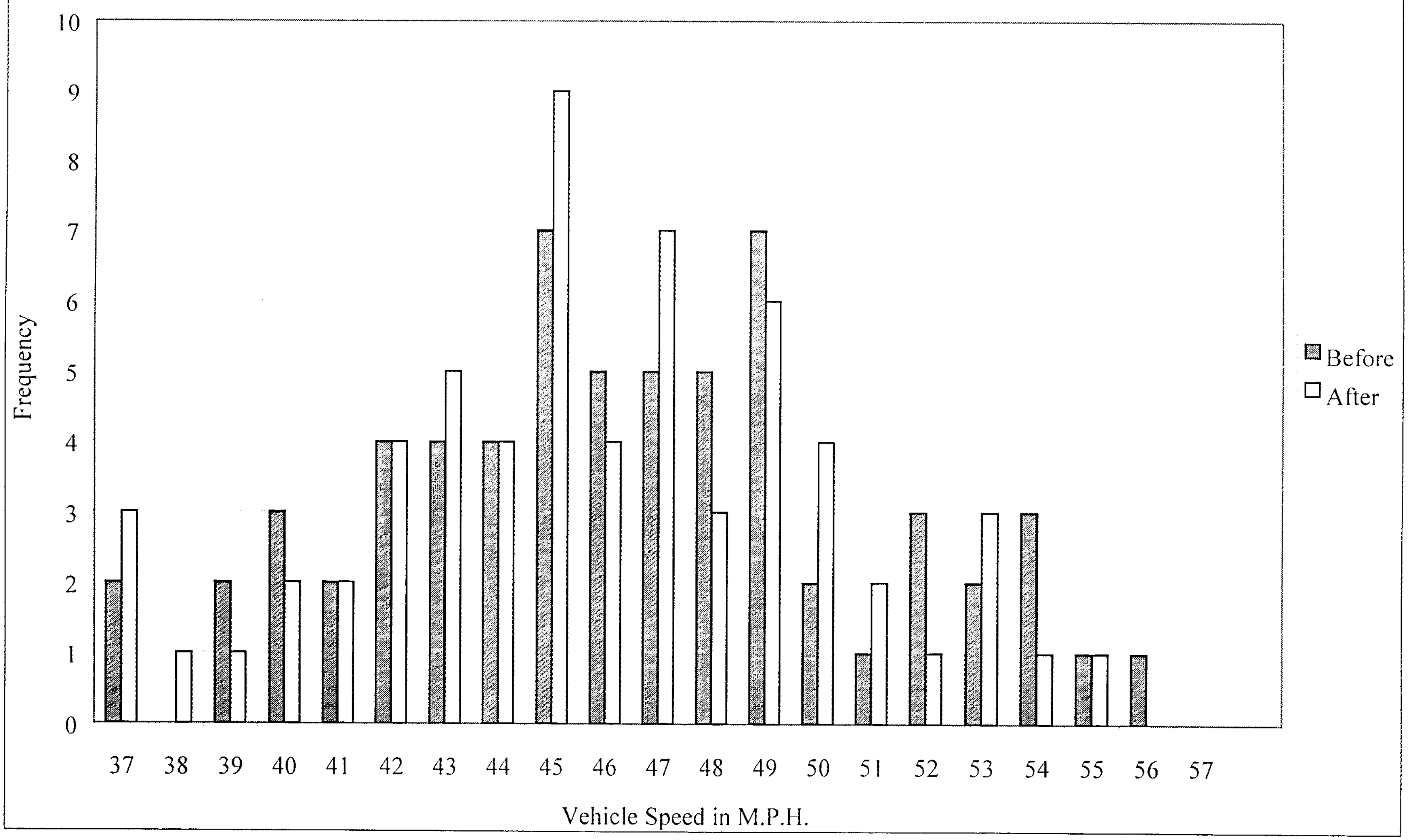
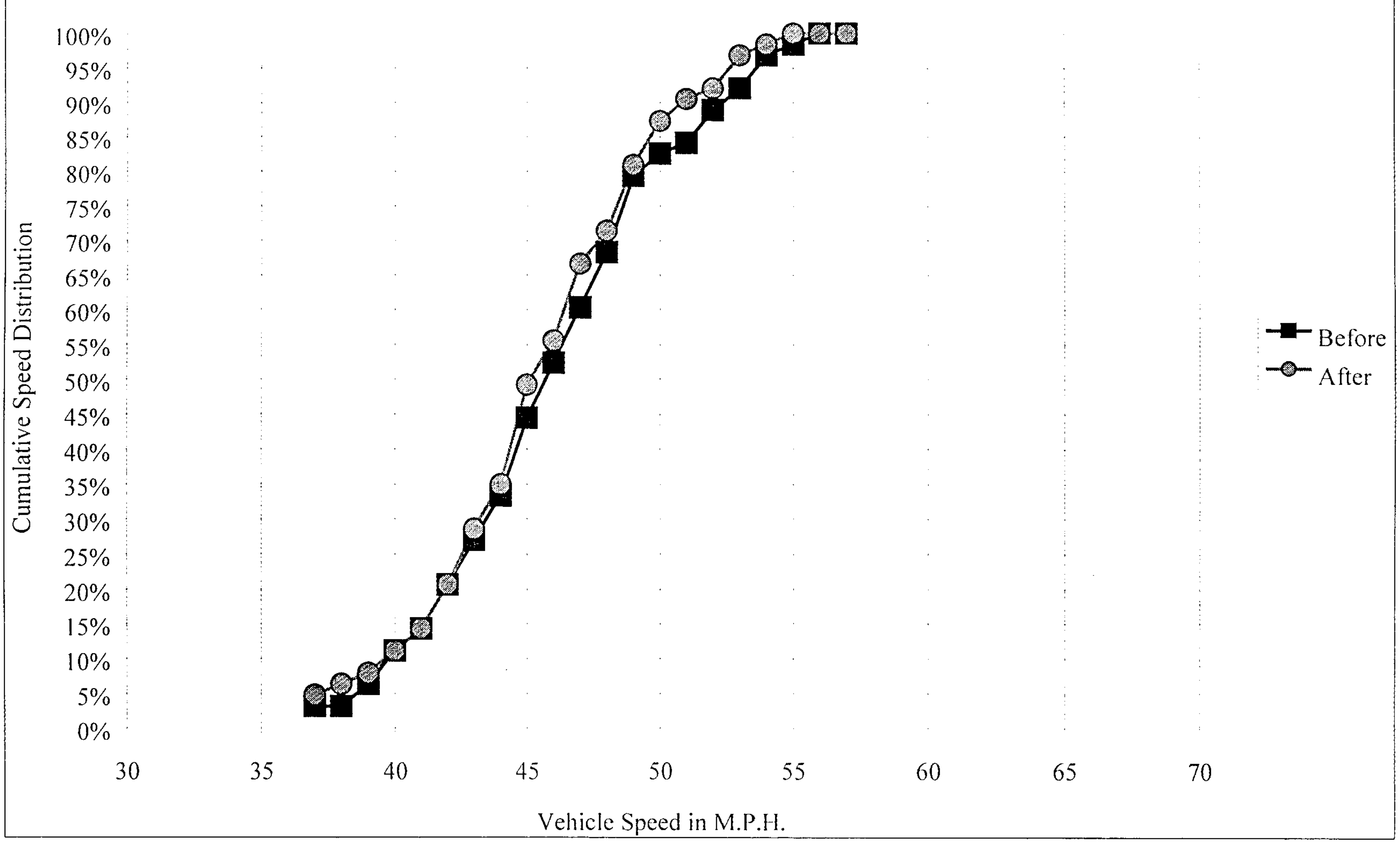


Figure 5-10: Comparison of Cumulative Distribution for Site I Westbound



The results of the hypothesis tests are presented in Table 5-20. Between the before and after period in the eastbound direction, the mean speed decreased by two miles per hour, the 50th percentile speed decreased by three miles per hour, and the 85th percentile speed decreased by 2.8 miles per hour. The test for significance between the before period and after period mean speed yielded a calculated *t* value of 2.2. The t-test validates that this reduction in the mean speed was significant at the 95% level. The calculated t-values for the 50th percentile and 85th percentile speed were 3.3 and 3.1 respectively. The t-test validates that both the 50th percentile and 85th percentile speeds reduction in the after period was significant at the 99% level. Figure 5-10 shows the shift in the curve.

Table 5-20: Results of Hypothesis Tests at Site I Eastbound

Null Hypothesis	Difference from Before to After	Calculated Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90%	95%	99%
Number 1: Mean Speed	-2.0	t=2.2	Reject	Reject	Accept
Number 2: 50th Percentile	-3.0	t=3.3	Reject	Reject	Reject
Number 3: 85th Percentile	-2.8	t=3.1	Reject	Reject	Reject
Number 4: Standard Deviation	-1.1	f=1.56	Reject	Reject	Accept

In the westbound direction, the mean speed decreased by 0.5 miles per hour from the before period to the after period. The 85th percentile speed decreased by 0.9 miles per hour and the 50th percentile speed remained the same. The null hypotheses that were tested for the westbound direction were as follows:

Null hypothesis number 1: The mean speed of the westbound vehicles in the after period was greater than or equal to the mean speed of the westbound vehicles in the before period.

Null hypothesis number 2: The 85th percentile speed of the westbound vehicles in the after period was greater than or equal to the 85th percentile speed of the westbound vehicles in the before period.

Null hypothesis number 3: The standard deviation of the speeds in the after period was greater than or equal to the standard deviation of the speeds in the before period.

The results of the hypothesis test for the westbound direction are presented in Table 5-21. The standard deviations both the eastbound and westbound samples decreased in the after period. The F-test reveals that the decrease in the eastbound direction was statistically significant at the 90% level, but the westbound decrease was not. Decreases in the mean and 85th percentile speed were also not significant at the 90% level.

Table 5-21: Results of Hypothesis Tests at Site I Westbound

Null Hypothesis	Difference from Before to After	Calculated Statistic	Accept or Reject the Null Hypothesis at Significance:		
			90%	95%	99%
Number 1: Mean Speed	-0.5	t=.65	Accept	Accept	Accept
Number 3: 85th Percentile	-0.9	t=1.20	Accept	Accept	Accept
Number 4: Standard Deviation	-0.4	f=1.17	Accept	Accept	Accept

Based on the measure of effectiveness selected at this Site I, the fluorescent yellow signs did not impact the safety of the location in the westbound direction. In the eastbound direction, the significant, although small, reduction in the mean, 50th percentile, and 85th percentile speeds may have increased the safety of the site, although readers must keep in mind that mean speed is only weakly related to safety in the literature.

