An Evaluation of the Safety Affects of Speed Enforcement Cameras in Charlotte, NC

Final Report

Presented to the

North Carolina Governors Highway Safety Program
and
Charlotte Department of Transportation

By

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DISCLAIMER

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EXECUTIVE SUMMARY

Enforcement of speeds by city and state patrols throughout the United States is a tough proposition. With growing numbers of commuters on our roadways and collisions continually on the rise, municipalities are looking at new and innovative ways to help drivers conform to posted speeds and increase safety on roads. One of the newest innovations is the automated speed enforcement camera. North Carolina has previously installed red light running cameras in growing numbers of municipalities across the state; however, the controversial nature of automated enforcement has necessitated the need for thorough analysis to show potential safety benefits.

In August 2004, Charlotte was given authorization to use mobile automated speed enforcement along fourteen key corridors. Automated enforcement of this kind was new to the state. The North Carolina Governor's Highway Safety Program (GHSP) tasked the Institute for Transportation Research and Education at North Carolina State University with analyzing the system in an unbiased manner. Four specific tasks were identified to help in this research effort. First, a literature review was conducted to determine the reported effects of other research efforts throughout the United States and other countries. Various types of studies have been conducted around the world. Of particular interest were studies that were rigorous in nature, such as those using comparison sites. Many studies indicate that photo-radar reduces speeds and the frequency of collisions along treated corridors. However, there are a limited number of rigorous studies (especially those in the United States and in North Carolina).

Four focus groups were convened in Charlotte and Raleigh in an effort to gather information on attitudes, opinions, and beliefs associated with photographic enforcement

to better enhance traffic law enforcement. These two cities had previously been involved with red light running automated enforcement and were considered fair candidates. One community and one professional focus group were assembled in each city. Overall, the perception of photographic enforcement was positive. Assuming these groups are a good representative sample of other North Carolina residents and professionals, the speed program is likely to be very popular. The focus groups all emphasized the need for continuous driver education to increase the effectiveness of the program. The groups felt that drivers need to be aware of program motives, operational details, and statistics through web sites, media, and perhaps other methods.

Speeds and collisions were the two measures of effectiveness used in our analyses. Speeds are generally thought to be somewhat related to collision frequency and severity. They are obviously the best indicators of conformity to posted speeds. Overall, speeds were affected positively along treatment corridors. Most of the treatment sites (that is, sites where speed cameras were employed) had mean speed reduction experience after camera installation while the comparison sites (sites similar to the treatment sites but without speed cameras) did not demonstrate a consistent pattern of mean speed change. Median and 85^{th} percentile speeds decreased significantly by 0.88 mph and 0.99 mph, respectively, at the treatment sites in the 'after' period. The percentage of vehicles exceeding the speed limit by 10 mph or more decreased significantly by an average of 55 percent at the treatment sites compared to the comparison sites.

The primary measure of effectiveness was collisions. Collisions are the ideal measure for traffic-related countermeasures because they are directly related to safety. Odds ratio calculations showed that collision frequencies at the comparison sites and the treatment sites tracked each other very well through the before period. Therefore, an analysis of collisions using a comparison group methodology was completed. Our findings indicated the following.

- Collision data from January 2000 to December 2003 were analyzed using the comparison group methodology. It was estimated that a reduction of 12% in total collisions was attributed to automated speed enforcement cameras.
- To make sure this analysis accounted for regression-to-the-mean (RTM), we reanalyzed the data using only data from the time period after the Charlotte DOT selected the treatment sites. This data set should eliminate any RTM effects. We concluded that an 11% reduction was found analyzing only data from this period, January 2003 to December 2004. Because findings were similar to the analysis of collisions for the entire data set (above), we determined that RTM bias was likely negligible and that the best estimate of the collision reduction due to cameras was in the 11 to 12 percent range.
- Last, a subset of collisions from the treatment sites was analyzed. This subset included only data from the five most heavily-enforced corridors. These corridors accounted for 90.4% of the total citations. Analyzing these sites, it is estimated that automated speed enforcement reduced collisions by 14% from what they otherwise would have been in the treatment corridors from September to December of 2004. It appears that the relatively heavy enforcement of these sites led to a slightly larger reduction in collisions than the group of treatment sites as a whole.

Although each of these analyses shows reductions in collisions, readers must keep in mind the serious limitations of the study (such as short duration of the after period, intense media attention on the program, and others) before attempting to generalize this finding.

In addition to the analysis of collisions, a study of collision trends was completed to try and determine any specific areas that collision reductions may have taken place. Collisions at comparison sites stayed fairly constant; however, treatment corridors showed small decreases in collisions. Trends seem to indicate that higher enforcement during daytime hours is decreasing collisions at a higher rate than in all previous years analyzed. Specific collision types including rear end, slow or stop, and sideswipe in same direction were also analyzed. During nighttime hours, these collisions at treatment sites showed a decreasing trend, while comparison sites had an increasing trend or stayed mostly constant. Last, crash severity was examined to determine differences between comparison and treatment sites during 2004. Although fatal and type-A injury collisions did not have large enough samples to draw inferences, type-B injury collisions decreased 1.6% during daytime hours and 5.1% during nighttime hours at treatment sites. Additionally, type-C injury collisions were estimated to have increased slightly at treatment sites by 2.7% during daytime hours and 4.0% during nighttime hours.

Based on these findings, automated speed enforcement cameras appear to have a positive effect on collisions and speed conformity. Various speed analyses indicated that speeds decreased slightly at treatment sites while speeds at comparison sites stayed relatively constant. More importantly, the comparison group methodology indicated total collisions decreased by around 12% at treated sites. In addition, focus groups indicated that overall there is a positive perception of photo-radar as a countermeasure to deter speed and reduce collisions. The speed camera program conducted by the Charlotte DOT appears to be successful and other agencies facing similar speed-related issues should consider similar programs of their own.

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INTRODUCTION

Municipalities across the State of North Carolina are becoming more aware of the possible safety benefits that photographic enforcement cameras offer. Until recently, red light running cameras have been the only enforcement of this type in North Carolina. However, legislation passed in June 2003 allowed a pilot period to test automated speed enforcement in Charlotte, North Carolina. If the program is successful at increasing safety, it is very likely that this form of enforcement could be used in other municipalities.

Crash statistics across the country show the need for safer speeds on our roadways. Statistics published by the National Highway Traffic Safety Administration show the need for countermeasures to deter speeding *(1)*:

- Motor vehicle crashes are leading cause of death from ages 4-33 years
- Estimated cost of speed related crashes is $40.4 billion/yr
- High speeds are related to nearly 30% of all reported crashes
- 86% of speeding related fatalities occurred on non-Interstate roadways.

Although statistics show the need for countermeasures to deter speeding drivers, automated speed enforcement cameras have not been considered until recently in North Carolina. This project will provide the first look at what benefits, if any, automated speed cameras give to the traveling public.

In October 2003, the Institute for Research and Education (ITRE) at North Carolina State University (NCSU) sought to answer the question "Do automated speed enforcement cameras provide significant safety benefits to the driving public?" during a project sponsored the North Carolina Governor's Highway Safety Program (NCGHSP).

In cooperation with the Charlotte Department of Transportation (CDOT), a two-year project was conducted. The scope of our research encompassed a literature review, multiple focus groups, and analyses of the automated speed enforcement cameras in Charlotte related to the two main measures of effectiveness: collisions and speeds.

NCSU-ITRE, with the help of the GHSP, has led similar projects with red light running cameras. Two previous related projects included "A Recommended Policy for Automated Electronic Traffic Enforcement of Red Light Running Violations" by Milazzo et al. *(2)* and "Expanding the Use of Photographic Enforcement to Enhance Traffic Safety in North Carolina" by Hummer et al. *(3)*. These reports dealt with the policy implications of implementing red light cameras and a study of collision rates before and after red light cameras are implemented.

Our look into research done on automated speed enforcement across the United States shows that the past work was limited, to say the least. Very little research was conducted on the safety benefits of speed enforcement cameras, and when research was done, it did little to account for external factors that cause results to be skewed. Most of the relevant research we were able to obtain was performed in other countries, primarily in Europe and Asia. Therefore, a need for a comprehensive study of automated speed enforcement was clear.

Focus groups were conducted to get a feel for public opinion and knowledge on automated speed enforcement, and in particular the enforcement program implemented in Charlotte, North Carolina. Through discussions guided by a mediator, we were able to obtain qualitative information related to knowledge of automated enforcement, specific goals of any speed enforcement program, funding, media coverage, driver behavior changes, and other subjects. These discussions should help guide Charlotte on the future of their program, as well as guide other cities wishing to implement similar speed enforcement programs.

The two measures of effectiveness (MOE's) our research group investigated related to the Charlotte automated speed enforcement program were collisions and speeds. Collision frequency is the ideal measure for traffic-related countermeasures because it is directly related to safety. Our analysis uses comparison sites (sites that were similar to those treated with speed cameras but did not receive speed camera treatment) to account for the historical and maturation biases that are common in before-and-after studies. This study is much more rigorous than the types of studies used in the majority of cities.

An analysis of speeds at all treatment sites (where speed cameras were employed) and comparison sites, in the before and after period, will give us another indicator of the effectiveness of automated speed enforcement. Speeds are important because they are related to collisions frequency and severity. In addition, a study of speeds in both periods gave a good indication of driver conformity with posted speed limits.

This report provides a thorough description of the activities of our research project. Following a chapter reviewing the literature, we provide the results from our focus groups. Next, we briefly outline the way the Charlotte speed camera program works. The report then presents the speed and collision data collection and analysis methodology. Following chapters on the speed and collision results, we conclude with recommendations for Charlotte, for other agencies contemplating speed camera programs, and for promising future research.

LITERATURE REVIEW

INTRODUCTION

Automated speed enforcement technologies have been used to improve road safety associated with speed in about 75 countries around the world. Most of Europe, Canada, and Australia have vigorously implemented automated speed enforcement technologies and have been successful in controlling speeding and reducing traffic collisions. Since starting the time-distance method of speed enforcement in 1902 in Westchester County, New York, the United States has continuously applied the latest technologies. However, automated speed enforcement has not been used nationally in the United States. They have been used in some states such as Arizona, California, Utah, and Oregon *(4)*.

There are three areas of concern in the literature associated with implementing speed enforcement cameras: the effect of speed enforcement cameras on reducing speeds and collisions, legal issues, and public opinion. This chapter will discuss each of these areas in turn.

EFFECTIVENESS OF SPEED ENFORCEMENT CAMERAS

Speeds

Speed enforcement technologies have advanced dramatically in recent years and a limited number of studies have been done to estimate the effectiveness of speed enforcement cameras on traffic safety in terms of speeds, traffic collisions, or both. However, the results of the studies have been restricted in most cases. The main reasons are limited sample sizes and the types of analysis designs employed.

One of the better studies, conducted by Richard A. Retting and Charles M. Farmer, involved the statistical comparison of traffic speed before and after the speed enforcement program in Washington, D.C. Seven enforcement zones and eight comparison sites were selected randomly in Washington, D.C. and Baltimore, MD, respectively. The comparison sites were selected to control for external factors that might affect traffic speeds such as weather and seasonal variability in travel patterns. Speed data were collected one year before enforcement and approximately six months after it began. The study evaluated changes in mean speed and the proportion of vehicles exceeding the speed limit by more than ten mph as the measures of the effectiveness. The former measure was evaluated statistically using linear regression models including terms accounting for site-to-site variability and time. The latter measure was evaluated using logistic regression models. This study showed that, overall, mean speeds and the proportion of drivers traveling more than ten mph above the speed limit at the Washington, D.C. sites declined significantly by 14% and 82%, respectively, compared with the Baltimore sites *(5)*.

A study by Nathaniel T. Price et al., also employed the before and after experiment design with comparison sites. The study estimated whether photo-radar is an effective means for speed control on residential streets in the city of Portland, OR. Speed data were collected on three comparison streets from October 1995 to September 1996 and the five test streets from January 1996 to September 1996. Photo-radar begun to be deployed on the test streets in March 1996. The comparison site data were used to account for the possibility of seasonal variation. The measure of effectiveness of the photo-radar program was the percentage of vehicles traveling at ten mph or more over the speed limit. Simple linear regression was used to compare the change in speed on the comparison streets and the test streets. The results of the study indicated that there was a reduction in mean speeds on residential streets with photo-radar and a decrease in the number of vehicles traveling at 10 mph or more over the speed limit. This decrease was more pronounced when photo-radar was more intensively deployed. The study also pointed that the decreases might be overestimated since the study design did not account for other confounding variables *(6)*

Another simple study, in Beaverton and Portland, OR, evaluated the effectiveness of photo-radar on reducing speed. The results of this study indicated that average speeds and the percentage of vehicles exceeding the speed limit decreased in the two cities *(7)* However, it has been pointed out that there are some methodological problems for this design including the failure to control for external factors and the short-term change of speeds.

The magazine, "Transportation Alternatives", discussed several states using speed cameras. In Fort Collins, CO, they noted that speed cameras reduced the collision rate per vehicle mile traveled (VMT) by 16% between 1995 and 1999. In Sandy, UT, they attributed the deployment of speed cameras to crash reductions of 27% and reduction in the 85th percentile speed of seven mph in one year. In Paradise Valley, town officers credited speed cameras with a decrease in collisions of 40% since 1987. In National City, CA, the town government assured readers that speed cameras reduced collisions by 26% in a ten-month period and 51% in six years *(8).*

Other studies have looked at the effects of other countermeasures (besides automated enforcement) on speeds. A study in Riverside, California by Steven A, Bloch compared the effectiveness of two speed enforcement methods, photo-radar and speed display boards. Three sites compatible in terms of speed limit, geometric, traffic volume, and road development were selected. Speed data for each site were collected over four weeks, two weeks without speed control measures and two weeks with them. In addition, data for carryover effects were collected at two sites, the experiment site and another size about 0.32 km downstream. The results indicated that all devices significantly reduced mean speeds (7 to 8 km/h) and reduced the number of vehicles exceeding the speed limit by more than 16 km/h. The study also showed that display boards produced short-term and long-term halo effects at the locations after they were removed *(9)*.

A study by Mark Freedman et al. estimated the effectiveness of radar drone operations on speeds at twelve high crash risk locations in Missouri. Speed data were collected by drone radar on a single day at three stations: a station with drone radar, a station out of range of the radar, and a station upstream of it. The main effects and interactions of the drone radar operation condition and vehicle type on speed were analyzed using the SAS General Linear procedure and the chi-square test. The study found that mean speeds were moderately lower when radar drone was operating, with meaningful reductions in the number of vehicles exceeding the speed limit, and these effects were slightly greater for tractor-trailers than for passenger cars *(10)*.