CHAPTER VI—SUMMARY AND CONCLUSIONS

Yellow warning signs are an important and abundant type of traffic control device. Yellow warning signs inform the motorist to conditions on, or adjacent to, a highway or street that are potentially hazardous to traffic operations. Improving traffic control devices has been identified as a possible traffic safety countermeasure with promise for reducing traffic collisions in a cost-effective manner. As with all signs, in order for the yellow warning signs to be effective, the operator must detect them and the information on the warning sign must be conveyed. The conspicuity of a traffic sign is the key to its detection. With increasing visual clutter and driver distractions, the conspicuity of warning signs becomes ever more important.

The use of fluorescent yellow sheeting in place of standard yellow sheeting provides a method to increase the conspicuity of the traffic sign while conforming to MUTCD guidelines. Fluorescent yellow sheeting increases the luminance of the sign. With the introduction of a long-lasting fluorescent retroreflective sign by the 3M Corporation, and later other companies, the opportunity is available to provide warning signs with an increased level of daytime conspicuity and a high level of nighttime retroreflectivity. Although the properties of the fluorescent yellow sheeting indicate that the conspicuity of the signs is much higher, the increased conspicuity ultimately must prompt a change in motorist behavior for highway safety to be improved. The current literature does not provide information on the change in motorist behavior. Therefore, the purpose of this research was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations.

In conducting the evaluation, the research team selected ten experimental sites in Orange County, North Carolina. The selected sites were locations collision histories showed that they were hazardous locations. The sites included curves, two-way stop-controlled intersections, stop-controlled t-intersections, and signalized intersections. The research team chose to use a simple before and after study to conduct the evaluation, mainly because the time between the before and after periods could be kept short so that most of the threats to validity were avoided. The measure of effectiveness (MOE) selected varied at each site but included safety surrogates such as vehicle speeds, centerline and edgeline encroachments, stop sign observance, stopping behavior, traffic conflicts, and traffic events. The research team collected before data from December 1999 through February 2000 with the existing yellow signs. In February, the existing signs were replaced with fluorescent yellow signs. The fluorescent yellow signs were in place for a minimum of three weeks before the after period began. The after data were collected in March and April 2000. Of the original ten experimental sites, seven were able to be used as experimental sites. The other three were excluded because the research team wasn't able to collect a meaningful sample of the MOE with the allotted resources.

Findings

Each site was analyzed individually between the before and after period. The research team performed relevant statistical analyses to determine if changes in the before period were statistically significant. All sites experienced some changes between the two periods, although not all changes were statistically significant. Additionally, a statistically significant change does not necessarily mean that there was a practical impact on traffic safety at the site.

Table 6-1 summarizes the results of this research. The relevant changes in the measures of effectiveness are displayed for each site. The table also indicates if the change was considered statistically significant and at what level. Based on the changes, the research team indicated if they considered those changes reflected an increase in safety.

Overall, fluorescent yellow appears to increase safety at some hazardous sites in this study. The signs appear to be most effective at the experiment sites where the warning signs provide advance information that is not reiterated by other features. For instance, at site B, the warning signs inform the motorist they are approaching a stop sign. Due to the geometry of the location, the stop sign itself is not visible until several hundred feet beyond the warning sign. The warning sign provides information vital to the motorist so that he or she can prepare for the stop sign. Similar geometry limitations are present at Site D1, Site D2, and Site F. At Site D1, the view of the traffic signal can be obstructed by a combination of the geometry and other vehicles. At Site D2, the view of the traffic signal is obstructed by a building until almost immediately before the intersection. At Site F, the surrounding environment masks the severity of the curve. At Site B, Site D1, and Site F, the research team concluded that the fluorescent yellow signs likely increased safety. At Site D2 although the mean, 50^{th} percentile, and 85^{th} percentile speeds were significantly decreased, the standard deviation was significantly increased, and therefore, the research team concluded that the fluorescent yellow signs did not increase safety at this site. By contrast, at Sites A and I the warning signs provide redundant information and the fluorescent yellow signs probably were not going to improve safety much at those sites.

Table 6-1: Summary of Findings

Site	MOE	Change from before to after	Significance	Reflect a probable increase in safety?
A	Centerline and Edgeline Encroachments	2.5% increase in the amount that maintained lane	Not at 90%	No
		3.6% decrease in the amount that encroached on the white edgeline	Not at 90%	
B	Stop Sign Observance	0.9% increase in the amount of voluntary full stops	Not at 90%	Yes
		8.7% decrease in amount of non-stopping vehicles	Yes, at 99%	
	Stopping Distance	9.3% increase in amount that began stopping at greatest distance	Yes, at 95%	
		6.4% decrease in amount that began stopping at least distance	Yes, at 95%	
D1	Traffic Conflicts	Decreased from 12 conflicts to 8	Not at 90%	Possibly, Yes
	Traffic Events	Decreased from 14 events to 6	Yes, at 95%	
D2	Speeds approaching intersection	Mean speed decreased by 1.4 m.p.h	Yes, at 95%	No
		1 mph decrease in 50th and 85th percentile speed	Yes, at 90%	
		Standard dev. increased by 0.7 mph	Yes, at 90%	
F	Centerline and Edgeline Encroachments	10.1% increase in the amount of vehicles that maintained lane	Yes, at 90%	Yes
		5.1% decrease in the amount that encroached on the white edgeline	Not at 90%	
		12.2% decrease in the amount that encroached on the yellow centerline	Yes, at 99%	
	Speeds approaching curve	2 m.p.h decrease in mean, 50th, and 85th percentile speed	Yes, at 99%	
		Standard dev. increased by 0.4 m.p.h.	Not at 90%	
H	Speeds approaching curve	Mean speed decreased by 0.3 m.p.h	Not at 90%	No
		Standard dev. decreased by 0.1 mph	Not at 90%	
I	Speeds approaching intersection EB	2 m.p.h. decrease in mean speed	Yes, at 95%	Possibly, yes (EB)
		3 mph decrease in 50th %tile	Yes, at 99%	
		2.8 mph decrease in 85th %tile	Yes, at 99%	
		Standard dev. decreased by 1.1 mph	Yes, at 95%	
	Speeds approaching intersection WB	0.5 mph decrease in mean speed	Not at 90%	No (WB)
		0.9 mph decrease in 85th %tile	Not at 90%	
		Standard dev. decreased by 0.4 mph	Not at 90%	

Recommendations for Similar Studies

During the course of this study, three experimental sites were dropped and two sites had their measure of effectiveness changed. The research team made these changes because they were unable to collect a relevant sample size at these sites in the allotted time. This reduced the number of experimental sites by thirty percent. It also increased the number of sites where vehicle speed, the weakest surrogate, was used as the measure of effectiveness. These problems could have been avoided if the research team had conducted another field review at each site to determine if a relevant sample size was achievable in the desired time frame before each site was selected for the experiment. One or two hours spent at each site collecting the selected measure of effectiveness would have provided enough information to determine if the site and the measure of effectiveness were viable for the study.

A measurement error by the data collector required that the chevrons were not replaced at Site A. Although errors can occur in any field evaluation, reviewing important information, such as the measurements for the sign request, can avoid unnecessary errors.

The research team intended to randomly select the experimental sites from a list of candidates. Although the list of locations received from the NCDOT had fifty-five locations on it, all but nine had to be excluded based on the criteria for candidates. Although at the time the request was made fifty-five sites seemed large enough, a larger list of locations should be requested for future research.

Recommendations for Future Research

The ultimate measure of effectiveness of a yellow warning sign is the number of collisions it prevents. The indirect measures employed for this study support that fluorescent yellow warning signs increase safety at hazardous locations. However, relating changes in the indirect measures to actual collision savings is difficult. Limited information is available on this subject, especially changes in vehicle speeds. A collision study would not only help to corroborate the findings of this study, but would also help quantify the collision savings. Additionally, due to the short duration of this study, the long-term effects of the fluorescent sheeting can not be known. A large-scale collision study could also determine if certain types of signs provide more collision savings when changed to fluorescent than others and if drivers eventually become acclimated to the fluorescent yellow signs.

Recommendations for Use

The results of this study were obtained from only seven sites in Orange County, North Carolina. This is a small amount of experimental sites. Additionally, the candidate sites for this experiment were not plentiful. Based on the limited results of this study, the research team recommends fluorescent yellow warning signs as a traffic safety countermeasure at hazardous locations. They have promise of being most beneficial at locations where the geometry of the location or other factors mask the hazard for which the sign is providing warning.

Although the fluorescent diamond grade sheeting costs approximately fifteen percent more than standard yellow diamond grade sheeting ($5.44 per square foot as opposed to $4.72 per square foot), over the lifetime of the sign the cost is not significant compared to other countermeasures. The estimated cost of installing a 36" standard yellow diamond grade sign is currently $161. The estimated cost of installing a 36" fluorescent yellow diamond grade warning sign is $178. This is a 10.5% increase in cost.

One method employed to increase the conspicuity of a warning size is to increase the size of the sign. When comparing the sheeting costs (in today's prices) of using an oversize diamond grade sign (42" by 42") yellow warning sign to increase conspicuity as opposed to using a fluorescent diamond grade yellow sign (standard size 36" by 36"), the sheeting for the oversize sign costs $58 as opposed to $49 for the fluorescent yellow sign.

Fluorescent yellow sheeting appears to provide a low cost method to increase the safety of a hazardous site by increasing the conspicuity of the warning sign. However, the findings of this study are limited to only seven experimental sites. More research is suggested before wide-scale application is recommended.

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APPENDIX A
Site Selection Lists

Table A-1: List of Hazardous Intersections in Orange County

Intersection Number	Area	Street	Street
1	Carrboro	Lloyd	Main
2	Carrboro	NC 54	Poplar
3	Carrboro	Jones Ferry	Davie
4	Carrboro	NC 54	Smith Level
5	Carrboro	NC 54	Main
6	Carrboro	Main	Rosemary
7	Carrboro	Greensboro	Main
8	Chapel Hill	Boundary	Franklin
9	Chapel Hill	Church	Franklin
10	Chapel Hill	Dobbin	Erwin
11	Chapel Hill	Franklin	Robeson
12	Chapel Hill	NC 54	Barbee Chapel
13	Chapel Hill	Raleigh	Franklin
14	Chapel Hill	Hamilton	Raleigh
15	Chapel Hill	Erwin	Weaver Dairy
16	Chapel Hill	Airport	Hillsboro
17	Chapel Hill	Airport	Weaver Dairy
18	Chapel Hill	Franklin	Graham
19	Chapel Hill	Country Club	South
20	Chapel Hill	Elliot	Fordham
21	Chapel Hill	Columbia	Rosemary
22	Chapel Hill	Estes	Seawell School
23	Chapel Hill	Estes	Franklin
24	Chapel Hill	Park	Franklin
25	Chapel Hill	Ephesus	Legion
26	Chapel Hill	Church	Rosemary
27	Chapel Hill	Estes	Willow
28	Chapel Hill	Mcauley	Pittsboro
29	Chapel Hill	Merrit Mill	Franklin
30	Hillsborough	Churton	Mayo
31	Hillsborough	Mayo	Orange Grove
32	Hillsborough	Churton	King
33	Hillsborough	Churton	Margaret
34	Hillsborough	Cardinal	Churton
35	Rural	NC 54	SR 1102
36	Rural	NC 57	NC 86
37	Rural	NC 86	SR 1727

Table A-2: List of Hazardous Sections in Orange County

Initial Number	Main Road	In the Vicinity Of
38	NC 54	SR 1006
39	NC 49	NC 86
40	US 70	SR 1561
41	SR 1777	SR 1728
42	SR 1009	SR 1129
43	I 40	SR 1141
44	SR 1710	SR 1723
45	US 70	SR 1709
46	US 70	SR 1322
47	I 40	SR 1143
48	NC 157	SR 1575
49	SR 1317	SR 1316
50	SR 1114	SR 1120
51	I 85	SR 1709
52	SR 1777	SR 1729
53	SR 1554	SR 1555
54	US 70	SR 1313
55	NC 86	SR 1730

Table A-3: List of Possible Experimental Intersection

Area	Street	Street
Chapel Hill	Dobbin	Erwin
Hillsborough	Mayo	Orange Grove
Rural	NC 54	SR 1102
Rural	NC 57	NC 86

Table A-4: List of Possible Experimental Sections

Main Road	In the Vicinity of
NC 54	SR 1006
NC 49	NC 86
US 70	SR 1561
SR 1777	SR 1728
SR 1009	SR 1129
SR 1710	SR 1723
US 70	SR 1709
NC 157	SR 1575
SR 1317	SR 1316
SR 1114	SR 1120
SR 1777	SR 1729
US 70	SR 1313

APPENDIX B
Site Descriptions

Figure B-1: Sketch of Orange County with Experimental Sites

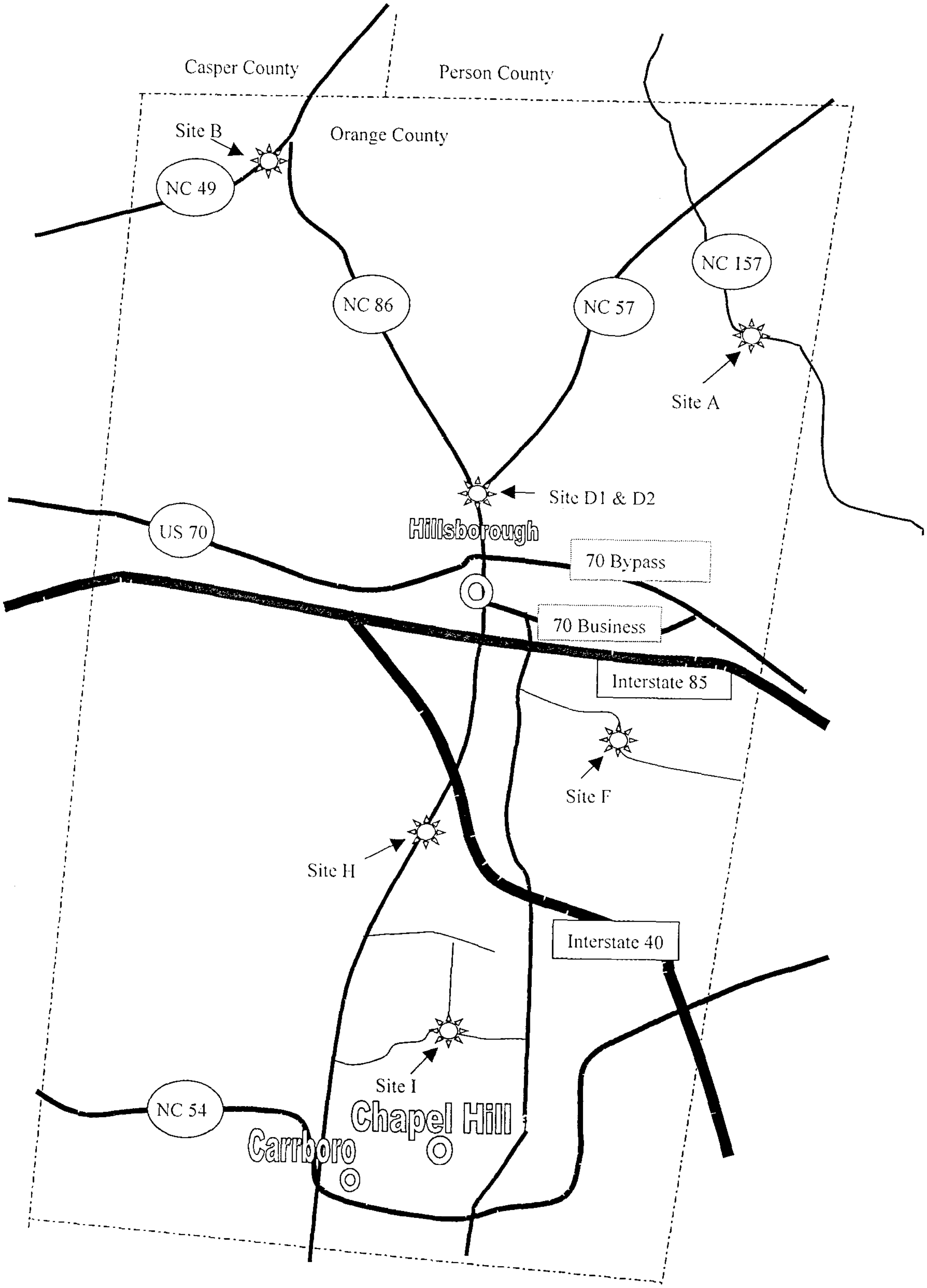
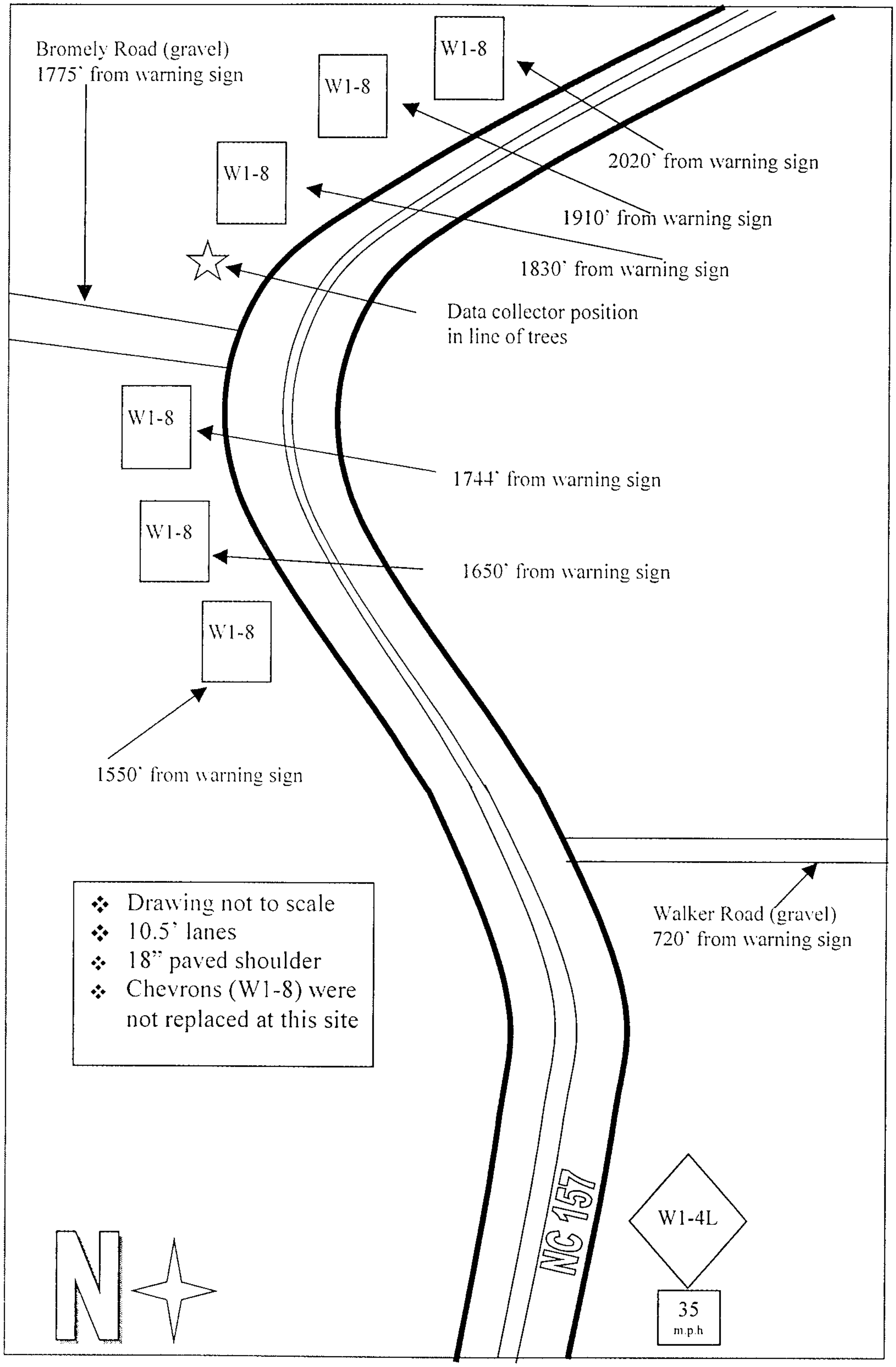


Figure B-2: Sketch of Site A



Pictorial Description of Site A (NC 157 in the Vicinity of Walker Road)