A 1976 study conducted in Durham, NC by Olin K. Dart, Jr. examined the effects of a variety of speed control devices (signs, patrol cars, and visual speed indicators) by the changes in speed characteristics such as mean, median, 85th percentile, and variance. The data indicated that a parked patrol vehicle significantly reduced the mean, the median, the 85th percentile, and the percentage of vehicles traveling faster than 55 mph.

Furthermore, it showed that the halo effect began to disappear 1000 ft after the treatment *(11)*.

Several studies have examined the feasibility of automated speed enforcement in terms of accuracy of the equipment. One study by Michael D. Fontaine, et al. evaluated the feasibility of a real-time, remote speed enforcement system for work zones in Texas. Another study, by Cheryl W. Lynn, et al., was conducted on the Capital Beltway in Virginia. These studies showed that there was a safety benefit to speed enforcement officers and drivers on work zones and that it was feasible to deploy the equipment on high-speed, high-volume roads *(12, 13)*.

Several international research efforts have examined speed enforcement programs with respect to speed. One study employed a before and after observational design with comparison sites to evaluate the effect of speed cameras on speed in Norway. The study was done by comparing speed data collected over approximately one year before and after implementing speed cameras. Eight treatment sites were selected randomly and comparison sites were located on the same type of road and in the same area. Speed data were collected at, before, and after speed cameras on each road section. Speeds estimated in the study reflected the net effect of speed cameras by adjusting for changes in the comparison sites. The results of this study showed that speed cameras led to reduction in speed by four to six km/hr, as Table 1 shows, and that speed cameras contributed to a longitudinal speed change as shown in Figure 1 *(14)*.

<Table 1> Change in Speed Before and After Speed Cameras at All Sites *(14)*

	Speed limit km/h	Traffic direction from	Number of sites	Number of vehicles BEFORE	Average speed BEFORE km/h	Number of vehicles AFTER	Average speed AFTER km/h	Before - after **Difference** km/h	Difference comparison sites km/h	Calculated net effect of cameras km/h
E6 Østfold	90	Oslo	4	1 586 944	85,72	3 070 893	80,61	-5,11	-1,28	-3,83
		Sverige	4	1 544 490	89,37	3 411 744	83,32	-6,05	-1,31	-4,74
	Sum		8	3 131 434	**87,52**	6 482 637	**82,04**	**-5,48**	-1,30	**-4,18**
E18 Østfold	80	Oslo	2	327 624	74,24	169 530	68,88	-5,36	0,26	-5,62
		Sverige	3	517 687	75,58	314 234	69,87	-5,71	0,11	-5,82
	Sum 80		5	845 311	**75,06**	483 764	**69,52**	**-5,54**	0,19	**-5,72**
	70	Oslo	2	386 804	65,11	291 593	60,65	-4,46	0,26	-4,72
		Sverige	2	384 790	66,97	292 922	61,72	-5,25	0,11	-5,36
	Sum 70		4	771 594	**66,04**	584 515	**61,19**	**-4,85**	0,19	**-5,04**
E6 Hedmark	90	Oslo	2	1 524 431	89,06	1 447 722	84,28	-4,78	1,10	-5,88
		Hamar	1	525 196	90,18	479 849	85,66	-4,52	1,76	-6,28
	Sum		3	2 049 627	**89,35**	1 927 571	**84,62**	**-4,73**	1,43	**-6,16**

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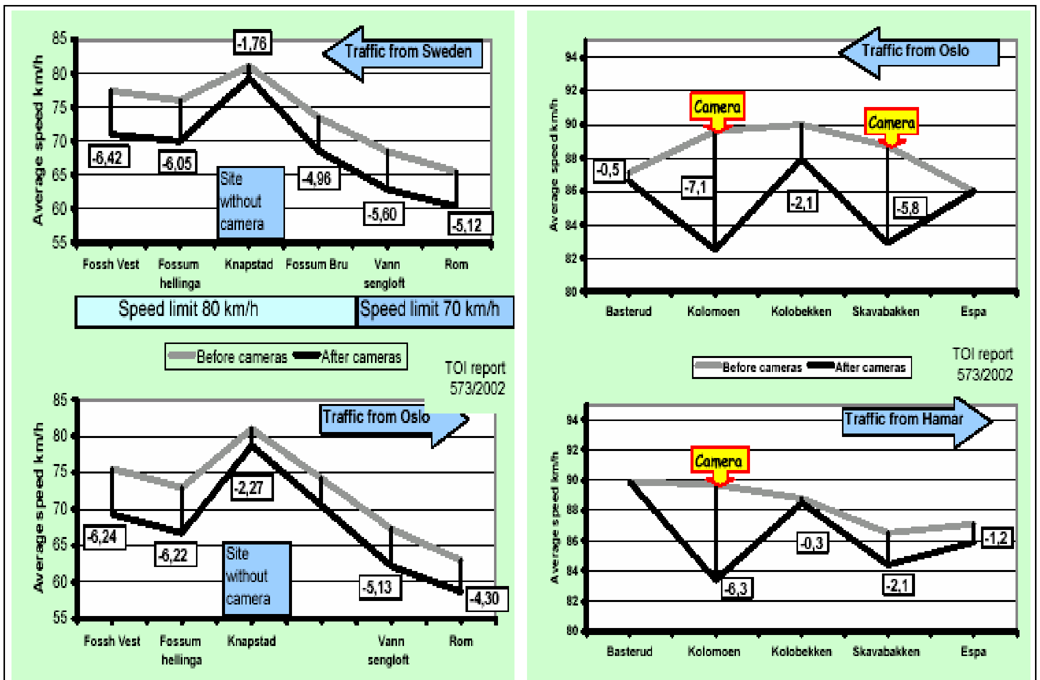
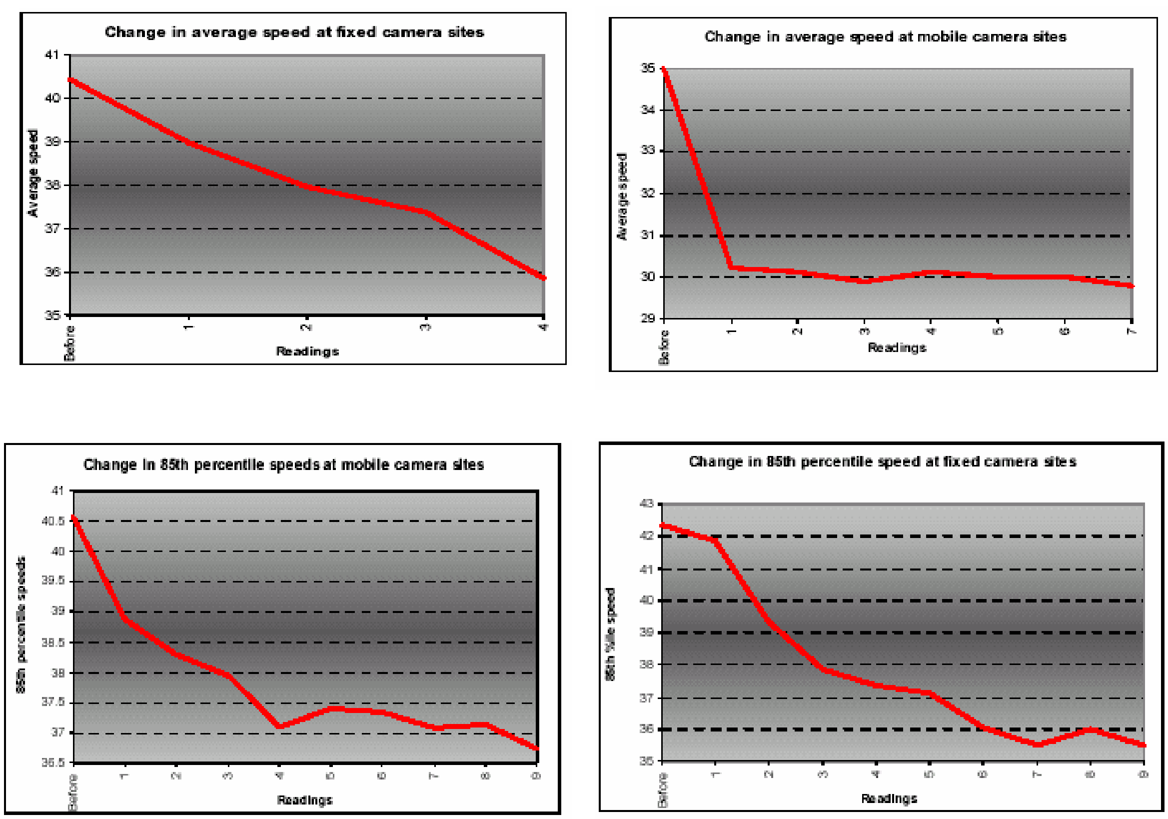


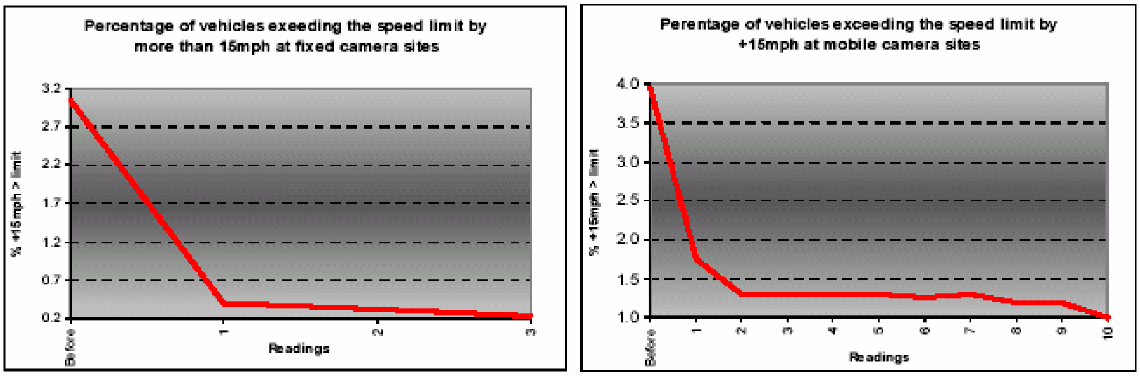
Longitudinal speed profile at one road section(1) Longitudinal speed profile at another road section(2)

<Figure 1> Longitudinal Speed Profile *(14)*

Other international studies employed simple comparisons before and after implementing speed enforcement programs without adjusting for the effect of external factors. Part of a study in England carried out by Adrian Gains, et al., evaluated the change of speeds at eight camera sites. Speed data were collected at the regular intervals over three years before implementing speed cameras and two years afterward. Speed data collected were averaged over all sites without considering the variability at each site and without investigating the effects of other factors. Figure 2 shows speed enforcement cameras reduced speeds and led to greater compliance with speed limits. Furthermore, the study concluded that the pattern of reduction in speeds had been sustained over a long time *(15)*.



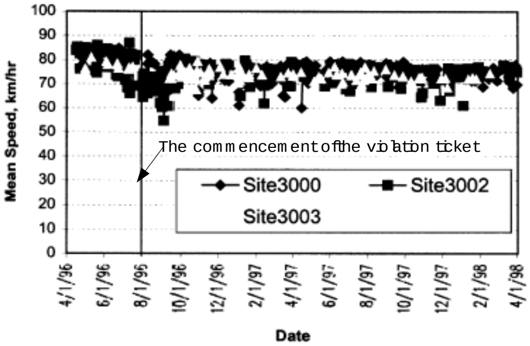
<Figure 2> Change in Speed at Fixed and Mobile Camera Sites *(15)*, continued next page



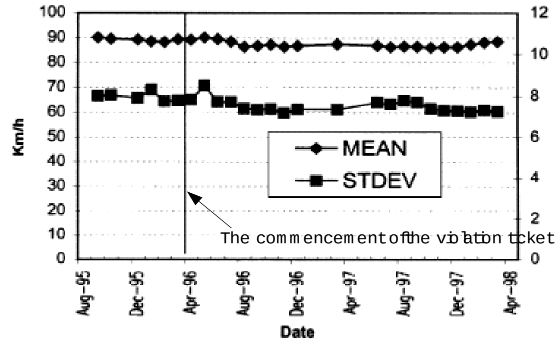
<Figure 2> Change in Speed at Fixed and Mobile Camera Sites *(15)*, continuation

Another study of the long term effects, by the Greg Chen, et al. in British Columbia, estimated the speed effect of the photo-radar program on a highway corridor 2 years after implementing it. The speed effect was estimated by a simple before and after comparison. Speed data were collected at photo-radar influence sites and non-radar sites. Figure 3 indicates that speeds gradually decreased after implementing the speed enforcement program and that there may have been some halo effect at the non-radar site in the same corridor *(16)*.

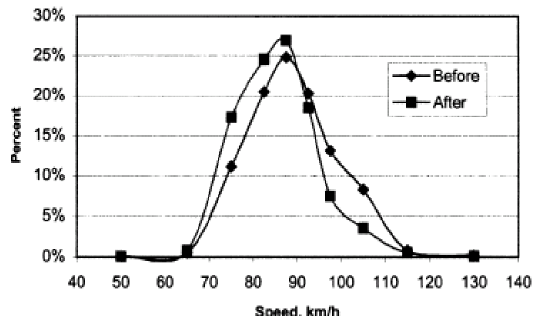
Greg Chen, et al., conducted an earlier, very similar study on another road in British Columbia. This study estimated the effect of the photo-radar program on speed after one year of implementation. Speed data were collected over an eight-day data collection period each month for about one year. The study indicated that speed is reduced dramatically at the speed camera site and that the speed reduction attributable to the generalized effect of photo-radar is about 2.4 km/h at sites without it *(17)*.



Mean speed at photo-radar sites



Mean and S.D. of speed at one no photo-radar site



Speed distribution before and after speed enforcement cameras at one site without it

<Figure 3> Speed Effect after the Introduction of Photo-Radar Program *(16)*

Unlike the analysis designs stated so far, a study in New Zealand, carried out by L. J. Povey, et al., developed regression models to estimate the changes in speed. This research involved describing the relationships between enforcement activity, vehicle speeds, and injury crashes. Speed data were collected in July and August of each year and collision data were included for "low alcohol" hours from 1996 to 2002. The multiple regression models included enforcement activity and fuel price variables and tried to estimate the change of speeds. Another regression model was also used in an attempt to describe the relationship between mean speeds and crashes. The results indicated that mean and 85th percentile speeds decreased with increases in enforcement activity and that a reduction in injury crashes and in injuries and deaths were estimated by 12 % and 13 % with a nationwide one km/h reduction in mean speed, respectively *(18)*.

Looking at the details of speed camera programs, a study by Michael D. Keall et al., estimated the relative effectiveness of a hidden versus visible speed camera program in New Zealand. The analysis indicated that hidden cameras had a more general effect on speeds and crashes than visible cameras by comparing the trial area with a control area using highly visible speed camera enforcement *(19, 20)*. Another study, conducted in London, England examined how different types of drivers responded to cameras using interviews and self-reports by drivers. This study showed that camera deployment could reduce drivers' speeds markedly and camera warning signs alone were moderately productive *(21)*.

Collisions

Most research projects involved with traffic collisions have had methodological problems. Commonly, these studies had ignored or failed to control the effect of time factors such as seasonality, long-term trends, and regression to mean. In addition, the number of treatment or comparison sites used in some studies was not appropriate or statistical significance tests were not employed properly.

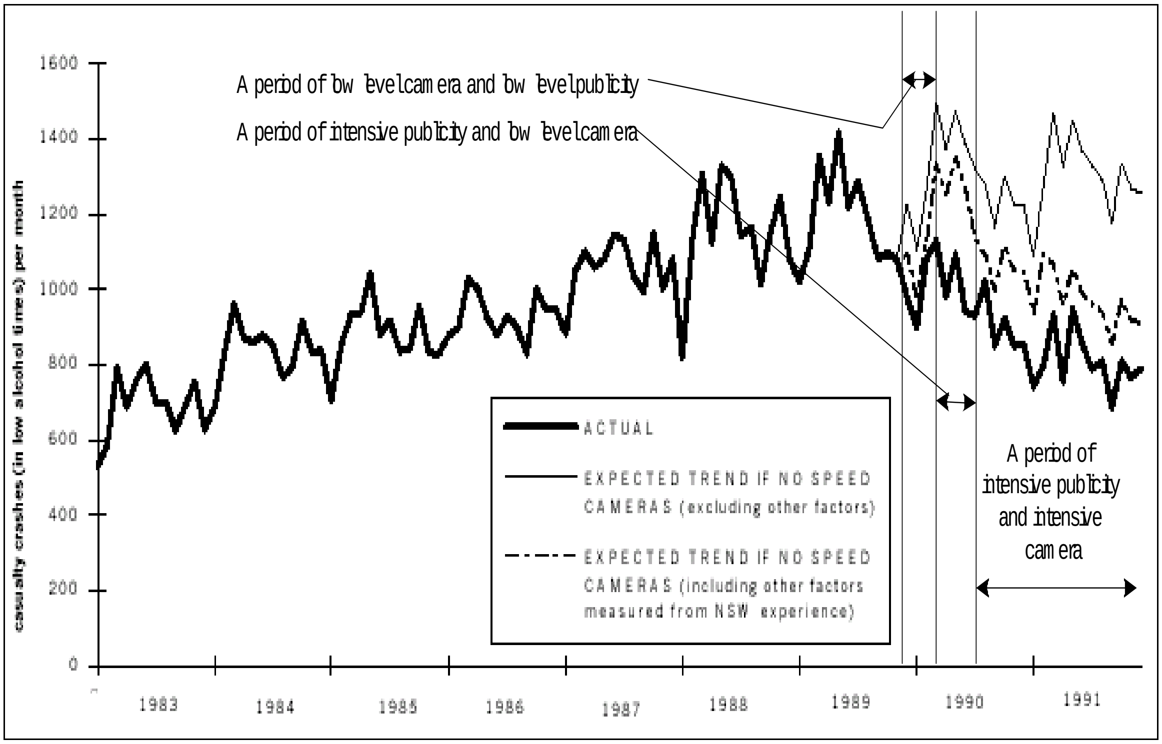
Several studies employed a before and after observational design with comparison sites. These studies were designed relatively well. A study by Stephane Hess and John Polak analyzed the effects of speed enforcement cameras on collision rates in Cambridgeshire, England. The number of sites used in this study was significantly higher than in other studies. Collision data recorded over 11 years from 1990 to 2001 in this county were used and divided into speed cameras sites and non-speed cameras sites. The data were fit into a time series model. Before fitting the model, the study controlled the effect of seasonality and trend by a new method. Regression to mean was detected by using the difference between the before period and the after period long-term means. Residual analysis was also conducted to check for autocorrelation errors, to test the normal distribution assumption, and to identify some outliers with fitting the model. Finally, model validation was performed by comparing the predictions to the observations. The result indicated that, after adjusting for the influence of external effects, the net effect of the speed enforcement cameras analyzed was a decrease in the monthly accident frequency by about 18% and a decrease in injury accidents by 31 % *(22)*.

A study by Rune Elvik in Norway, where a automatic speed enforcement by means of photo-radar was introduced in 1988, was also well designed. All road sections where speed cameras had been introduced were covered in the study. In addition to the treatment sites, comparison sites were included to control for regression-to-the-mean. The number of sites (64 road sections) and sample size (around 3.94 years of the before and 4.61 years of the after) were considered. In the study, the Empirical Bayes method proposed by Hauer was used to control for regression to mean and a model using the number of comparison accidents in the before and after was employed to detect general trends. This study estimated that the reduction in the number of injury accidents was about by 20%, as Table 2 shows *(23)*.

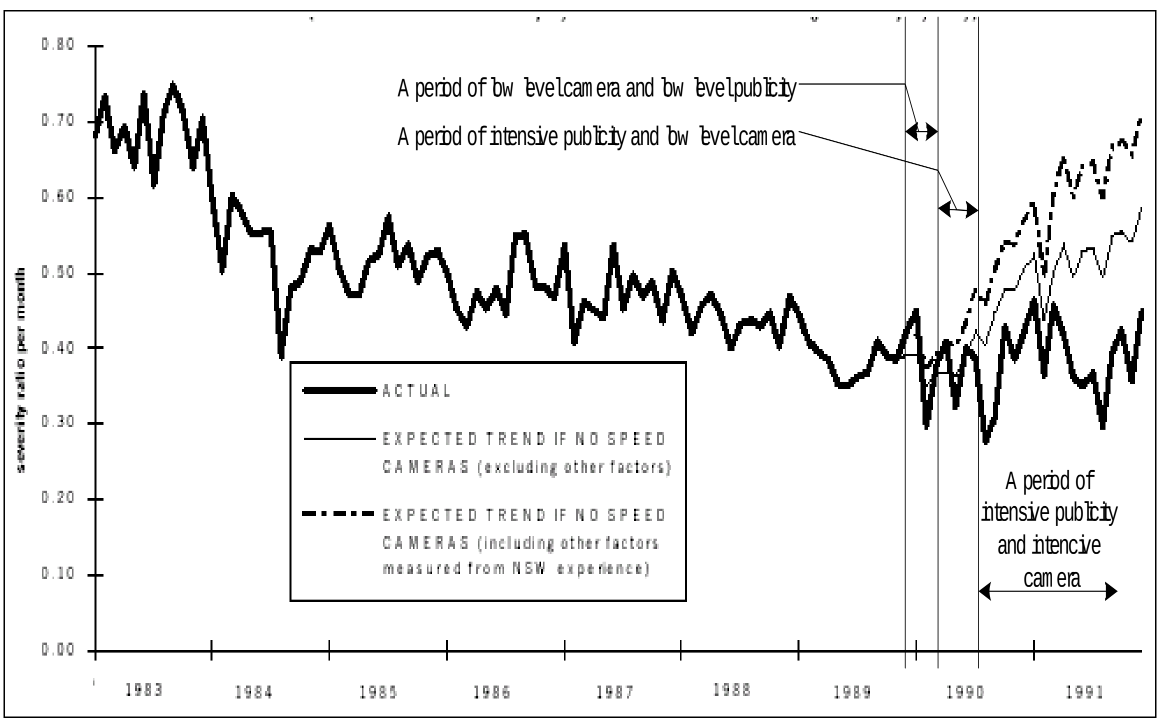
<Table 2> Effects of Automated Speed Enforcement on Collisions by Level of Conformance with Warrants for the Use of Automatic Speed Enforcement *(23)*

Section		Percent change in the number of injury accidents		
Accident rate warrant satisfied	Accident density warrant satisfied	Lower 95% limit	Best estimate	Upper 95% limit
Yes	Yes	-36	-26	-16
Yes	No	-42	-24	0
No	Yes	-25	-15	-4
No	No	-28	-5	+24
Total		-26	-20	-13

A study by Max Cameron et al. quantified the effects of a speed enforcement program on the incidence and severity of road crashes and the effect associated with the program operations in Victoria, Australia. Comparison sites were used to control the effects of extraneous factors. Multivariate time series models were fitted to each site, considering the respective unemployment rates of each area to account for differential changes. Then, the net collision change in the treatment sites were estimated by subtracting from the corresponding comparison sites. As shown in Figures 4 and 5, the study indicates that speed enforcement cameras were associated with decreases in the collision frequency and injury severity. It also suggested that the extent of reductions in collisions was linked to program operational mechanisms such as hours of camera operation and number of speeding tickets issued *(24)*.



<Figure 4> Number of Casualty Crashes per Month in Day Time Hours 1983-1991 *(24)*

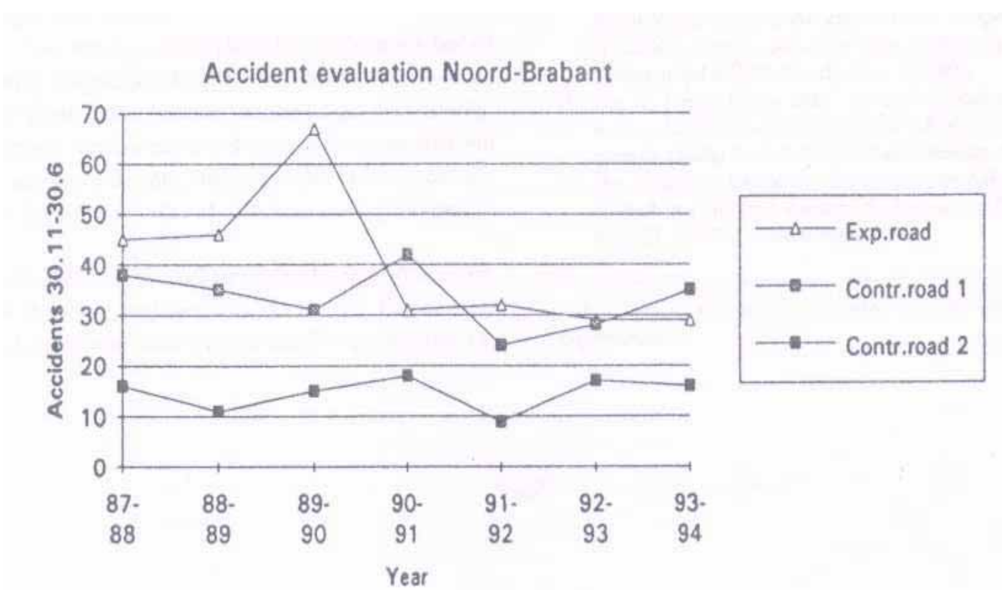


<Figure 5> Severity Ratio (Fatal and Serious Injury/Minor Injury) per Month in Day Time Hours 1983-1991 *(24)*

A study conducted by Greg Chen, et al., investigated the two-year collision and spillover effects of a photo-radar program on a highway corridor in British Columbia, Canada. The study was designed using the observational before and after method. Photo-radar and non-photo-radar influence sections were chosen on the study corridor. Other highways in the same three police districts were selected as the comparison sites. Two years of before and after collision data were used. The Empirical Bayes method developed by Hauer was employed in this study. The study found that the reduction in expected collisions at the speed camera sites was about 14% $\pm$ 11% and at non-speed cameras sites was 19% $\pm$ 10%, supporting the possibility of a spillover effect. However, the study was confined in terms of sample size to one study highway *(17)*.

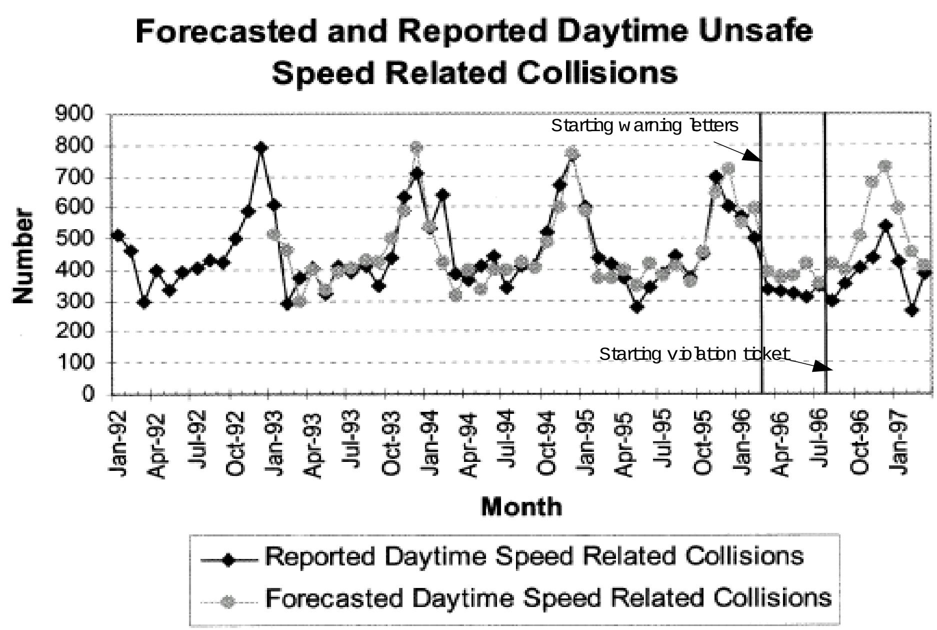
Stuart Newstead and Max Cameron investigated the collision effects of a speed camera program and the relationship between the change of crash and program operational measures over the period from 1997 to 2001 in Queensland, Australia. This study hypothesized that the localized influence area of speed cameras is within a 6 km radius. The study compared the collision frequency of treatment sites with that of control sites that were all areas distant from the treatment sites with a similar level of urbanization and in the same police district. The data collected from control sites were used to isolate the confounding effects of other factors. The before collision data covered five years to minimize regression-to-the-mean. The net crash effect associated with the speed camera program was estimated through a log-linear statistical model. This study estimated a 21% reduction in all reported severity levels and found that that was statistically significant. Furthermore, the study found that variations in estimated crash reductions over time were strongly related to the size of the overall program and the density of enforcement *(25)*.