Figure B-3: Southeast NC 157 at Curve Warning Sign

Figure B-4: Southeast NC 157 Immediately Before Walker Road

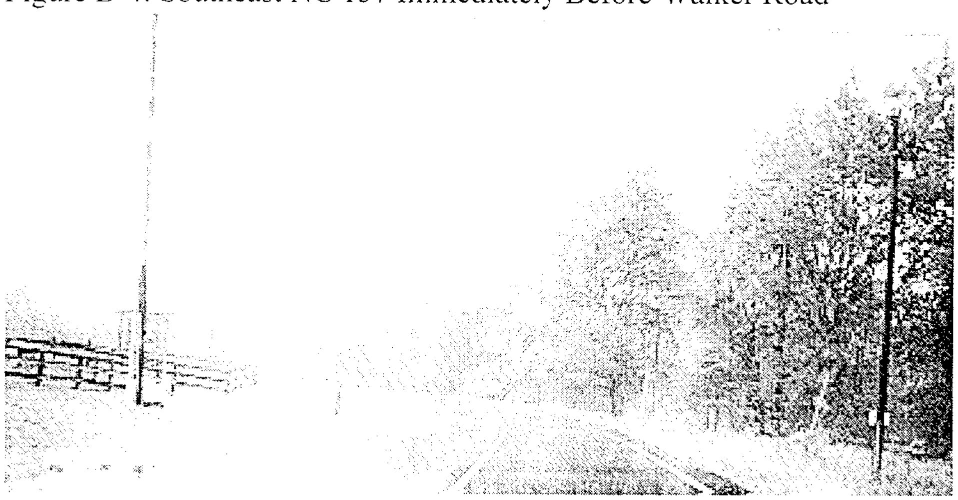


Figure B-5: Southeast NC 157 Entering the Curve at the Chevrons

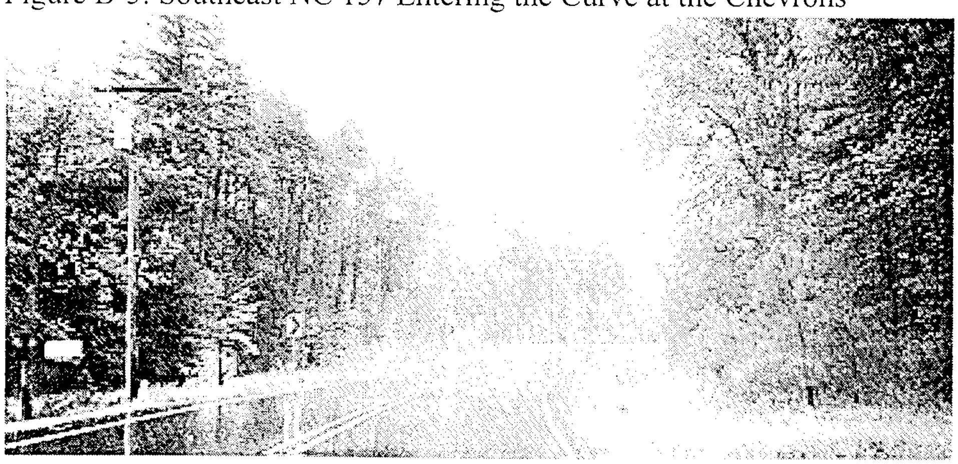
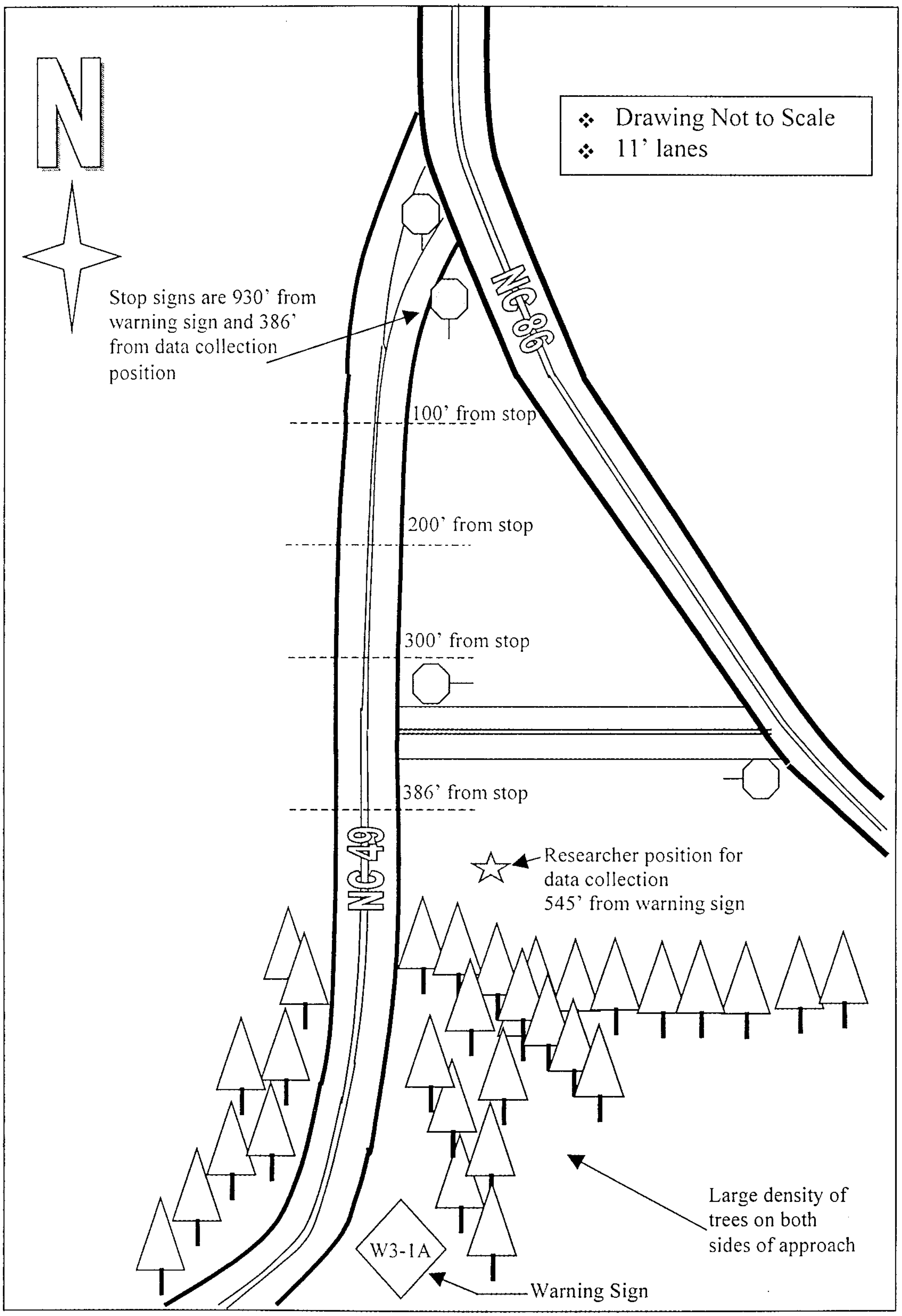


Figure B-6: Sketch of Site B



Pictorial Description of Site B (NC 49 and NC 86)