A study in the Netherlands carried out by Hway-Lien Oei evaluated the collision effect of automatic speed management techniques like speed warning systems, police enforcement, and information campaigns on four two-lane rural roads with speed limits of 80km/hr. The experiments were conducted for seven months. The total collision data collected were paired against data from the same seven months of the before 3-year period and with four control highways. Time effects in the study were not considered because the experiment period was short. The study also examined a long-term collision pattern in three years after concluding the experiment on one section. The results showed that the total number of collisions associated with automatic speed management reduced by 35% and the reduction level was sustained after the end of the experiment as shown in Figure 6 *(26)*.



<Figure 6> Number of Accidents Before, During, and After Experiment *(26)*

Greg Chen et al. employed time series models to examine the collision effects of speed cameras. The study compared trends for five years, including one year after speed cameras were introduced. Daytime data were used in order to remove the effect of the concurrent traffic safety programs. An interrupted time series analysis, controlling for trend, seasonality, and traffic volume, was used to fit the monthly data. Diagnostic checks, the test of the residuals of the model, and chi-square tests were conducted to validate the model and the data. The result of the study indicated that traffic collisions associated with photo-radar program reduce significantly after the violation ticket phase began, shown in Figure 7 *(17)*.



<Figure 7> Monthly Daytime Speed Related Collisions *(17)*

Several studies used simple before-after experiment designs, differing from the above before and after observational designs in terms of how they selected sites and controlled for external factors. The results from this method might be overestimated or underestimated. The "West London Speed Camera Demonstration Project" estimated the change of collision frequency by a comparison of 36 months accident data before and after introducing speed cameras. Although they showed that there was a highly significant reduction in the total number of collisions and casualties after implementing speed cameras, the result could reflect effects caused by external factors such as regression-to-the-mean *(27)*.

Another study, by Tae-Jun Ha et al., analyzed the effects of automated speed enforcement systems on collisions in Korea, where automatic speed enforcement was first installed at 41 stations in 1997. The study was conducted by comparing the number of accidents for six months before and after the installation. The study indicated that there was a decrease of 29% in the number of collisions and 40% percent in the number of fatalities *(21)*. As noted earlier, no external factors were accounted for.

LEGAL ISSUES

Several legal issues must be addressed prior to the implementation of an automated speed enforcement program to prevent problematic legal challenges in the future. These include how the driver of the violating vehicle is identified, whether photographs are admitted as legal evidence, and whether there needs to be some statutory changes to provide for the certification of speed enforcement cameras. Two studies have been done to address these legal issues.

As part of the study on the potential use of photo-radar equipment in Virginia conducted by Janice V. Alcee et al., the legal issues raised by the use of photo-radar technology were addressed. Constitutional issues include a right to privacy, the Fourth Amendment right to be free from unreasonable searches, freedom of association in the First Amendment, equal protection claims, a denial of due process of law, and the common law right of privacy. Evidentiary issues include whether a photograph may be admitted into legal evidence by the pictorial testimony theory, which required a witness's testimony whether the photograph correctly portrays facts, and by the "silent witness" theory, in which a photograph is admitted as legal evidence. Other issues include requirements for legal service, the adoption of statutes for servicing citations by mail, and Federal approval for covert speed enforcement systems use. Models enabling legislation for implementing photo-radar technology were drafted. This paper also indicated that although photo-radar units may face constitutional challenges from speeders, there are no terminal legal problems against it and current jurisprudence supports the constitutionality of photo-radar *(28)*.

Another study, by Shawn Turner and Amy Ellenn Polk, briefly stated that the legal issues against implementing speed enforcement cameras are privacy, distribution of ticket revenue, ticketing procedures, and the accuracy of automated enforcement. The study also suggested photographing receding vehicles and not mailing the photograph with the ticket were good ways to preserve the right of privacy *(30)*.

PUBLIC OPINION

The long-run success of speed enforcement cameras in most countries depends upon good public opinion. A review of studies on the opinion of citizens living in a city where automated speed enforcement devices are being used, may give some insight into how local citizens will react toward speed cameras and why public campaigns may be needed to ease the public's attitudes toward speed enforcement cameras.

The following two studies examined public opinions in areas where speed enforcement cameras have been used and the majority of survey respondents were familiar with the system. Retting surveyed public opinion regarding speed cameras among licensed drivers 18 or older in Washington, D.C. in May 2002, approximately nine months after speed enforcement camera began. Surveys were conducted by random sample telephone interviews. The average age of 500 respondents was 43 years old, with 25% younger than 30, 58% between the ages of 30-59, and 17% ages 60 and older. Overall, 51% of drivers favored speed cameras versus 36% opposed; while 13% expressed no opinion. As a group, young drivers aged 18 to 29 were more opposed to speed cameras than drivers ages 30-59 and 60 and older (48% versus 33% and 29%, respectively) and the differences among the three groups were significant. Support for speed enforcement cameras was significantly higher among drivers who had not received a speeding ticket than among those who had received it (62% versus 44%, respectively). Support was also higher among drivers who said speeding was a problem than among those who said it was not (59% versus 35%, respectively) *(29)*.

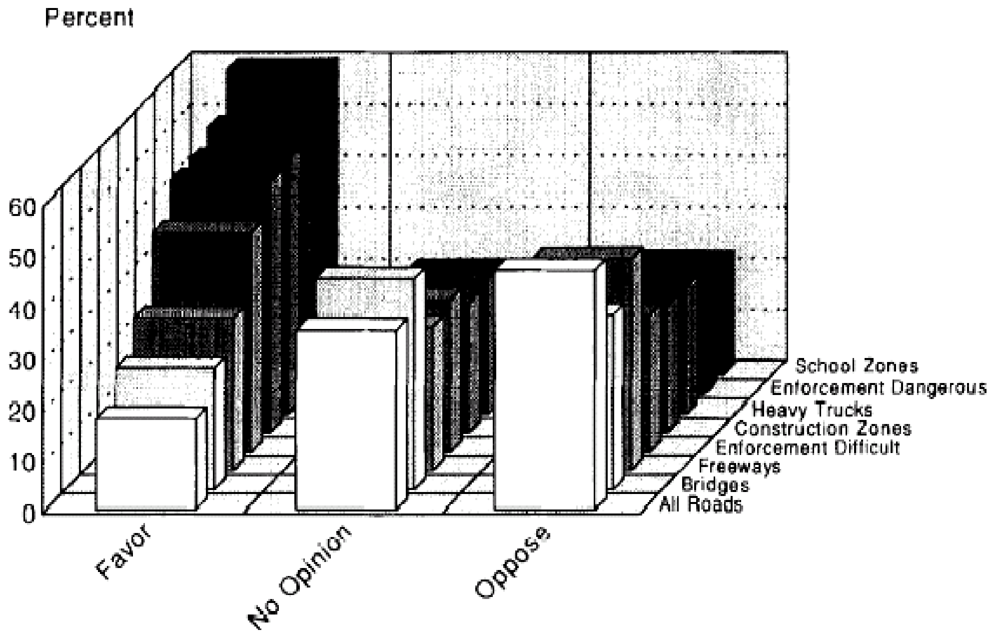
Another study in Paradise Valley, Arizona and Pasadena, California, conducted by Mark Freedman, et al. investigated three areas: awareness of photo-radar, public attitude toward photo-radar, and driver's behavior in response to photo-radar. Photo-radar has been operated in Paradise Valley since September 1987 for 30 hours per week and in Pasadena since June 1988 for 15 to 25 hours per week. Telephone surveys were conducted from August through September 1989. Approximately equal numbers of respondents were randomly selected, totaling about 500 interviews for each area. The main results of the survey were that most of the respondents are aware of photo-radar being used (Paradise Valley, 72%; Pasadena, 56%; near Paradise Valley, 39%; near Pasadena, 24%) and that overall, 58% of the respondents approved of the use of photo-radar, while 37% disapproved. The main reasons for disapproving were the possibility of errors, the wrong person getting a ticket, considering it as "sneaky" and giving police an "unfair advantage". The study also indicated that photo-radar has made many respondents (47% overall) drive more slowly through the two cities *(30)*.

Public opinion surveys were conducted concerning the extent of photo-radar's public acceptance before and after implementing speed enforcement cameras in Portland and Beaverton, Oregon. The two cities began using speed enforcement cameras in January 1996. Surveys were conducted in September 1995 before the speed enforcement camera program began and in September 1996, approximately eight months after it began. According to the survey results shown Table 3, public opinion in the two cities strongly support photo-radar and felt that photo-radar is an effective community policing tool *(7)*.

<Table 3> Summary of Public Opinion Survey Results, Beaverton and Portland *(7)*

	Beaverton			Portland		
	Sept 1995	Sept 1996	% change	Sept 1995	Sept 1996	% change
Awareness of photo-radar	28	85	+60 %	42 %	88 %	+46 %
Approval for photo-radar use in school zones	81 %	88 %	+7 %	82 %	89 %	+7 %
Approval for photo-radar use in school zones	68 %	78 %	+10 %	69 %	74 %	+5 %

Unlike the above studies, a NHTSA study investigated public opinions regarding automated speed enforcement devices in Kalamazoo and Oakland County, Michigan where the majority of respondents have not seen it in use. The study was conducted as part of a field test of automated speed enforcement devices in 1992. A mail response survey of 4,288 drivers was performed. This sample consisted of three parts: 2,000 randomly selected licensed drivers from each county, 141 drivers to whom a warning letter was sent, and 147 drivers who were identified as speeding by automatic speed enforcement devices, but to whom no letter was sent. The survey showed that people supported the use of automated speed enforcement devices in specific sites such as school zones and construction zones, as Figure 8 shows, and those speeders and persons who reported having multiple citations were in greater opposition to the use of speed enforcement cameras than the general population *(31)*.



<Figure 8> Opinions about Automatic Speed Enforcement Use *(31)*

Two other studies offered guidance on how speed enforcement cameras can have long-term success. Turner and Polk, mentioned previously, suggested that public education and awareness of automated enforcement activities is a critical element of nearly all successful automated enforcement programs. They also noted that the active involvement of the local judiciary system is needed *(4)*.

One final study, carried out by Polk, highlighted keys to success in automatic enforcement programs: being respectful of privacy concerns, passing enabling legislation first, getting the judiciary system involved, combining enforcement with a public campaign, not publicizing enforcement locations too widely, not using photo-radar where speed enforcement thresholds are unrealistic, keeping notification lag time short, and not demanding more from the technology than it can deliver. She also suggested some difficult issues relative to speed enforcement cameras including moving violation vs. the equivalent to a parking ticket, ticketing the owner vs. ticketing the driver, obtaining the picture of the driver vs. the picture of the license plate, whether to mail the photograph of the alleged violation with the ticket, and what purpose revenue generated will be used *(32)*.

SUMMARY OF FOCUS GROUPS FROM SUMMER - FALL OF 2004

The Institute for Transportation Research and Education at North Carolina State University completed four focus groups during the summer and fall of 2004. Focus groups are a powerful means to evaluate services or test new ideas. Basically, focus groups are interviews, but of 5-10 people at the same time in the same group *(33).* The purpose of our focus groups was to collect a range of information related to the topic of automated speed enforcement in order to obtain qualitative information related to the subject. The group dynamic provides this information through discussion, guided by a mediator. Opinions and reactions can be observed during this discussion and thus be sources of additional, relevant information for Charlotte and for cities wishing to start automated speed enforcement programs.

Our research group conducted a total of four focus groups, two in Charlotte and two in Raleigh, North Carolina. One community and professional focus group was conducted in each region. A professional focus group consisted of individuals who worked in the subject being studied, while community groups consist of people interested or knowledgeable about the subject but not working in the subject area (2). In Charlotte, the focus groups were conducted with transportation engineering professionals in the Charlotte area and with the University Park Neighborhood Association. Raleigh's participants included the Raleigh Police Department (RPD) and the Heatherbrook Home Owners Association.

Conducting focus groups in Charlotte gave us an indication of the views and opinions of each group within the region with cameras. By conducting focus groups in Raleigh, we got a feel for what citizens expected and felt about the program while they were not directly involved. Both Charlotte and Raleigh groups were previously introduced to red light running cameras, and therefore were thought to have some interests and knowledge in the speed enforcement program.

Three objectives were the primary concerns in our focus group meetings. These were, in order:

I. Assess the participant's general knowledge of automated speed enforcement, and establish what automated speed enforcement means to the participants.
II. Assess personal opinions on automated enforcement as well as discuss your involvement, past or present, in automated enforcement programs.
III. Assess opinions on the City of Charlotte's automated speed enforcement program.

A breakdown of each of these three areas shows various questions related to each objective. Questions were not asked in any particular order, nor were they all asked. Their primary purpose was to help guide the moderator through the discussion. Another member of the research team recorded the discussion using a tape recorder and laptop. The following findings are grouped by objective.

OBJECTIVE I: Assess the participant's general knowledge of automated speed enforcement, and establish what automated speed enforcement means to the participants.

Most everyone had previously heard or knew of automated enforcement

Participants from each of the four groups had heard of automated enforcement of some form. Many were familiar with red light running (RLR) cameras either in Charlotte or Raleigh. With respect to RLRs, both community groups asked general questions about RLR systems, primarily dealing with the functionality of the camera, and wanted to know when the camera actually took the photograph when a vehicle was found to run the red light. In the community meetings, discussions began quickly about grace periods and how much time was "fair". No consensus was reached. In addition, dilemma zones were brought up because many of the members of this group were unsure when they should stop if they see a yellow light.

Most participants agreed on the goal of automated speed enforcement

When questioned about the specific purpose or goal of automated speed enforcement, the large majority of responses revolved around safety. The Raleigh Police Department (RPD) all agreed that "slowing traffic in order to reduce accidents and the severity of accidents" was the main goal of the program. Other groups mentioned that program would likely have some other potential benefits associated with these goals such as less need for police to enforce speeds and dedicate their time to other issues and a possible long term goal of reducing insurance rates.

OBJECTIVE II: Assess personal opinions on automated enforcement as well as discuss your involvement, past or present, in automated enforcement programs.

Many group members experienced or knew of people receiving tickets

Every group had members that were involved in red light automated enforcement either directly or indirectly.

Participants believed that driver behavior was affected in some degree

No one from the groups had been involved with the speed enforcement program. However, from the media coverage both groups in Charlotte said that they believed it has been implemented in a similar manner as the previous RLC program. All groups believed the red light and speed cameras raised public awareness with minimal punishment using fines.

Opinions on automated speed enforcement were diverse

Opinions of automated enforcement varied widely. One RPD participant stated that "The root of the problem is speed. People are distracted for various reasons such as cell phones, kids, work, school, etc." The RPD, as well as both community groups mentioned that anything you can do to slow "some" drivers down and prevent collisions is better than nothing.

However, not all comments were positive related to enforcement of this type. Funding was brought up with respect to revenue and profit sharing with vendors. Most of the group's participants agreed that a system should be set up to allow money to be used in the enforced municipality, thus supporting the community. Another issue was the fact that cameras could not necessarily catch other types of violations that a police officer would find. A police officer pulling over a driver for speeding may find drunk or impaired drivers. The Charlotte community group also noted that tailgating is a problem that needed more attention and cameras would not be able to catch this type of violation.

The program should be primarily concerned with decreasing collisions and speeds

A question came up dealing with measures of effectiveness in the professional group in Charlotte. A consensus was reached that reduced collisions and speeds were the appropriate measures to validate the speed enforcement program. An analysis of specific collision types was another possibility discussed. One member mentioned that it would be nice to see if effects of the cameras spilled over into other areas. Another option was to poll people on their awareness and driving behaviors since the inception of the camera system.

Safety to the public should be the primary concern, not the public's opinion

Attitudes towards RLC's in many municipalities and cities changed after cameras were installed. The group was asked if they believed this would be the case with automated speed enforcement cameras. Charlotte's professional group noted that they did not believe that attitudes would necessarily change, but speeds would be affected. RPD agreed when one member stated, after some discussion, that, "we have to separate public opinion from the actual benefit of the cameras. If they are working to reduce collisions and improve safety then you shouldn't worry about the public opinion. If there are hard facts that the cameras are improving safety, then the public shouldn't mind them."

Other possible countermeasures mentioned were engineering and better equipment in squad cars

The groups were asked if other countermeasures may have been effective at reducing speeds and collisions. One professional from Charlotte said that, "Education is the first and primary issue in dealing with aggressive drivers." The belief was that people who receive a citation may have a negative attitude and this professional stated that, "People who accept responsibility for themselves and/or the person driving their vehicle might be likely to respond positively if good information is provided about why the road they were on is being targeted for enforcement and what drivers can do to help make the road safer for everyone." RPD group members stated that, "Speed Enforcement will not slow people down; it will only slow down the one we catch. Engineering will do more to slow down cars using traffic calming techniques." In addition, police officers noted that one way to provide more enforcement would be better equipment in squad cars to process tickets. Manually writing tickets takes a significant amount of time which could be spent enforcing roadways.

Neighborhoods and school zones were discussed as potential uses for automated speed enforcement

Potential uses of automated speed cameras were discussed. The two uses discussed frequently were in school zones and neighborhoods. Most groups agreed that aggressive driving in neighborhoods was dangerous but that funding would likely never happen due to the large expense of the cameras. Use of speed enforcement in school zones made perfect sense to all groups, however. School zones are highly prone to collisions with pedestrians and other vehicles. Many thought this was a very viable option. In addition to these alternative uses, the RPD and Charlotte professional groups both mentioned that the use of placebo camera housings and/or vans may also be an alternative.

Revenue should be kept in the State

Revenue from citations was a topic generating great excitement in a couple of the focus groups. No participants thought that profits from tickets should go to the vendor. The RPD was particularly concerned about police officers working to make money for private vendors. They said, "It would be particularly nice if the government purchased the equipment, vans, etc, and cut out the vendor. All the money should go to the police department to be used for further investment for more equipment or the general local fund." The Charlotte groups said funds should go towards roadway safety efforts such as school zones, driver education training, more camera equipment, or other efforts. No comments were made about how equipment contracts were made between the vendor and the city, or what issues came up with safety versus profit issues related to citations.

Fines seemed to be satisfactory

The $50 fine for receiving a citation seemed to satisfy all groups. Many participants said the fine didn't hurt as bad as having to go to court or insurance premium increases. Some thought that insurance should be affected; however, others said that would not be fair because the driver cannot be identified. Some of the community group members had received citations for running red lights and said that the fines were enough to make you think twice. One member cited that it was especially evident in his case because he forgot to pay the citation twice, and it ended up costing $150.

Privacy concerns were not an issue

Privacy issues have been discussed in many cities as some of the public expressed their issues with red light camera systems. However, our focus groups noted that there were "big brother" issues, but none said they were of major concern. One professional member in the Charlotte group said that "If you are in a public place, you can not complain about privacy. If you are operating a vehicle on public road and you violate the law, you give up your right to privacy." One Charlotte community group member concurred with this statement stating, "I believe that when you put my life in jeopardy, there is no privacy issue."

Most members suggested a 10 mph threshold

Many police, as well as drivers, believe there is a threshold that, when driving, should not be crossed or a citation will be issued. Members of the groups had varying answers when asked if they thought there should be a threshold, and if so what should it be. Most agreed that a threshold was needed to help eliminate any bias; however the exact threshold could not be decided upon. The thresholds suggested ranged from 5 – 10 mph, with most suggesting 10 mph.

<u>OBJECTIVE III</u>: Assess your opinions on the Charlotte DOT's automated speed enforcement program.

The mobile system was perceived to be a positive way of identifying speeding drivers

Many participants felt that having an individual interact with the radar and camera in a mobile van was a very good idea. They believed that treatment of drivers in the same manner (in particular with the choice of thresholds) as they had been dealt with in the past would eliminate the implications of having a vendor involved in setting up systems, such as red light cameras fixed at intersections. They also felt that mobility added another functional characteristic to the enforcement system by being able to move around the city.

Participants were concerned about photographs being able to deal with special circumstances

Pictures were passed around the room showing the mobile unit and the citation. Many groups said the van seemed to operate the same way any police officer would. However, two different issues were brought up. As mentioned earlier, one group noted the mobile unit does not give an officer face to face contact, and therefore hinders an officer's ability to see if drivers are impaired or special circumstance such as hospital emergencies. Second, the picture was not adequate enough for a few focus group members because someone else may have driven the car. In addition, it was noted that there are many products on the market which cause pictures of license plates to become blurred.

Most participants believe the mobile unit is discrete

Because the unit must be parked fairly close to the roadway, participants were asked if they thought this had potential to hurt the program in anyway. Participants in both professional groups said that they believed the van was fairly indiscrete and exposure was likely not that large a factor. RPD participants strongly agreed that seeing marked police cars was much more likely to cause exposure. However, one Charlotte community participant said, "I saw the speed van the other day and speeds seemed much faster on the other side of the road." With signs marking the approaches, added to the media coverage, it is possible the vans are detected.

Group members believed the media was positive and that updates and news and radio coverage were received by the majority of the city

Both Charlotte groups were asked if the media coverage seemed to be adequate. Both groups had many comments. The professional group commented that the media has been covering it in the news and in many discussions on the radio. They noted that there were many different "slants" given, depending on what they were trying to get across, but that public awareness was likely in place. A couple of group members referred back to when red light cameras were first implemented. They remarked that once they were in place, the media seemed to only concentrate on negative publicity. They went on to say that it is important that people have as much information as possible about the programs, and that the media must be as informed about how the system actually works in order to make more accurate reports.

The community group thought that most people in the city had probably heard about the speed enforcement program. A couple of members also said that it was nice to see the number of violations for the first eight hours. Most agreed that the media treated it fairly and let everyone know it was coming. Delays in the start up times were publicized and the start date was given. In contrast, a couple members said that there was little "thinking out of the box". No special campaigns to specific areas of the city were taken into account.

Long term sustainability was an alternate issue brought up among two focus groups

Long term sustainability of the program came up in all group meetings. Groups felt that the previous red light campaign had practically stopped. They would like to hear how the program is going more than once or twice a year and would like more public education on how the programs work. One member mentioned that a way one could publicize statistics is to put signs on the roads letting people know percentages, similar to what is done with seat belt usage around the US.

CHARLOTTE'S AUTOMATED ENFORCEMENT PROGRAM

LEGISLATIVE BILL 562

On June 6, 2003 by a vote of 25 to 20, the NC Senate passed Bill 562 allowing use of automated speed enforcement in Charlotte, North Carolina *(34).* On June 17, 2003, the NC House of Representatives also passed Bill 562 by a vote of 71 to 37. The ratified Bill was put into law on June 30, 2003, and the program, "Safe Speed", officially began issuing tickets on August 1st, 2004. This program was named after its sister red light running program, "*Safe*Light".

Bill 562 lays out the basic framework for the three-year pilot program in Charlotte, NC. This framework is important, not only because it specifies the way in which the enforcement program must proceed in Charlotte, but also that it is the basic framework that other municipalities will possibly follow in the future should other programs be allowed in North Carolina. The basic guidelines for the program include:

- Automated speed enforcement devices will be approved, calibrated, and tested for accuracy.
- The system must be monitored by a sworn law enforcement officer.
- Speed monitoring vehicles must be identifiable. Signage must be used within 1000' of the parked monitoring vehicle.
- Owners of the vehicles will be responsible for any violation unless it can be proved otherwise (i.e., rental agency gives address of driver using rental car).
- Violations are deemed non-criminal and will be issued a $50 citation.
- The owner of the vehicle can challenge any violation within a specified time period. If the citation is not paid by the due date, a late fee of $50 will be assessed each month not paid.

- Municipalities must provide a nonjudicial hearing process to review objections.
- Proceeds must go the county school fund.
- The system in Charlotte may only be used on the previously specified fourteen corridors.
- The pilot will expire July 1, 2006.

See Appendix A for more information.

SIGNAGE

As noted in the previous section, Bill 562 stated, "Signage must be used within 1000' of a parked monitoring vehicle." *(34)* CDOT and the City of Charlotte decided to place signage indicating the use of photographic enforcement of speeds underneath speed limit signs, as shown in Figure 9. This method should prove beneficial to the driver because it is easily identifiable, and is one of the firmest reminders to conform to posted speed limits along Charlotte roadways.

<Figure 9> Charlotte Posted Signage for Photo-Enforced Corridors *(35)*

MOBILE UNIT

Currently, the City of Charlotte has three mobile units. These units became deployable from August 1st through the end of September 2004. The units can only be parked for enforcement purposes at previously designated locations along the fourteen photo-enforced corridors. Figure 10 shows a side view of the van. Note that the van is marked with the "Safe Speed" logo to make it identifiable.

<Figure 10> Charlotte Deployment Van *(35)*

Figure 11 shows a view of the back of the van. The van is parked in this manner so that the deflection angle is minimal, allowing it to fall within the recommended threshold for the laser speed gun.

<Figure 11> Charlotte Deployment Van Parked on Side of Road *(35)*

AUTOMATED ENFORCEMENT – LASER GUN AND VIDEO CAMERA

The City of Charlotte's choice of laser speed gun was a Pro Laser III produced by Kustom Signals, Inc. This laser gun has a range of approximately one thousand feet. It is known for its quick acquisition of targets and multiple operating modes in differing weather conditions *(36)*. Figure 12 shows a picture of the unit on top of the video camera.

<Figure 12> Laser Speed Gun and Camera *(35)*

Figure 13 shows a view of the combination laser speed gun and camera facing out of the drivers' side back window and upstream of the mobile unit.

Once a speeding vehicle is detected, the speed of the vehicle, along with the vehicle's license plate number, is identified and recorded on a computer. Figure 14a shows an officer targeting a vehicle. Figure 14b shows the officer identifying the speed of the vehicle and zooming in the license plate to identify the owner of the vehicle. Two pictures are saved and are used when issuing the citation at a later time and date. Note that the information recorded on the screen in Figure 15 provides the speed of the vehicle, how far away it was located, and a visual of the vehicle license plate number.

<Figure 13> Laser Speed Gun and Camera Viewed from Outside Van *(35)*

<Figures 14 a,b> Screen Shots of Speeding Vehicle *(35)*

A copy of a typical citation can be seen in Figure 15. Note that the two pictures in Figure 14 are used in the example citation. An explanation of the penalty is given in the citation. In addition, a website with information about a specific ticket and the process for paying for or appealing the ticket is given.

CHARLOTTE.

City of Charlotte
Safe Speed Camera Enforcement Program
229 South Brevard Street, Suite 102, Charlotte, NC 28202
(704) 375-3177

SAFE SPEED

NOTICE OF CITATION
AVISO DE CITACION

Payment Due Date: 09/07/2004
Fecha de vencimiento de pago

Citation Number 3710927
Numero de citacion

Internet Password: 7C9VS1[redacted]
Contrasena del Internet

Amount ~ Cantidad: $50.00

* 3 7 1 0 9 2 7 *

[redacted]
Charlotte, NC 28227

Amount Paid ~ Cantidad pagada $

Contact us on the Internet for
citation information and payments at:
https://onlineviolation.com/charlottenc/speeding

Pongase en contacto con nosotros por Internet para
obtener informacion sobre citaciones y pagos en:
https://onlineviolation.com/charlottenc/speeding

Detach here and return the above portion with your payment
Separe aqui la hora y devuelva la parte superior con su pago

Speed limit limite de velocidad	Speed Velocidad	Vehicle Tag Number Numero de calcomania del vehiculo	Date / Time Fecha / Hora	Location of Violation Ubicacion del vehiculo
45.00	**59.00**	[redacted]	**08/03/2004 11:54 AM**	**3500-3700 Independence Blvd west**

On August 03, 2004 at 11:54 AM your vehicle was photographed (see below) while exceeding the posted speed limit in violation of Charlotte City Code Section 14-203. The civil fine for this violation is $50.00. No points will be assessed against your driving record or insurance as a result of this violation. Please see the reverse side for payment and the process to appeal this citation.

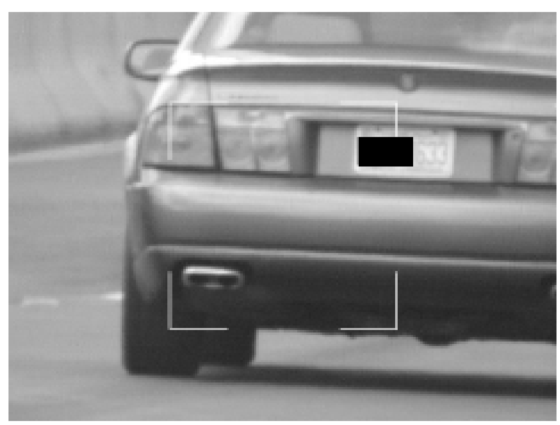
This program has been initiated to increase roadway safety and reduce accidents, injuries and fatalities.

Important Notice: Failure to pay this civil fine by the due date shown above will result in an additional late penalty of $50.00. Request for appeal, transfer of responsibility, or payment must be received prior to the due date to be considered. On-line payments and appeal is available at the internet address noted above.