Figure B-7: NC 49 Approach to Intersection View in Advance of Yellow Sign

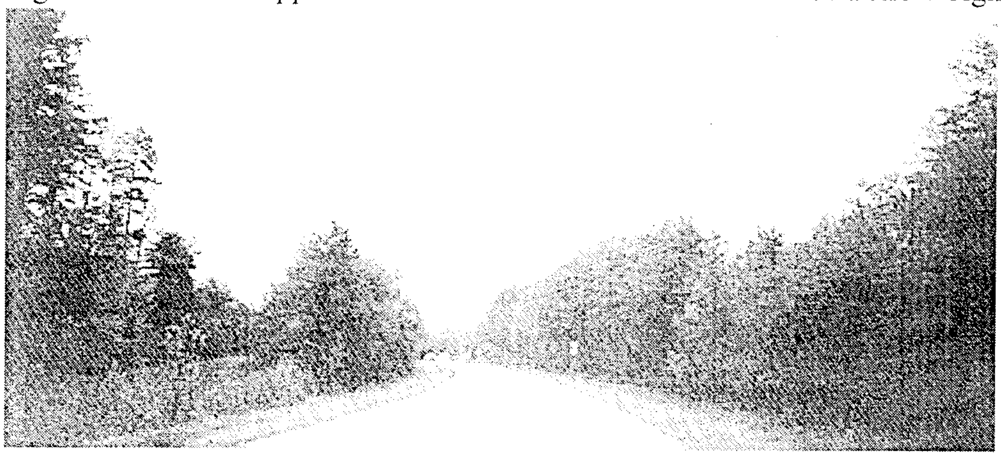


Figure B-8: NC 49 Approach View Nearing Yellow Sign

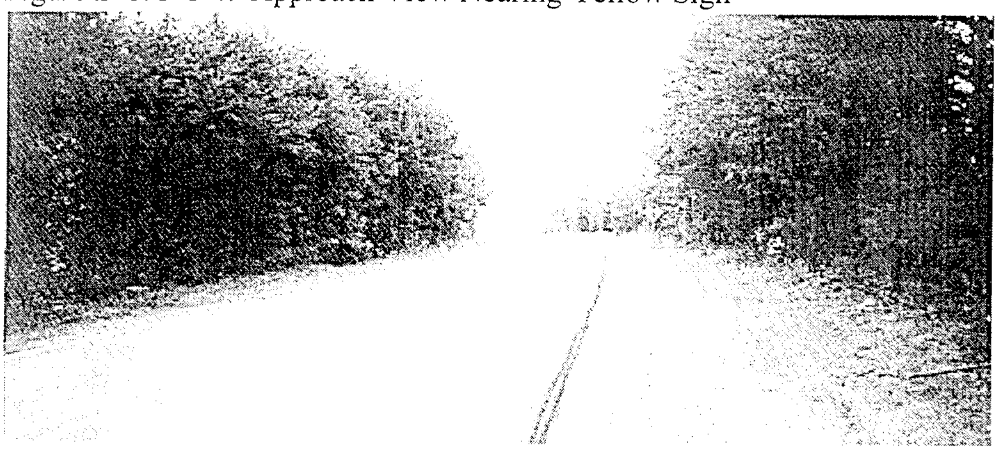
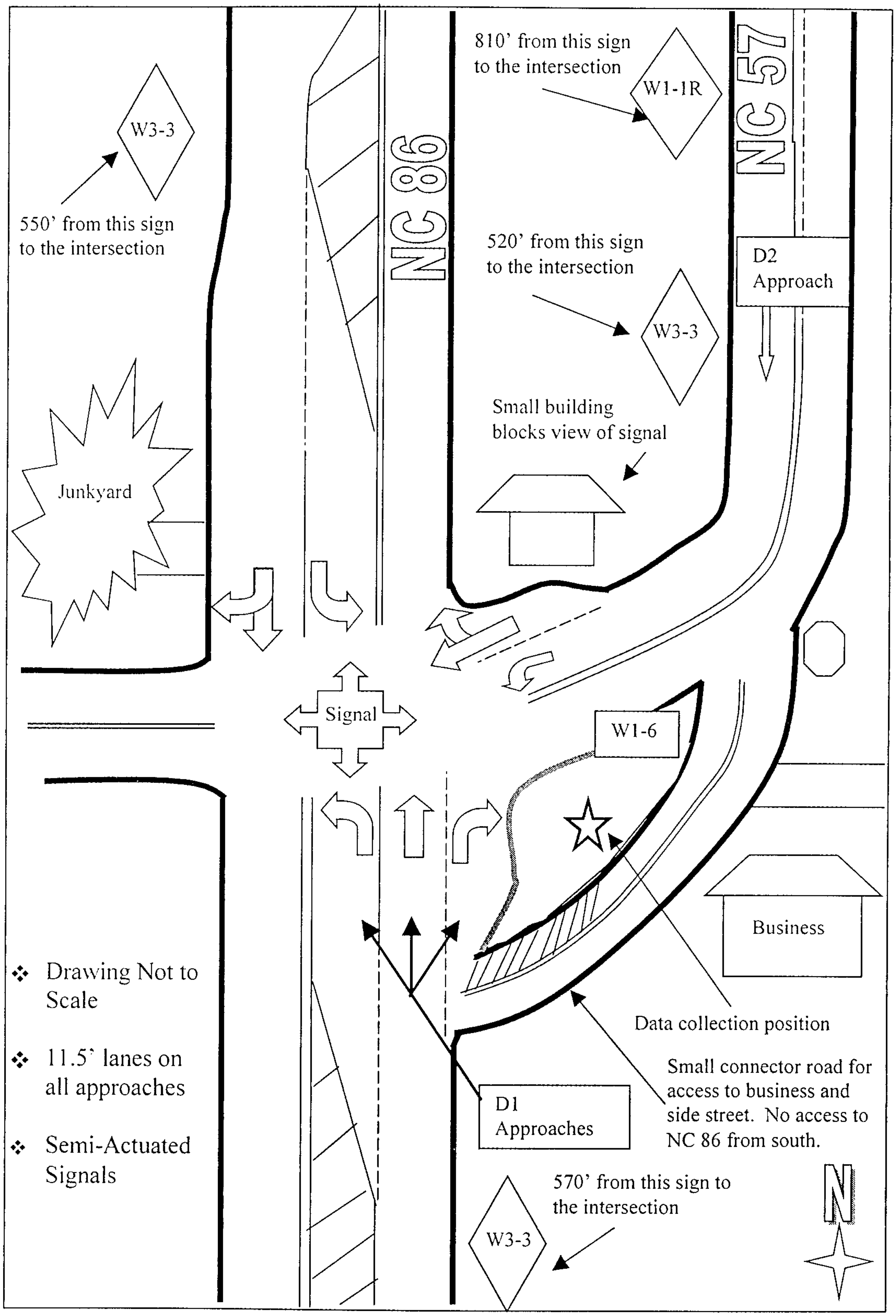


Figure B-9: NC 49 Approach Nearing the Stop Controlled Intersection

Figure B-10: Sketch of Site D1 and D2



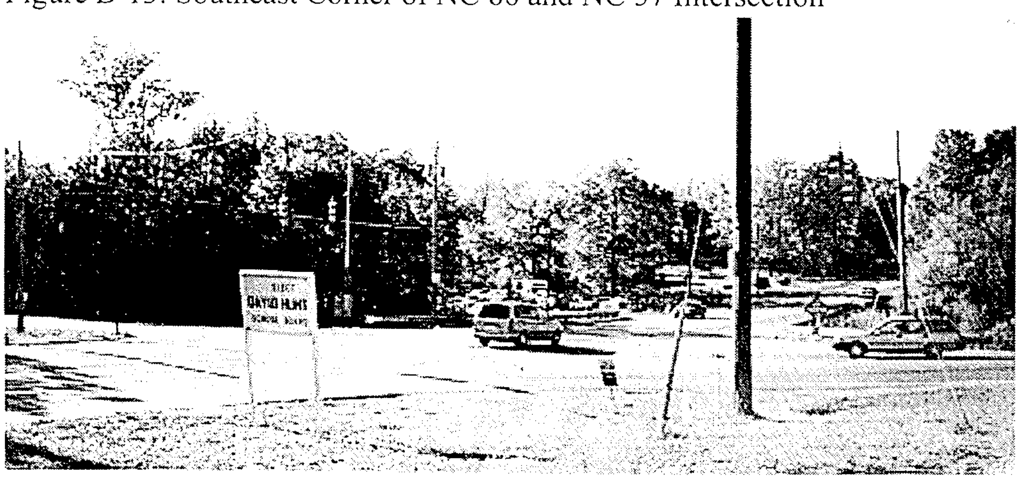
- Drawing Not to Scale
- 11.5' lanes on all approaches
- Semi-Actuated Signals

Pictorial Description of Site D1
(Northbound NC 86 Approach to Signalized Intersection)

Figure B-11: NB NC 86 Approaching Yellow Warning Sign

Figure B-12: View on NB NC 86 After Yellow Warning Sign

Figure B-13: Southeast Corner of NC 86 and NC 57 Intersection



Pictorial Description of Site D2
NC 57 Approach to Signalized Intersection with NC 86

Figure B-14: NC 57 Approach to Intersection at First Yellow Warning Sign

Figure B-15: NC 57 Approach to Intersection at Second Yellow Warning Sign

Figure B-16: NC 57 Approach View at Spot Speed Position

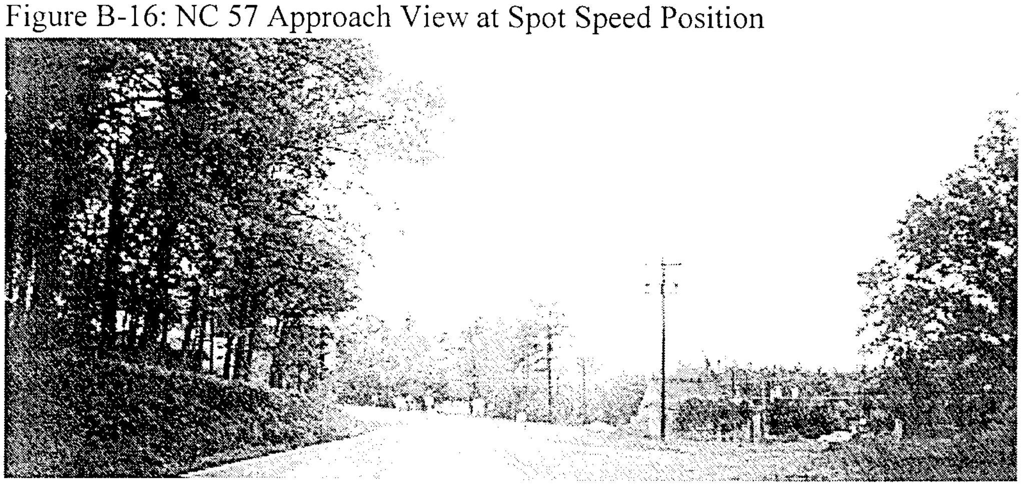
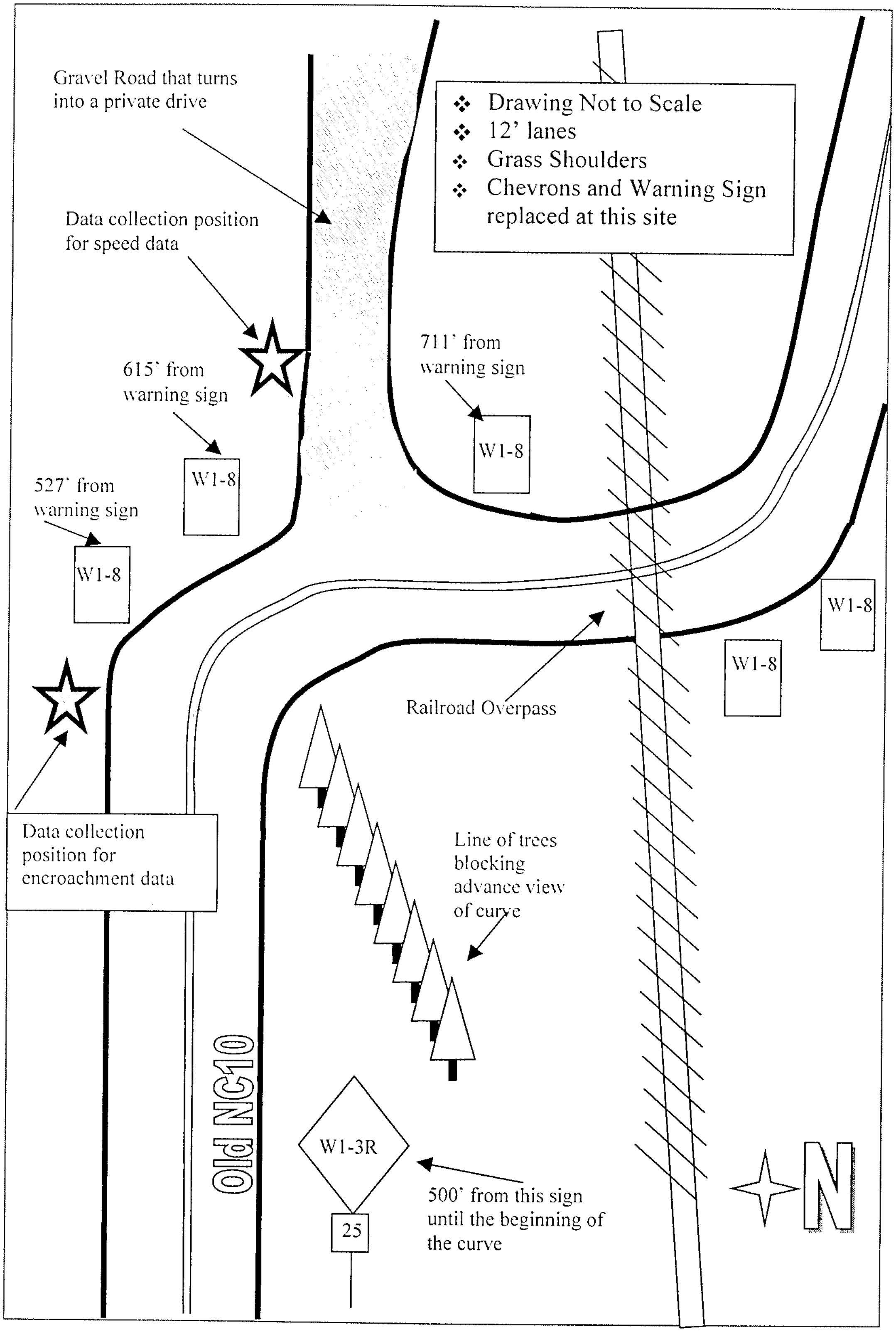