El August 03, 2004 a las 11:54 AM su vehiculo fue fotografiado (vease abajo) mientras excedia el limited anunciado de velocidad en violacion a la Seccion del Codigo de la Ciudad de Charlotte 14-203. La multa civil por esta violacion es de $50.00. No se agregaran puntos a su historial de infracciones de transito o a su seguro como resultado de esta violacion. Favor de ver el lado reverso para saber sobre el pago y el proceso de apelacion de esta citacion.

Este programa se ha inciado para aumentar la seguridad de transito y para reducir accidentes, lesiones y muertes.

Aviso importante: No pagar esta multa civil antes de la fecha de vencimiento arriba tendra como resultado una multa por retraso de $50.00. Se deben recibir las peticiones por apelacion, las transferencias de responsabilidad, o los pagos, antes de la fecha de vencimiento para que se tomen en consideracion. Los pagos y las apelaciones en linea estan disponibles en la direccion del Internet escrita arriba.



Safe Speed Saves Lives in Charlotte ~ Las velocidades seguras salvan vidas en Charlotte

<Figure 15> Example Citation

MEDIA CAMPAIGN

Various types of media were used in order to make the public aware of the upcoming automated speed enforcement program in Charlotte. Various radio and television stations, as well as flyers from the City of Charlotte, alerted various communities of the program prior to commencement. The goal was to give everyone ample opportunity to change driving habits to conform with local speed limits so that the risk of receiving a citation could be eliminated by the driving public should they choose, thus indirectly reducing speed-related collisions in the long run. Some of these campaigns were discussed by the Charlotte focus groups as described in the previous section.

The City of Charlotte's Safe Speed program has been employed for over a year as of this writing, since inception on August 1, 2004. During that time a flyer has been used to answer many of the frequently asked questions (FAQ's) about the program *(35).* FAQ's answered in the flyer included, "Why do we need Safe Speed," "How is Safe Speed funded," "Where can Safe Speed be deployed," "Doesn't Safe Speed violate my rights," and "Can I appeal a citation." The flyer also gives some interesting statistics on public acceptance of the program. A poll by the University of North Carolina at Charlotte noted a 67% acceptance rate of an automated speed enforcement program. The poll also found that 70% of respondents believed speeding was a major problem contributing to collisions along roadways. A copy of the flyer can be found in Appendix B.

CITATION HISTORY

From August 2, 2004 to September 19, 2005, citations were issued at multiple locations along fourteen previously designated treatment corridors. The City of Charlotte provided our team with the citation history along the various corridors. A breakdown of the site-by-site citation history can be found in Appendix C. Table 4 shows a summary of the citation history for each of the fourteen photo-enforced corridors.

<Table 4> Summary of Citation History for Treatment Sites *(35)*

Citation History August 2, 2004 to September 19, 2005				
Corridor	**Incidents Recorded**	**Citations Issued**	**% Issuance**	**% Citations Issued**
Highway 51	203	124	61	0.4
Albemarle	43	17	40	0.1
Billy Graham Parkway	3,637	2,283	63	7.3
Central Ave.	4,529	2,812	62	9.0
Eastway Dr	62	33	53	0.1
East W T Harris	1,058	662	63	2.1
Independence Blvd.	22,784	12,867	56	41.3
Monroe Rd.	103	53	51	0.2
Providence Rd.	13	8	62	0.0
South Blvd.	9,135	5,206	57	16.7
Sharon Amity Rd.	1,561	973	62	3.1
Tryon Street	8,886	5,972	67	19.2
West W.T. Harris Blvd.	332	172	52	0.6
Total	**52346**	**31183**	**60**	**100**

Table 4 shows some very interesting statistics. Assuming that each van was deployed every day of the year for the entire 13.5 months, approximately 43 speeding vehs/day/van were recorded. Out of those 43 recorded, approximately 25 vehs/day/van were actually issued citations. The issuance rate of citations ranged from 40 to 67%, with an average of 60%.

The most interesting information in this table is the percentage of citations issued at each site. It is clear that certain sites are enforced much more heavily than others. In particular, Independence Boulevard, Tryon Street, South Boulevard, Central Avenue, and Billy Graham Parkway -- with 41.3%, 19.2%, 16.7%, 9.0%, and 7.3% of the citations issued at these five sites, respectively -- are enforced more vigorously. These five sites account for a total of 90.4% of the total citations issued by the automated speed enforcement program. This enforcement pattern could play into our analysis of speeds and collisions and could help explain any trends in the upcoming sections. The research team also asked the City of Charlotte for information pertaining to time of day for issuance of tickets. The City was not able to retrieve this information in time for this analysis; however, it was noted that approximately 75% of citation were issued during daytime hours, with the remaining 25% issued during nighttime hours *(35)*.

EVALUATION PLAN

INTRODUCTION

The City of Charlotte has embarked on an automatic speed enforcement program in fourteen key corridors scattered throughout the city. The program began issuing tickets August 1, 2004 with one van in operation. Two more vans were in use by the end of September, 2004 *(35)*. The Institute of Transportation Research and Education (ITRE) at NC State, funded by the NC Governor's Highway Safety Program (GHSP), has conducted an independent evaluation of the automated speed enforcement program. The contract calls for ITRE to conduct a literature review, a series of focus groups, and a formal evaluation of Charlotte's automated speed camera enforcement program. The purpose of this chapter is to describe the plan that the ITRE team used to conduct its evaluation.

STATISTICAL ANALYSES

For collision data, the ITRE team will primarily rely on the analysis methods in the seminal textbook "Observational Before-After Studies in Road Safety" by Professor Ezra Hauer to guide the collision analysis *(37)*. In particular, we relied on Chapter 9 to adjust for history and maturation biases using comparison sites. The results from this analysis will be the best possible estimates of the mean changes in collisions from the speed camera program and the standard deviation around those means.

In this analysis, we attempted to adjust for possible regression to the mean bias. This classic bias in safety studies typically occurs when the most hazardous (with the highest collision frequencies) entities in the "before" time period are treated. Reductions in collisions in the "after" period are attributed to the treatment, when they may well be due to natural fluctuations in the collision frequency whereby a high value should be followed by a lower value in a random way. Our research team suspects that regression-to-the-mean bias should not affect the findings of our study for the following reasons.

- We had a very high number of collisions in the before period at the treatment sites. These were the highest volume corridors in the most populous city in the state, and we had over 4.5 years of collision data to analyze. The random fluctuations that lead to regression to the mean bias were damped down considerably, in percentage terms, by these high magnitudes.
- Many other factors played into the choice of treatment corridors besides high collision frequencies, including traffic volumes, speed study results, impressions of the officials leading the program, and the desire for geographic balance around the city.
- The treatment corridors were selected in early 2003, well before the end of the "before" period, based on collision data from 1999 through 2001. Thus, over half of the "before camera" period collision data available to us—from 2002 through July 2004—would be unaffected by regression to the mean.
- It would have been difficult and costly to identify a good set of "reference" sites with which to conduct an analysis (using the Empirical Bayes method described in Chapter 11 of Hauer's book) to remove any bias, since the treatment corridors were so unique. We would have had to collect data in the highest volume corridors in other cities around the state, with great uncertainty about whether those other sites belonged in the same population as the treated sites in Charlotte.

Although we suspect that regression-to-the-mean is likely not affecting the analysis of collisions based on these factors, we tested this by conducting an analysis of the collision data from the period after the treatment locations had been chosen. Treatment sites were chosen on the basis of collision data from 1999-2001. Therefore, according to the theory of regression-to-the-mean, the collision frequencies at those sites would be expected to decrease in the subsequent years because the sites were already at their peaks. Analyzing collision data after this drop (including only these data in the "before" period,) should account for any regression-to-the-mean effect, and comparing the finding from this analysis to the finding from the overall collision analysis using the full 2000-2004 "before" period should give an indication how much regression-to-the-mean was present in our overall analysis.

For speeds, we calculated and examined changes in statistics such as mean speeds, the 85th percentile speed, the 10 mph pace, and the difference in mean speed and posted speed. We also examined statistics related to the shape of the speed distributions such as the standard deviation, the skewness, and the kurtosis.

MEASURES OF EFFECTIVENESS

The ITRE team is relying on two basic measures to evaluate the program. The first and most important measure is the number of collisions. The speed cameras are a safety countermeasure, and collision frequency is traditionally the best way to estimate whether safety (the long run average number of collisions) truly has improved at the speed camera sites. We are also examining measures related to collision frequency such as trends in collision severity and type of collisions to see what other changes related to collisions may have occurred due to the program. The City has assembled collision reports at the sites of interest through 2004. Our analysis of the collision data is contained in a later chapter of this report. Further analysis using 2005 data will be performed in a continuation project with the City of Charlotte following the completion of this project.

The second basic measure will be vehicle speeds. Speeds are important because they are indirectly related to collision frequency and severity, and because they are an indication of conformity with the speed laws. As noted earlier, the City of Charlotte has collected a large sample of vehicle speeds on the corridors of interest, and will continue to add to the samples as the program continues. The ITRE team extracted the speed statistics it needed from these samples. The samples were collected using the same methodology in the "before" and "after" periods to avoid bias.

ANALYSIS OF SPEEDS

INTRODUCTION

We are considering two basic measures to evaluate the safety effects of the speed camera enforcement program. The first is the number of collisions and the second is vehicle speeds. Estimating the safety effect associated with collision frequency will be covered in the next chapter separately. This chapter is concerned with the second measure, which is speed. The City of Charlotte collected a large sample of vehicle speeds on the corridors of interest before and after speed camera enforcements began. We evaluated whether speeds have changed at the speed camera (treatment) sites relative to the comparisons sites.

STUDY SITE AND SPEED DATA

In the first phase of this project, fourteen sites were chosen as treatment sites and eleven sites as comparison sites of the selected twenty five corridors in the City of Charlotte, North Carolina. As shown in Tables 5 and 6, the geometric and environmental characteristics of each site were collected: region of city, interchange of proximity, speed limit, land use (industrial, residential, and retail), median type (none, raised, and TWLTL), development intensity (light, medium, and heavy) and density of all intersections (per mile). Since these factors might have an impact on speeds differently at each site, some of the surveyed data were considered in the statistical analysis as co-variables.

<Table 5> Physical Characteristics of Sites

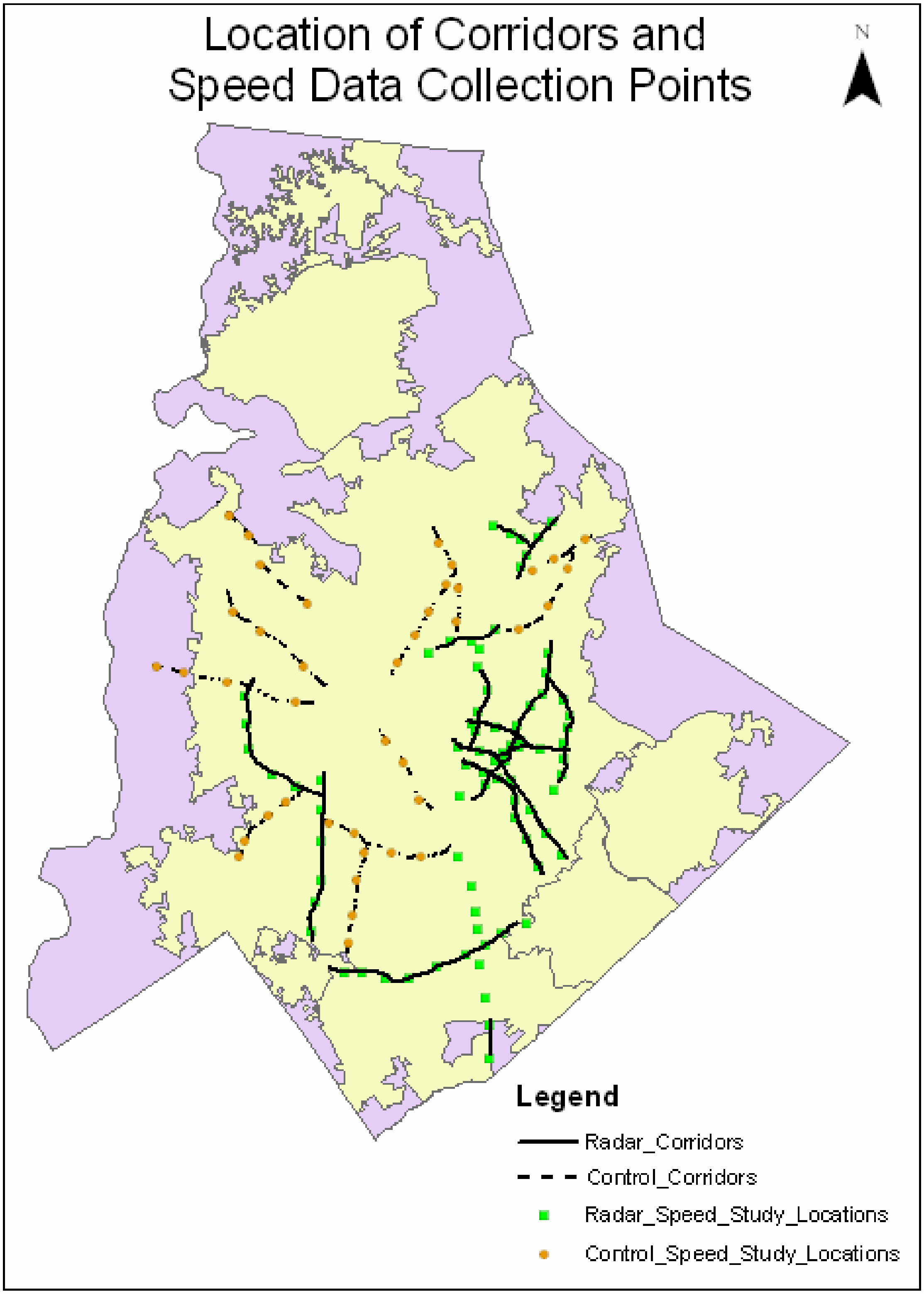
Corridor	Treatment or Comparison	Region of City	Interchange Proximity	Speed Limit	Predominant Type		
					Land Use	Median Type	Development Intensity
Billy Graham/ Woodlawn	Treatment	Northwest	I-77, I-85	55	Industrial	Raised	Light
South	Treatment	Southwest	None	35, 40, 45	Industrial	None	Medium
Pineville-Matthews (NC-51)	Treatment	South	I-485	45	Residential	TWLTL	Medium
Providence	Treatment	South	I-485	45	Residential	None	Light
WT Harris (north)	Treatment	Northeast	I-85	45	Retail	Raised	Medium
Tryon (north)	Treatment	Northeast	None	45	Retail	Raised	Medium
WT Harris (south)	Treatment	Southeast	None	45, 40	Residential	Raised	Medium
Tryon (south)	Treatment	Northeast	None	45	Industrial	TWLTL	Medium
Sharon Amity	Treatment	Southeast	None	45, 35	Retail	TWLTL	Medium
Central	Treatment	Southeast	None	35, 45	Retail	None	Heavy
Albemarle	Treatment	Southeast	None	45	Retail	TWLTL	Medium
Eastway	Treatment	Southeast	None	45	Residential	None	Heavy
Independence	Treatment	Southeast	US-74	45	Retail	Raised	Heavy
Monroe	Treatment	Southeast	None	40, 45	Industrial	None	Medium
Brookshire	Comparison	Northwest	I-85	55, 45	Industrial	Raised	Light
Freedom	Comparison	Northwest	I-85	45	Retail	Raised	Light
Wilkinson	Comparison	Northwest	I-77	45	Industrial	Raised	Light
Tryon (west)	Comparison	Southwest	I-77	45	Industrial	TWLTL	Light
Fairview / Tyvola	Comparison	South	None	35, 45	Retail	TWLTL	Medium
Park	Comparison	South	None	35	Residential	TWLTL	Medium
Morehead / Queens Providence	Comparison	South	I-77	35	Residential	None	Heavy
Graham	Comparison	Northeast	I-85	35, 45	Industrial	None	Medium
Sugar Creek	Comparison	Northeast	I-85	35, 45	Retail	TWLTL	Medium
University City	Comparison	Northeast	I-485	45	Retail	Raised	Medium
Old Concord	Comparison	Northeast	None	45	Residential	None	Light