Figure B-17: Sketch of Site F



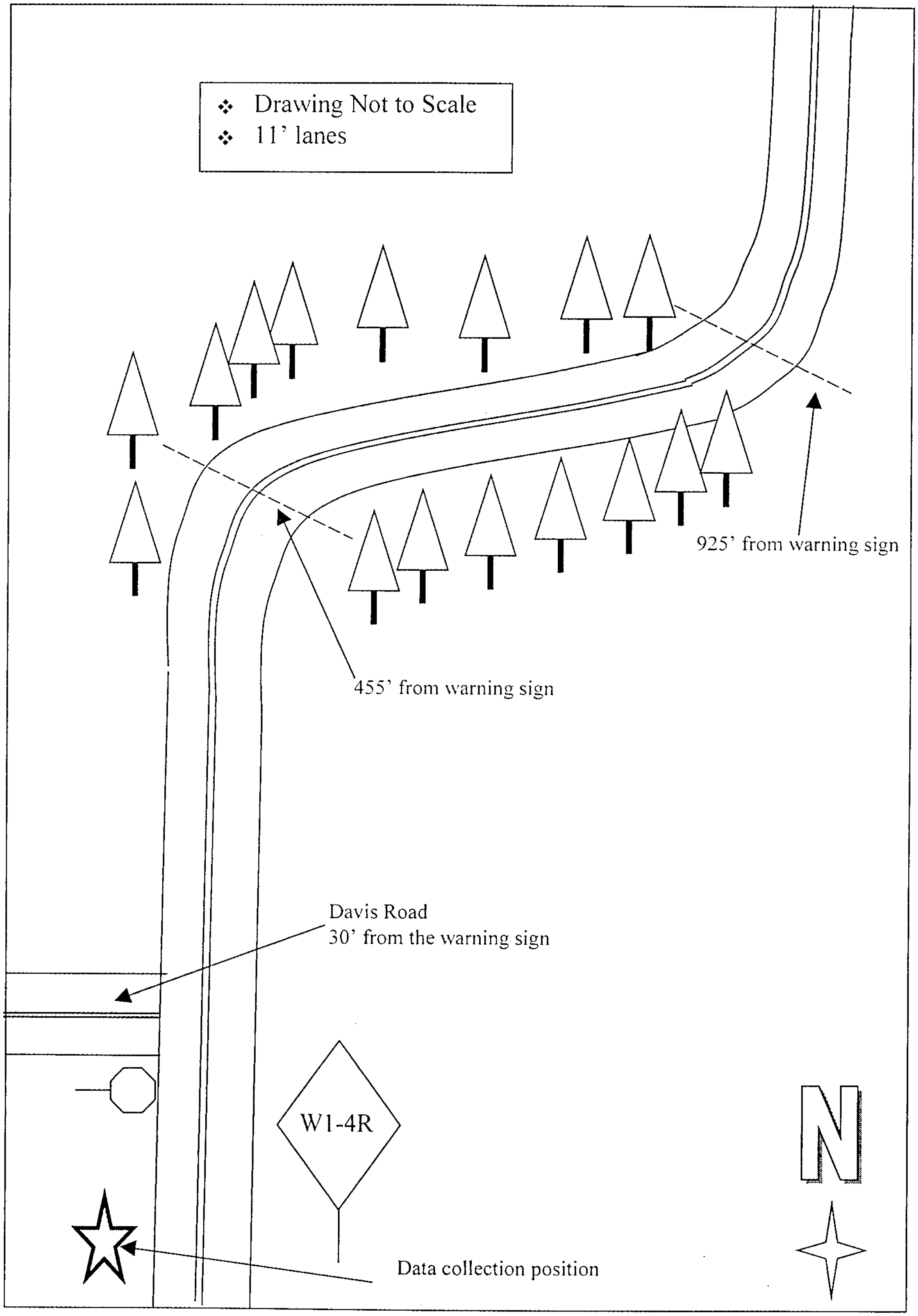
Pictorial Description of Site F (Old NC 10 Reverse Turn)

Figure B-18: WB Old NC 10 Approaching Yellow Warning Sign

Figure B-19: WB Old NC 10 Entering Curve

Figure B-20: WB Old NC 10 in Curve

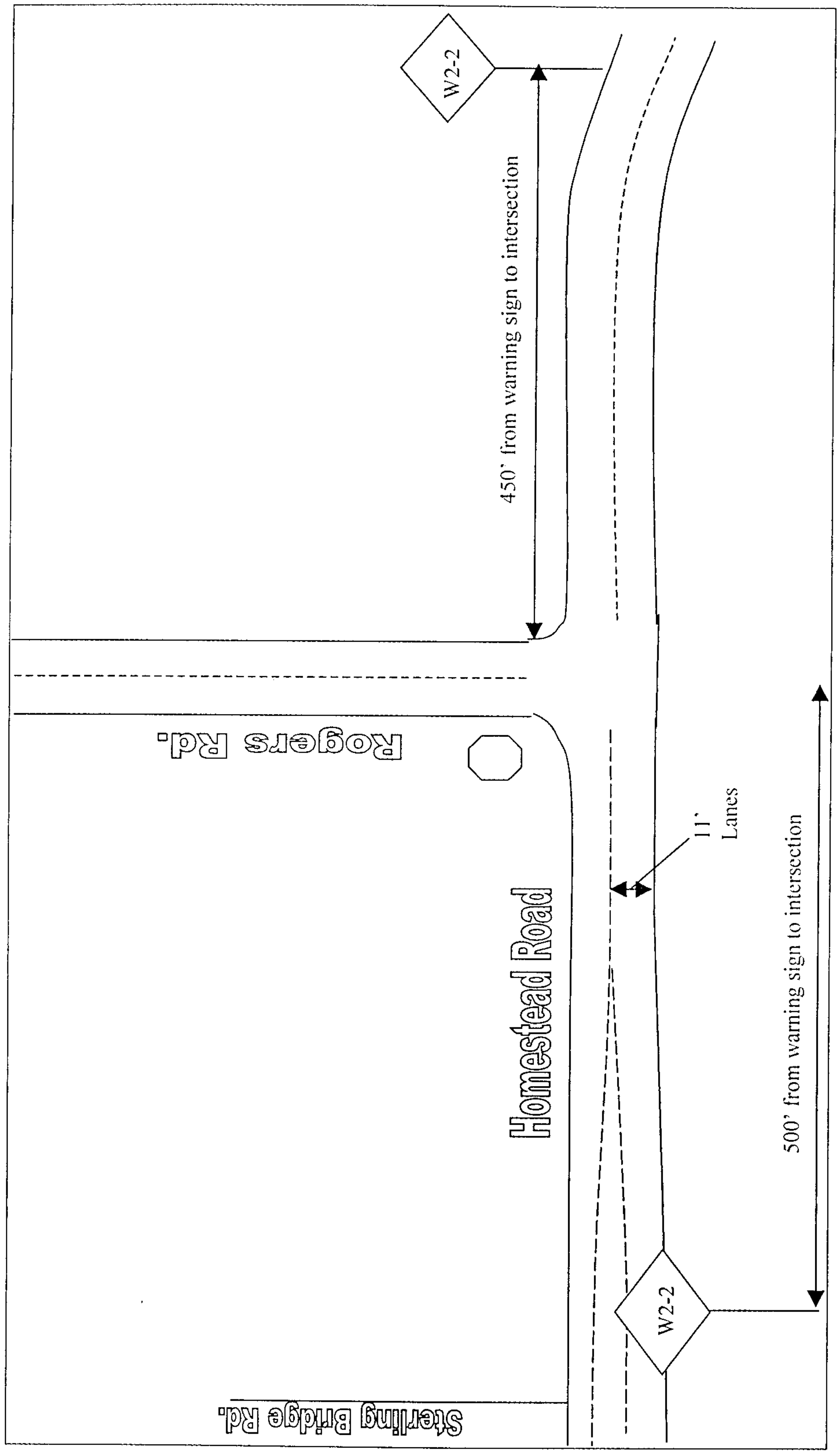
Figure B-21: Sketch of Site H



Pictorial Description of Site H: NB Old NC 86 Curve at Davis Road

Figure B-22: NB Old NC 86 Approaching Yellow Warning Sign

Figure B-23: Sketch of Site I



Pictorial Description of Site I
Homestead Road at the Intersection with Rogers Road

Figure B-24: EB Homestead Road at Yellow Warning Sign for Rogers Road

Figure B-25: EB Homestead Road at Intersection with Rogers Road

APPENDIX C
Data Sheets

Centerline and Edgeline Encroachment
Field Sheet

Site___________________________Observer________________________________

Weather____

Date__________________________________Time__________________________

Major White Edgeline Encroachment	
Minor White Edgeline Encroachment	
Stayed in Lane	
Minor Yellow Centerline Encroachment	
Major Yellow Centerline Encroachment	

Notes____

____

____

Driver Braking Distance and Observance of Stop Signs
Field Sheet

Site______________________________Observer____

Weather____

Date____Time__________________________________

	Over 386'	300-386'	200-300'	Under 200'	Indeterminate
Voluntary Full Stop					
Stopped By Traffic					
Practically Stopped					
Non-Stopping					

Notes____

____

Non-Platooned Spot Speed
Field Sheet

Site__________________________ Observer________________________________

Weather____

Date__________________________________Time__________________________

Speed (m.p.h.)	Speed (m.p.h.)	Speed (m.p.h.)	Speed (m.p.h.)	Speed (m.p.h.)