<Table 6> Speed Sample Sizes

Corridor	Treatment or comparison	Sample size (# of vehicles)				Intersection density (EA per mile)		
		Before		After		All intersection	Signal	Non signal
		Day	Night	Day	Night			
Billy Graham/ Woodlawn	Treatment	129,404	55,279	113,358	45,122	5.0	1.7	3.3
South	Treatment	128,096	40,290	91,668	34,504	5.2	2.3	2.8
Pineville-Matthews (NC-51)	Treatment	203,571	63,182	196,001	49,656	5.2	1.5	3.7
Providence	Treatment	39,649	12,699	42,669	12,902	9.0	4.1	4.9
WT Harris (north)	Treatment	92,099	39,080	58,092	29,621	8.9	5.5	3.4
Tryon (north)	Treatment	105,798	36,307	80,384	35,497	11.4	1.9	9.5
WT Harris (south)	Treatment	198,602	89,818	180,812	74,108	7.7	1.3	6.4
Tryon (south)	Treatment	75,044	27,457	72,632	25,129	6.7	2.0	4.7
Sharon Amity	Treatment	90,866	38,947	84,716	36,478	8.2	1.7	6.5
Central	Treatment	47,198	21,114	52,658	20,683	10.3	2.7	7.6
Albemarle	Treatment	60,936	30,657	49,240	23,983	7.0	3.7	3.3
Eastway	Treatment	68,656	31,018	74,872	32,425	9.0	2.0	7.0
Independence	Treatment	251,218	120,524	204,876	104,648	5.9	1.7	4.3
Monroe	Treatment	141,853	38,825	123,490	40,035	8.8	2.0	6.8
Brookshire	Comparison	69,053	25,434	64,710	23,686	3.1	1.4	1.7
Freedom	Comparison	41,847	13,271	40,475	12,357	7.9	2.0	5.9
Wilkinson	Comparison	56,416	16,881	57,624	17,686	7.1	1.5	5.6
Tryon (west)	Comparison	69,269	23,818	62,364	25,463	6.3	2.2	4.1
Fairview / Tyvola	Comparison	76,718	24,731	84,560	27,345	6.8	2.3	4.5
Park	Comparison	75,845	22,983	73,788	22,501	7.5	2.0	5.5
Morehead / Queens Providence	Comparison	43,853	14,205	41,213	13,208	9.6	2.8	6.9
Graham	Comparison	46,738	13,999	37,803	11,216	8.7	3.3	5.4
Sugar Creek	Comparison	62,135	25,454	50,849	23,180	11.4	2.0	9.4
University City	Comparison	77,194	31,983	60,477	29,533	5.9	2.6	3.3
Old Concord	Comparison	30,216	9,761	28,677	10,031	6.1	0.6	5.4

Figure 16 shows that speed data were collected at eighty points along the treatment corridors and forty points in the comparison corridors. Speed data were collected approximately ten months before implementing speed cameras and approximately three months after speed cameras began enforcing at the same locations on each corridor. This allowed for any seasonal variation to practically be eliminated. In addition, comparison sites helped eliminate any historical bias that could have taken place. Speed data were collected using an induction speed loop in two directions at each point. The device measured and recorded the speed of every vehicle over a continuous twenty four hours, collected during a weekday. It is important to note that speed collection points not directly located on the corridors of interests were not used in the analysis of speeds but are shown in the figure.

The individual speed observations were placed into one of fourteen speed interval levels: 0-15, 16-20, 21-25, 26-30, 31-35, 36-40, 41-45, 46-50, 51-55, 56-60, 61-65, 66-70, 71-75, and 76-999 miles per hour. The frequency measured in the 0-15 speed interval was excluded in our analysis since the speed is mostly associated with turning vehicles. In addition, the 76-999 mph interval level, in which there were only a few observations, was assumed as 76 mph during statistical analyses in the study. To consider differences in speeds attributed to time of day, we grouped the speed data into day time from 7:00 AM to 7:00 PM and night time from 7:00 PM to 7:00 AM. Since there are some corridors having two or more speed limits, the corridors were also divided by speed limit.



<Figure 16> Location of Corridors and Speed Data Collection Points

APPROACH

The main questions addressed during the speed analyses were as followings:

- Were mean speeds after implementing speed camera enforcement reduced compared to before the enforcement?
- If there was a decrease in the mean speeds, what amount of decrease occurred? Can the decrease be attributed to the enforcement?
- In addition to mean speeds, were median speeds, 85th percentile speeds, and the percentage of vehicles exceeding the speed limit by more than 10 mph affected by the beginning of the camera enforcement?
- Under what conditions were speed cameras more effective at reducing speeds? For example, did speed cameras have a greater effect at night or during the day?

To answer these questions, we first completed F-tests and t-tests to check whether the variances and means of speed in each corridor were significantly different between the 'before' and 'after' periods by individual corridor. Specifically, since it was shown by some studies that a larger variance in speeds might result in the higher likelihood of collisions, it is worthwhile to compare changes in the variances of speeds between treatment and comparison sites. In addition to the parametric tests, Wilcoxon sign tests (a traditional non-parametric test) were performed to evaluate whether speed camera enforcement affected mean speeds in treatment sites as a whole.

Second, linear regression and logistic regression models were adopted to quantify the safety effect of speed cameras between treatment and comparison sites. Table 7 shows the factors available to fit the regression models. The other variables we collected in Tables 5 and 6 were not used in regression analyses because there were no available data for some levels of those factors. Models including all the factors might have created biased results.

<Table 7> Variables for the Regression Analyses

Variable	Description	Level
Site	Each speed collection site	120 sites (80 sites for treatment 40 sites for comparison)
Time	Day time: 7:00 AM to 7:00 PM Night time: 7:00 PM to 7:00 AM	Day Night
Period	Before and after implementing speed camera enforcements	Before After
Test	Treatment sites and comparison sites	Treatment site Comparison site
Speed Limit	Speed limit for each corridor observed speeds	35, 40, 45, 55

The basic formula of the adopted linear and logistics regression models were as follows:

$$Y = f(Time, Period, Speed\ Limit, Sites)$$

$$Logit(Y) = f(Time, Period, test, Sites)$$

The five dependent variables used in the efforts were:

- Mean speed
- Median speed
- 85 percentile speed
- Change in mean speed minus speed limit

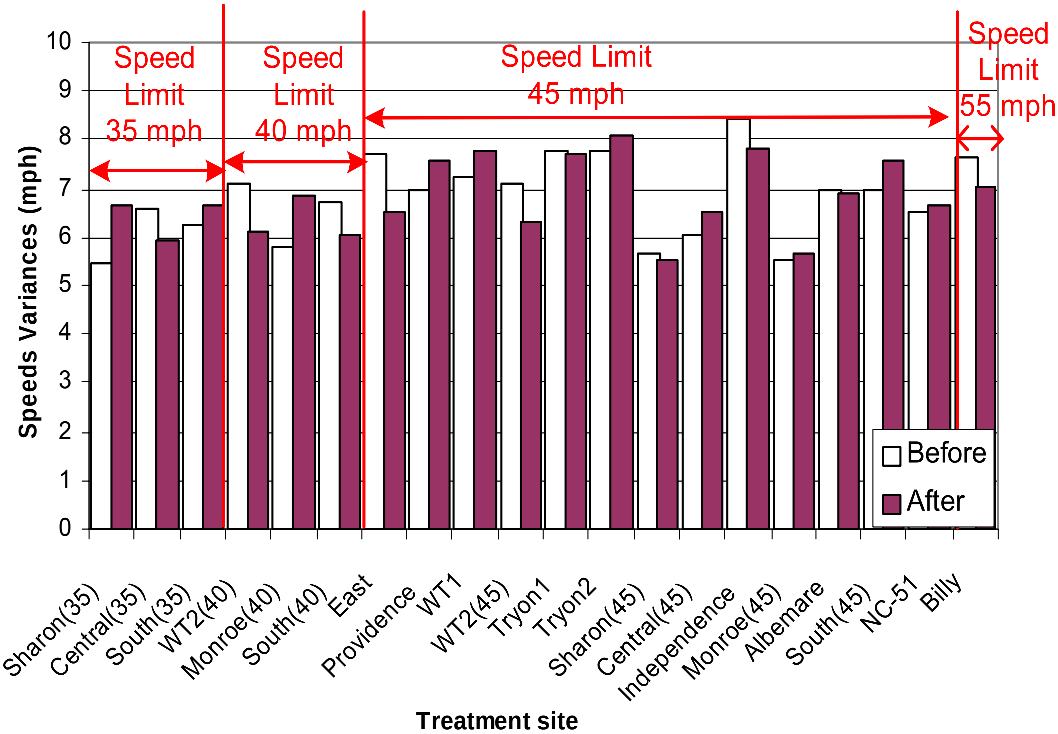
The linear regression model is applicable to evaluate statistically the changes in mean speed, median speed, and 85th percentile speed due to speed camera enforcement. The logistic regression model is suitable to estimate statistically the proportion of vehicles exceeding the speed limit by more than ten mph because the response relates to proportions from counts. Each model was fit using the SAS program. The sites variable in the statistical models was considered a random variable nested within the speed limit variable to account for variations in the speeds or the proportions that might have been affected by other factors than speed camera enforcement (for example, traffic volumes). The models for each response variable are described in detail in subsequent sections.

SPEED ANALYSIS

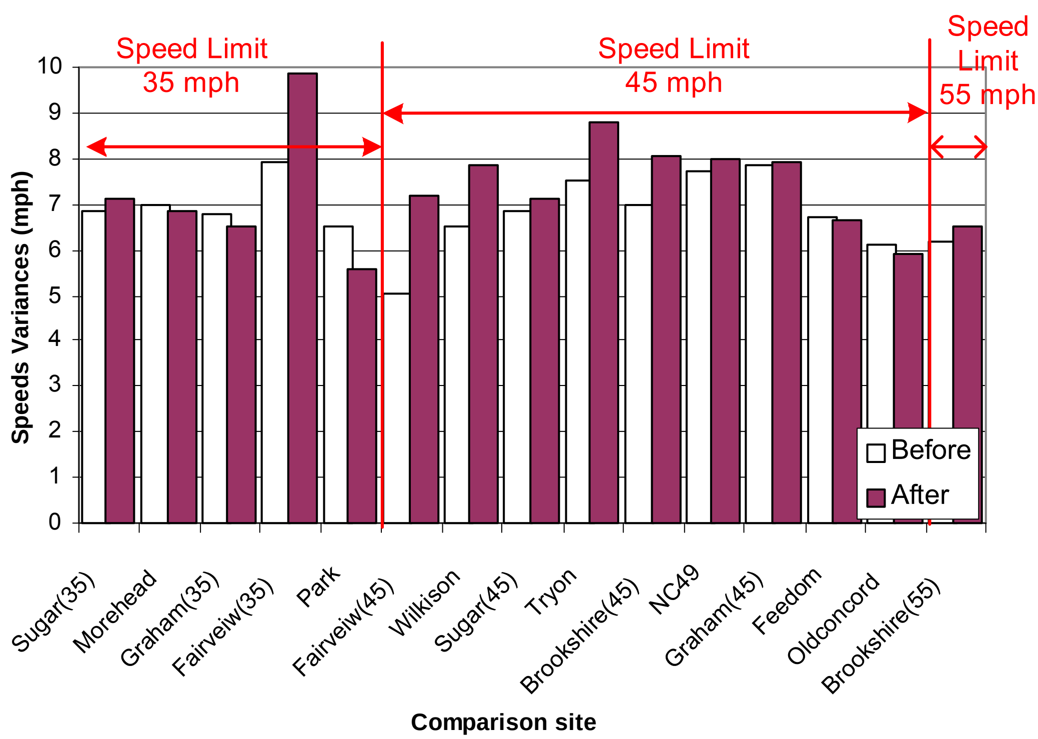
Testing the Difference in Variance

Two-tailed F-tests with significance levels of 0.05 were performed to evaluate whether there were differences in variances of mean speeds between 'before' and 'after' periods for each corridor for day and night times.