Notes____

____

____

APPENDIX D
Data

Figure D-1: Before Data at Site A

Walker Road Curve
10:15 to 12:15
sunny, brisk wind 50 degrees
2/17/00

SB Towards Durham County	
Stayed in Lane	71
Minor Yellow Encroachment	4
Major Yellow Encroachment	0
Minor White Encroachment	35
Major White Encroachment	3

Volume	
SB Towards Durham	115
NB Away from Durham	72

Walker Road Curve
2:15 to 3:15
sunny, brisk wind 50 degrees
2/17/00

SB Towards Durham County	
Stayed in Lane	19
Minor Yellow Encroachment	0
Major Yellow Encroachment	0
Minor White Encroachment	7
Major White Encroachment	2

Volume	
SB Towards Durham	28
NB Away from Durham	53

Figure D-2: After Data at Site A

Walker Road Curve
9:30 to 11:30
Sunny, 60*, cloudless
4/6/00

SB Towards Durham County	
Stayed in Lane	78
Minor Yellow Encroachment	4
Major Yellow Encroachment	0
Minor White Encroachment	34
Major White Encroachment	4

Volume	
SB Towards Durham	140
NB Away from Durham	82

Walker Road Curve
2:00 to 4:00
Sunny, cloudless, 71*
4/6/00

SB Towards Durham County	
Stayed in Lane	56
Minor Yellow Encroachment	4
Major Yellow Encroachment	0
Minor White Encroachment	20
Major White Encroachment	2

Volume	
SB Towards Durham	122
NB Away from Durham	209

Figure D-3: Before Data at Site B

12/16/99
12:40-3:00

	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	8	5	4	0	7	24
Stopped by Traffic	9	10	7	1	10	37
Practically Stopped	6	2	3	1	2	14
Non-stopping	0	2	0	2	2	6
	23	19	14	4	21	81

2/4/00
0:45-12:45

	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	16	9	3	0	7	35
Stopped by Traffic	6	5	0	0	2	13
Practically Stopped	1	5	1	0	1	8
Non-stopping	2	6	0	0	1	9
	25	25	4	0	11	65

2/4/00
2:30-3:30

	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	9	7	0	0	3	19
Stopped by Traffic	6	6	2	0	0	14
Practically Stopped	2	3	1	0	2	8
Non-stopping	0	0	0	0	0	0
	17	16	3	0	5	41

Total

	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	33	21	7	0	17	78
Stopped by Traffic	21	21	9	1	12	64
Practically Stopped	9	10	5	1	5	30
Non-stopping	2	8	0	2	3	15
	65	60	21	4	37	187

Figure D-4: After Data at Site B

3/28/00 10:30-2:30	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	22	12	4	0	11	49
Stopped by Traffic	18	15	3	0	8	44
Practically Stopped	6	14	4	0	4	28
Non-stopping	0	0	0	0	0	0
	46	41	11	0	23	121

4/7/00 1:00 to 2:00	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	8	2	1	0	4	15
Stopped by Traffic	8	6	1	0	9	24
Practically Stopped	2	2	0	0	1	5
Non-stopping	2	1	0	0	0	3
	20	11	2	0	14	47

4/11/00 :00 to 12:00	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	13	4	2	0	9	28
Stopped by Traffic	7	6	2	0	4	19
Practically Stopped	6	3	0	0	4	13
Non-stopping	0	0	1	0	1	2
	26	13	5	0	18	62

Total	Over 386	300-386	200-300	Under 200	Indeterminant	
Voluntary Full Stop	43	18	7	0	24	92
Stopped by Traffic	33	27	6	0	21	87
Practically Stopped	14	19	4	0	9	46
Non-stopping	2	1	1	0	1	5
	92	65	18	0	55	230

Figure D-5: Conflict and Event Data at Site D1

Before Period Data				
Date	Period	Time	Conflicts	Events
12/15/99	4:00-5:31	4:40	3 hestitated on green, 13 e.d.	
12/16/99	7:00-9:00	7:54	2 hesitated on green, 12 ed.	
		8:36		8 ran red
12/16/99	4:00-5:31	4:00		2 E.D. for signal
		4:12		2 E.D. for signal past stop bar
		4:20		2 ran red
		4:31		2 ran red
		4:39	2 left into junkyard, 12 e.d.	
1/21/00	4:00-5:57	4:21	2 hesitated on green, 12 ed.	
		4:30		2 e.d. (truck with squealing tires and smoke)
		4:38		2 ran red (truck)
		4:38		12 e.d. (view may be obstructed by truck)
		4:50	2 left into junkyard, 12 e.d.	
		4:58	2 stopped, 12 emer. Stop @ queue	
		5:43		2 ran red
2/3/00	7:30-9:00	8:10		2 ran red
		8:43		8 ran red
2/16/00	4:00-6:00	4:12	2 hestitate, 12 e.d.	
		4:14		2 ran red
		4:19		8 ran red
		4:23		8 ran red
		4:57	2 left into junkyard, 12 e.d.	
		5:26	2 truck slow up hill after signal, 12 e.d.	
		5:30	2 left into junkyard, 12 e.d.	
		5:35	7 turned left, 2 e.d.	
		5:47	2 slowed for queue, 12 e.d.	

After Period Data				
Date	Period	Time	Conflicts	Events
3/28/00	4:00-6:00	5:01	1 turned left, 8 e.d.	
		5:26	2 left into junkyard, 12 e.d.	
3/30/00	4:00-6:00	5:27	2 left into junkyard, 12 e.d.	
		5:45		2 ran red
4/4/00	4:00-5:00	4:23	2 hestitate, 12 e.d.	
		4:37	2 hestitate, 12 e.d.	
4/11/00	7:00-9:00	7:34	1 turned left, 8 e.d.	
		7:45		8 ran red
		8:16		8 ran red
4/11/00	4:00-6:00	4:17	2 crawling up hill, 12 e.d. back in queue	
		4:30		2 e.d. for signal
		4:51	2 left into junkyard, 12 e.d.	
4/19/00	7:00-9:00	7:45		2 ran red (truck)
		8:03		8 ran red

Total Before Volumes					
NBL	NBT	NBR	SBL	SBT	SBR
106	4047	1849	51	3714	67

Total After Volumes					
NBL	NBT	NBR	SBL	SBT	SBR
131	4533	1958	54	4273	40

Figure D-6: Before Data at Site D2

Date	2/16/00
Time	8:00 to 11:00
Weather	Sunny, 40*

Speed (in mph)		
40	43	37
36	44	48
31	43	44
46	44	45
40	45	42
44	44	44
45	40	42
47	42	49
42	47	44
46	44	48
40	41	43
35	41	44
45	44	39
40	46	48
33	41	46
43	56	51
48	41	50
44	34	51
42	37	53
38	45	40
44	42	41
41	40	31
41	44	38
46	51	57
44	53	41
28	45	38
46	42	39
38	41	39
39	44	42
38	40	38
39	46	34
47	41	41
39	41	46
41	39	44
35	46	45

3/6/00
1:00 to 2:00
Sunny, 70*

Speed (in mph)
40
43
44
44
42
37
36
38
51
45
45
37
38
51
40
47
47
34
42
43
47
45
52
38
40
43
44
44
43
44

Average	42.6
ST D	4.8
Sample	135
Range	28 to 57
50th %tile	43
85th %tile	47

Figure D-7: After Data at Site D2

Date	4/12/00	4/19/00	4/19/00
Time	8:00 to 11:00	9:00 to 10:00	5:00 to 6:00
Weather	Sunny, 60*	Sunny, clear 55*	Sunny, clear 70*

Speed (in m.p.h.)	
42	40
39	45
43	43
43	43
48	36
40	45
39	37
45	43
39	36
48	28
38	42
45	46
38	42
32	33
47	32
48	45
50	36
44	
51	
44	
41	
41	
44	
38	
40	
32	
31	
44	
41	
45	
29	
43	
41	
41	
39	
42	
37	

Speed (in m.p.h.)
40
39
40
39
47
17
49
45
39
54
36
46
43
39
40
38
38
35
42
53
51
43
43
46
48
44
36
39
36
43
40
36
51

Speed (in
38
41
31
38
39
44
30
36
38
43
47
43
37
52
43
39
46
38
35
49
43
40
40
48
46
37
43
43
43
43
42
40
40
42
43
50

Average	41.2
ST D	5.5
Sample	123.0
Range	17 to 54
50th %tile	42.0
85th %tile	46.0

Figure D-8: Curve Data at Site F

Before Data

2/16/00
12:00 to 3:00
Sunny, 60 to 65, breezy

	Amount
Stayed in Lane	31
Minor Yellow encroachment	3
Major Yellow Encroachment	0
Minor White Encroachment	20
Major White Encroachment	1

3/6/00
4:00 to 5:00
Sunny, clear, 70*

	Amount
Stayed in Lane	33
Minor Yellow encroachment	6
Major Yellow Encroachment	1
Minor White Encroachment	15
Major White Encroachment	1

After Data

4/19/00
1:30 to 3:30
Sunny, clear, 70*

	Amount
Stayed in Lane	47
Minor Yellow encroachment	1
Major Yellow Encroachment	0
Minor White Encroachment	20
Major White Encroachment	2

4/19/00
4:00 to 5:00
Sunny, clear, 70*

	Amount
Stayed in Lane	31
Minor Yellow encroachment	0
Major Yellow Encroachment	0
Minor White Encroachment	14
Major White Encroachment	0

Figure D-9: Before Speed Data at Site F

Date	12/21/99	2/9/00	2/9/00
Weather	Sunny, 30*	Sunny, 40*	Part sun, 45*
Time Period	12:30 to 2:00	9:15 to 10:15	12:30 to 2:00
	Speed (in m.p.h.)	Speed (in m.p.h.)	Speed (in m.p.h.)
	34	35	36
	31	39	33
	36	39	37
	33	48	31
	32	31	35
	41	34	36
	29	31	36
	37	32	42
	28	35	39
	31	36	35
	34	38	42
	37	37	41
	42	40	45
	37	34	36
	35	35	34
	43	35	34
	34	38	38
	35	38	47
	36	33	42
	31	36	36
	34	38	42
	39	32	33
	41	36	35
	38		41
	40		33
	41		36
	40		35
	35		44
	38		34
	31		40
	42		
	42		
	36		

Figure D-10: After Speed Data at Site F

Date	4/18/00	4/19/00	
Weather	Overcast, 60*	Sunny, 60*	
Time Period	12:00 to 1:30	11:15 to 1:15	
	Speed (in m.p.h.)	Speed (in m.p.h.)	
	39	33	39
	33	28	46
	34	31	39
	33	31	34
	36	31	30
	35	31	35
	34	31	35
	41	36	38
	36	37	37
	34	36	34
	40	28	35
	34	44	34
	24	30	40
	31	32	32
	38	34	31
	33	33	33
	30	32	38
	32	32	26
	47	31	33
	30	38	32
	38	34	26
	32	36	37
	45	35	31
	45	36	34
	33	35	32
	34	31	
	31	43	
	37	30	
		36	
		33	
		43	
		38	
		32	
		39	
		31	

Figure D-11: Spectrometry Measurements on February 15, 2000

Site	Sign Description	Material	Installation	Existing Sign						Fluorescent Yellow		
				Retroreflectivity			Luminance (cd/m^2)	Chromoticity		Luminance (cd/m^2)	Chromoticity	
								X	Y		X	Y
New Hope Curve WB	Curve Sign	Engineering	10/19/95	73	60	75	5696 (yellow) 652 (black)	0.464 0.32	0.453 0.333	9806	0.532	0.458
	Auxillary Speed	Engineering	10/19/95	60			6344	0.503	0.463			
	Chevron 1	High Intensity	3/23/98	253	243	241	2619 (yellow) 194 (black) 1171 (overall) 378 (left bkgrnd) 542 (right bkgrnd)	0.528 0.308 0.489 0.371 0.374	0.457 0.325 0.435 0.389 0.389	7992	0.535	0.459
	Chevron 2	High Intensity	3/23/98	231	225	226	5308 (yellow) 445 (black) 2007 (overall) 1167 (left bkgrnd) 1976 (right bkgrnd)	0.521 0.312 0.431 0.382 0.387	0.46 0.33 0.405 0.379 0.38	Overload		
Davis NB	Curve Ahead	Engineering	10/11/95	60	60	59	6511 (yellow) 728 (black) 3838 (overall) 838 (left bkgrnd) 370 (right bkgrnd)	0.493 0.299 0.496 0.366 0.353	0.46 0.318 0.463 0.371 0.36	9524	0.529	0.458
Homestead WB	Intersection	Engineering	34975	45	47	43	810 (yellow) 104 (black)	0.508 0.337	0.442 0.35	1323	0.54	0.436
Walker Road SB	Curve Sign	Engineering	1/2/98	62	62	65	1027 (yellow) 169 (black)	0.462 0.315	0.426 0.327	1353	0.536	0.443
	Speed template	Engineering	1/2/98	60	62	57	939	0.476	0.438			
	Speed template	Engineering	1/2/98	61	57	60	815	0.482	0.465			
NC 86 NB at NC 59	Signal Ahead	Engineering	2/12/97	49	48		11000 (yellow) 3943 (red) 2197 (green)	0.481 0.528 0.209	0.451 0.337 0.414	Overload		
NC 59 SB at NC 86	Signal Ahead	Engineering	2/12/97	50	47	47	1399 (yellow) 583 (red) 491 (green) 214 (black)	0.454 0.477 0.234 0.284	0.422 0.319 0.375 0.295	2285	0.514	0.432
NC 49 and NC 86	Stop Ahead		No date	55	56	16 (red)	621 (yellow) 156 (red) 96.9 (black) 521 (overall) 1166 (left bkgrnd) 308 (right bkgrnd)	0.45 0.514 0.283 0.441 0.403 0.372	0.441 0.315 0.299 0.421 0.416 0.401	1078	0.52	0.462

Figure D-12: Spectrometry Measurements taken on May 2, 2000

Site	Sign Description	Direction	Retroreflectivity			Luminance (cd/m^2)		Chromoticity		Orientation
								X	Y	
D1	Signal Ahead	NB	248	270	260	Yellow	2243	0.529	0.45	45
						Black	347	0.339	0.345	
						Green	453	0.247	0.378	
						Red	608	0.47	0.329	
						Whole Sign	1430	0.5	0.442	
						Right Background	608	0.345	0.398	
						Left Background	832	0.338	0.375	
D2	Curve Ahead	SB	272	292		Yellow	3652	0.534	0.454	45
						Black	132	0.337	0.372	
	Signal Ahead	SB	275	243	255	Yellow	3107	0.504	0.437	45
						Black	394	0.322	0.336	
						Green	574	0.241	0.378	
						Red	757	0.454	0.331	
						Whole Sign	1627	0.457	0.418	
						Right Background	668	0.334	0.382	
						Left Background	784	0.336	0.383	
	Junction Marker (for reference)	SB				White	1967	0.326	0.35	
						Black	56.2	0.325	0.357	
	Arrow Board	SB	243	235	235	Yellow	2703	0.525	0.444	0
						Black	346	0.322	0.337	
						Whole Sign	1191	0.514	0.445	
						Right Background	443	0.351	0.413	
						Left Background	342	0.337	0.402	
A	Curve Ahead	SB (towards Durham County)	266	250		Yellow	1466	0.537	0.454	45
						Black	42	0.366	0.412	
						Whole Sign	1046	0.498	0.448	
						Right Background	540	0.368	0.438	
						Left Background	390	0.359	0.448	
						Yellow (duplicate)	1308	0.539	0.454	
						Black (duplicate)	45.2	0.37	0.415	
	35 mph plaque		372	384	381		1067	0.499	0.448	90

Figure D-13: Spectrometry Measurements taken on May 2, 2000 Continued

Site	Sign Description	Direction	Retroreflectivity			Luminance (cd/m^2)		Chromoticity		Orientation
								X	Y	
B	Stop Ahead	NB	270 (yellow)	175 (red)		Yellow	1612	0.528	0.452	45
						Yellow (duplicate)	1555	0.531	0.453	
						Red	188	0.62	0.318	
						Black	48.2	0.32	0.335	
						Whole Sign	884	0.506	0.431	
						Whole Sign (duplicate)	865	0.499	0.43	
						Right Background	581	0.37	0.438	
						Left Background	498	0.359	0.413	
F	Curve Ahead	WB	288	295		Yellow	2275	0.531	0.456	45
						Black	322	0.321	0.336	
						Whole Sign	1291	0.507	0.451	
						Right Background	420	0.355	0.408	
						Left Background	386	0.348	0.4	
						Yellow (duplicate)	2963	0.501	0.433	
						Black (duplicate)	421	0.314	0.329	
	25 mph plaque	WB	370			Yellow	1992	0.534	0.454	90
						Black	62.7	0.341	0.362	
						Yellow (duplicate)	2141	0.532	0.454	
						Black (duplicate)	71	0.345	0.375	
	Chevron 1	WB	259	258	263	Yellow	1002	0.534	0.453	0
						Black	33	0.328	0.363	
	Chevron 2	WB	236	258	243	yellow	2846	0.535	0.456	0
H	Curve Ahead	NB	257	342	314	Yellow	8172	0.543	0.452	45
						Black	122	0.358	0.385	
						Whole Sign	1555	0.471	0.45	
						Right Background	645	0.363	0.451	
						Left Background	1160	0.364	0.447	
						Whole Sign (duplicate)	1548	0.464	0.452	
I	Side Road	EB	284	268	264	Yellow	5716	0.541	0.453	45
						Black	83	0.355	0.387	
						Yellow (duplicate)	6947	0.541	0.452	
						Black (duplicate)	137	0.363	0.389	

Figure D-14: Before Speed Data at Site H

Date	12/21/99	2/28/00
Time	9:00 to 11:00	2:15 to 3:15
Weather	Full sun, 20-30*	Cloudy, 45*

Speed (in m.p.h.)		Speed (in m.p.h.)
52	61	55
49	41	48
54	44	49
44	45	43
49	49	48
54	54	52
49	46	50
50	47	47
51	47	51
44	57	46
48	49	48
46	45	46
56	47	55
53	47	57
49	54	53
50		50
49		52
49		43
52		50
49		51
46		50
34		49
52		49
50		50
52		49
44		49
44		53
52		47
46		45
50		47
52		54
48		46
48		
54		
46		
51		

Figure D-15: After Speed Data at Site H

Date	4/11/00	4/19/00
Time	1:00 to 3:00	10:15 to 10:45
Weather	Sunny Clear 70*	Sunny, clear 55*

Speed (in m.p.h.)		Speed (in m.p.h.)
52	50	49
50	48	48
49	47	46
49	44	49
41	45	45
49	50	49
57	48	46
50	54	47
40	41	51
53	51	49
45	43	49
47	44	45
59	47	54
50	56	48
44	54	
49	53	
51	54	
47	43	
55	45	
48	45	
50	53	
49	53	
49	51	
52	57	
41	49	
49	47	
50	52	
47	47	
49	53	
47	46	
50	52	
45		
46		
47		
58		
46		
50		
49		

Figure D-16: Before Data at Site I

Date	3/6/00
Time	10:00 to 11:30
Weather	Sunny, 50*

EB Speed (in m.p.h.)	
49	49
39	51
48	53
57	48
45	48
53	49
45	43
46	46
48	43
50	42
48	32
52	49
43	49
49	56
44	50
36	46
55	45
41	41
46	42
47	42
41	49
50	52
53	43
51	42
47	49
53	46
64	
47	
51	
54	
48	
42	
48	
60	

WB Speed (in m.p.h.)	
44	50
49	43
53	49
42	39
48	44
46	48
49	41
44	54
45	47
46	47
37	51
43	55
43	44
47	50
52	45
42	46
45	42
54	46
53	41
48	40
46	52
49	39
49	56
43	45
45	47
48	42
45	37
40	54
49	52
45	
49	
47	
48	
40	

Figure D-17: After Speed Data at Site I

Date	4/18/00
Time	9:00 to 10:30
Weather	Overcast, 55*

EB Speed (in m.p.h.)	
41	46
45	44
44	48
42	48
40	44
44	47
43	43
55	49
46	49
41	39
45	46
44	51
51	39
58	40
54	44
46	42
38	48
53	43
52	38
47	45
50	43
51	42
40	50
46	49
45	44
47	51
46	50
42	41
41	43
44	
46	

WB Speed (in m.p.h.)	
45	37
48	49
45	40
53	50
47	53
50	52
42	49
45	39
51	44
50	47
48	41
43	37
43	43
44	55
47	54
44	44
49	46
53	47
42	46
47	42
46	45
49	41
49	50
43	45
45	42
47	37
45	43
49	47
45	40
45	51
46	38
48	