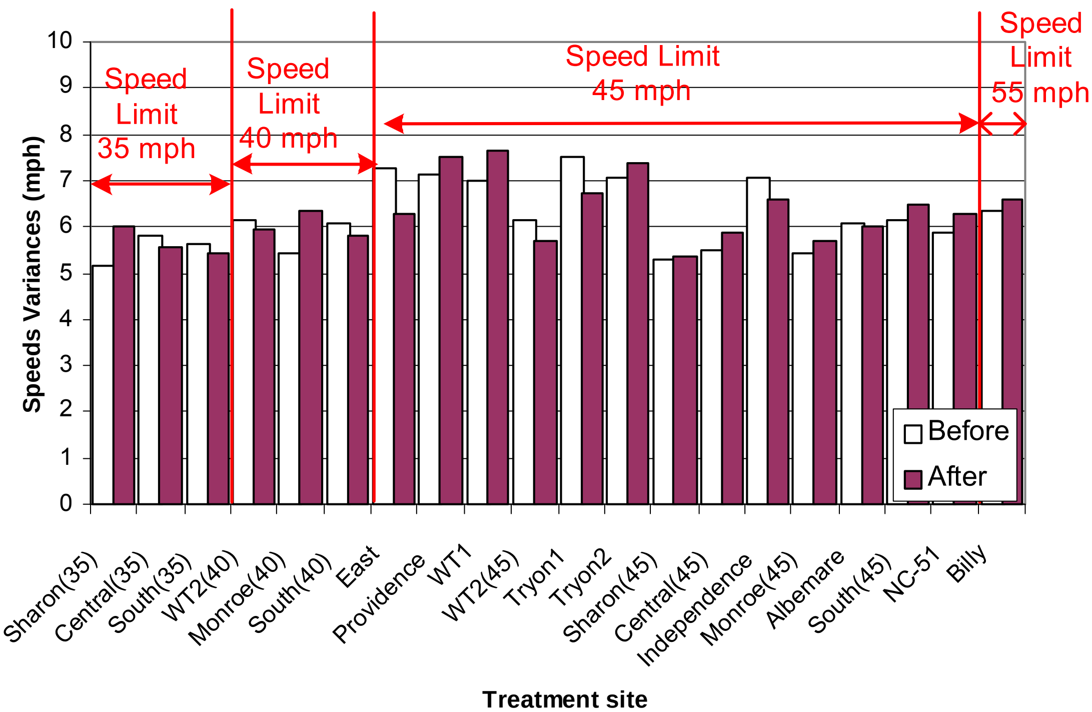
Tables 8 and 9 summarize the results of the tests for each corridor and show which period is lower in variance for each corridor. Figures 17, 18, 19, and 20 show comparisons of variances in mean speeds between the two periods as well. As is seen in Tables 8 and 9, there are significant differences in the variances of mean speeds between 'before' and 'after' periods at most of the treatment and comparison sites. However, reductions in the variances of mean speeds for the after periods occurred substantially more at the treatment than at the comparison sites: 19 (48 %) of the total 40 treatment observations and 9 (30 %) of the total 30 comparison observations, respectively. It is doubtful that the differences in Tables 8 and 9 only could be attributed to the large sample sizes.



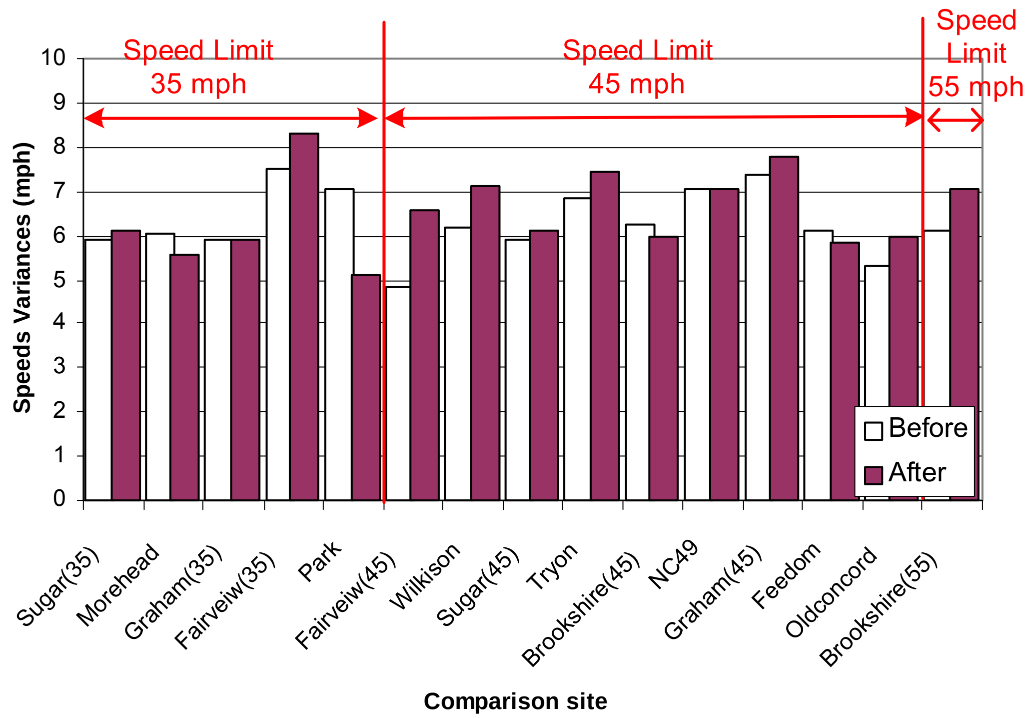
<Figure 17> Speed Variances at Treatment Sites for Daytime



<Figure 18> Speed Variances at Comparison Sites for Daytime



<Figure 19> Speed Variances at Treatment Sites for Nighttime



<Figure 20> Speed Variances at Comparison Sites for Nighttime

<Table 8> Results of F-tests for Treatment Sites

Site	Corridor	Time	Variance (mph)			F-test	p-value	Conclude
			Before	After	Difference[1)]			
Treatment	East	Day	7.70	6.54	-1.16	1.39	< 0.0001	Reject Ho
Treatment	East	Night	7.26	6.24	-1.02	1.35	< 0.0001	Reject Ho
Treatment	Providence	Day	6.99	7.55	0.56	1.17	< 0.0001	Reject Ho
Treatment	Providence	Night	7.11	7.52	0.42	1.12	< 0.0001	Reject Ho
Treatment	WT1	Day	7.24	7.79	0.55	1.16	< 0.0001	Reject Ho
Treatment	WT1	Night	7.00	7.63	0.63	1.19	< 0.0001	Reject Ho
Treatment	WT2(45)	Day	7.14	6.33	-0.81	1.27	< 0.0001	Reject Ho
Treatment	WT2(45)	Night	6.13	5.66	-0.47	1.17	< 0.0001	Reject Ho
Treatment	WT2(40)	Day	7.13	6.11	-1.02	1.36	< 0.0001	Reject Ho
Treatment	WT2(40)	Night	6.17	5.94	-0.23	1.08	< 0.0001	Reject Ho
Treatment	Tryon1	Day	7.77	7.69	-0.07	1.02	0.004	Reject Ho
Treatment	Tryon1	Night	7.54	6.74	-0.80	1.25	< 0.0001	Reject Ho
Treatment	Tryon2	Day	7.76	8.10	0.34	1.09	< 0.0001	Reject Ho
Treatment	Tryon2	Night	7.08	7.40	0.33	1.09	< 0.0001	Reject Ho
Treatment	Sharon(45)	Day	5.66	5.53	-0.13	1.05	< 0.0001	Reject Ho
Treatment	Sharon(45)	Night	5.31	5.35	0.04	1.01	0.19	No reject
Treatment	Sharon(35)	Day	5.43	6.65	1.22	1.50	< 0.0001	Reject Ho
Treatment	Sharon(35)	Night	5.15	5.98	0.83	1.35	< 0.0001	Reject Ho
Treatment	Central(35)	Day	6.55	5.95	-0.60	1.21	< 0.0001	Reject Ho
Treatment	Central(35)	Night	5.81	5.55	-0.26	1.10	< 0.0001	Reject Ho
Treatment	Central(45)	Day	6.03	6.54	0.51	1.18	< 0.0001	Reject Ho
Treatment	Central(45)	Night	5.49	5.85	0.36	1.13	< 0.0001	Reject Ho
Treatment	Independence	Day	8.40	7.85	-0.55	1.14	< 0.0001	Reject Ho
Treatment	Independence	Night	7.08	6.62	-0.46	1.14	< 0.0001	Reject Ho
Treatment	Monroe(40)	Day	5.78	6.87	1.09	1.41	< 0.0001	Reject Ho
Treatment	Monroe(40)	Night	5.46	6.33	0.87	1.34	< 0.0001	Reject Ho
Treatment	Monroe(45)	Day	5.54	5.68	0.14	1.05	< 0.0001	Reject Ho
Treatment	Monroe(45)	Night	5.42	5.68	0.26	1.10	< 0.0001	Reject Ho
Treatment	Albemarle	Day	6.99	6.92	-0.08	1.02	0.011	Reject Ho
Treatment	Albemarle	Night	6.11	6.03	-0.08	1.03	0.031	Reject Ho
Treatment	Billy	Day	7.62	7.04	-0.58	1.17	< 0.0001	Reject Ho
Treatment	Billy	Night	6.33	6.61	0.29	1.09	< 0.0001	Reject Ho
Treatment	South(35)	Day	6.22	6.62	0.40	1.13	< 0.0001	Reject Ho
Treatment	South(35)	Night	5.63	5.43	-0.20	1.07	0.023	Reject Ho
Treatment	South(40)	Day	6.71	6.08	-0.63	1.22	< 0.0001	Reject Ho
Treatment	South(40)	Night	6.11	5.81	-0.30	1.11	< 0.0001	Reject Ho
Treatment	South(45)	Day	6.97	7.54	0.58	1.17	< 0.0001	Reject Ho
Treatment	South(45)	Night	6.14	6.44	0.30	1.10	< 0.0001	Reject Ho
Treatment	NC-51	Day	6.51	6.65	0.14	1.04	< 0.0001	Reject Ho
Treatment	NC-51	Night	5.90	6.24	0.34	1.12	< 0.0001	Reject Ho
Total lower variance			20 (50%)	19 (48 %)				

Lower variance (grey shading)

Statistically, similar variance between 'Before' and 'After' periods (red shading)

1) After – Before

<Table 9> Results of F-tests for Comparison Sites

Site	Corridor	Time	Variance (mph)			F-test	p-value	Conclude
			Before	After	Difference[1)]			
Comparison	Wilkinson	Day	6.49	7.87	1.37	1.47	< 0.0001	Reject Ho
Comparison	Wilkinson	Night	6.20	7.09	0.89	1.31	< 0.0001	Reject Ho
Comparison	Sugar(45)	Day	6.85	7.09	0.24	1.07	< 0.0001	Reject Ho
Comparison	Sugar(45)	Night	5.89	6.11	0.22	1.08	< 0.0001	Reject Ho
Comparison	Sugar(35)	Day	6.85	7.09	0.24	1.07	< 0.0001	Reject Ho
Comparison	Sugar(35)	Night	5.89	6.11	0.22	1.08	0.002	Reject Ho
Comparison	Tryon	Day	7.50	8.76	1.27	1.37	< 0.0001	Reject Ho
Comparison	Tryon	Night	6.87	7.42	0.55	1.17	< 0.0001	Reject Ho
Comparison	Brookshire(45)	Day	6.99	8.08	1.09	1.34	< 0.0001	Reject Ho
Comparison	Brookshire(45)	Night	6.27	5.96	-0.31	1.11	< 0.0001	Reject Ho
Comparison	Brookshire(55)	Day	6.18	6.50	0.32	1.11	< 0.0001	Reject Ho
Comparison	Brookshire(55)	Night	6.10	7.03	0.93	1.33	< 0.0001	Reject Ho
Comparison	Morehead	Day	6.99	6.86	-0.14	1.04	< 0.0001	Reject Ho
Comparison	Morehead	Night	6.01	5.59	-0.43	1.16	< 0.0001	Reject Ho
Comparison	NC49	Day	7.72	7.96	0.24	1.06	< 0.0001	Reject Ho
Comparison	NC49	Night	7.05	7.04	-0.01	1.00	0.79	No reject
Comparison	Graham(45)	Day	7.85	7.92	0.06	1.02	0.15	No reject
Comparison	Graham(45)	Night	7.39	7.78	0.39	1.11	< 0.0001	Reject Ho
Comparison	Graham(35)	Day	6.76	6.52	-0.24	1.07	0.0004	Reject Ho
Comparison	Graham(35)	Night	5.90	5.88	-0.01	1.00	0.91	No reject
Comparison	Freedom	Day	6.73	6.63	-0.10	1.03	0.002	Reject Ho
Comparison	Freedom	Night	6.12	5.86	-0.26	1.09	< 0.0001	Reject Ho
Comparison	Fairview(35)	Day	7.89	9.89	2.00	1.57	< 0.0001	Reject Ho
Comparison	Fairview(35)	Night	7.49	8.32	0.83	1.23	< 0.0001	Reject Ho
Comparison	Fairview(45)	Day	5.06	7.17	2.11	2.01	< 0.0001	Reject Ho
Comparison	Fairview(45)	Night	4.82	6.57	1.76	1.86	< 0.0001	Reject Ho
Comparison	Park	Day	6.49	5.55	-0.94	1.37	< 0.0001	Reject Ho
Comparison	Park	Night	7.02	5.11	-1.91	1.89	< 0.0001	Reject Ho
Comparison	Old concord	Day	6.14	5.93	-0.20	1.07	< 0.0001	Reject Ho
Comparison	Old concord	Night	5.29	5.95	0.65	1.26	< 0.0001	Reject Ho
Total lower variance			18 (60%)	9 (30%)				

Lower variance (grey shading)

Statistically, similar variance between 'Before' and 'After' periods (red shading)

1) After – Before

Testing the Difference in Mean Speed

T-tests were performed to evaluate whether there were differences in mean speeds between 'before' and 'after' periods for day and night times by each corridor. Two-tailed tests with significance levels of 0.05 were used in this study. T-tests for non-equal variance or for equal variance were adopted according to the results of the previous F-tests.

Tables 10 and 11 summarize the results of the tests for each corridor and show that mean speed is lower, comparing 'before' periods with 'after' periods. The mean speeds were significantly different between the 'before' and 'after' periods at most of the treatment sites and comparison sites. This trend is likely due to large sample sizes. Although there are statistically significant differences in mean speeds at most of the sites, declines in mean speeds occurred in the treatment sites more than in comparison sites: 28 (70 %) of the 40 treatment site observations and 18 (60 %) of the 30 comparison site observations, respectively.

<Table 10> Results of t-tests for Treatment Sites

Treat	Site	Time	Mean Speed (mph)			T value	p-value	Conclude
			Before	After	Difference[1)]			
Treatment	East	Day	38.99	39.30	0.31	12.85	< 0.0001	Reject Ho
Treatment	East	Night	38.78	39.28	0.50	9.23	< 0.0001	Reject Ho
Treatment	Providence	Day	40.89	39.57	-1.32	26.03	< 0.0001	Reject Ho
Treatment	Providence	Night	41.83	40.94	-0.89	9.76	< 0.0001	Reject Ho
Treatment	WT1	Day	41.30	40.88	-0.42	10.50	< 0.0001	Reject Ho
Treatment	WT1	Night	43.65	42.36	-1.29	22.82	< 0.0001	Reject Ho
Treatment	WT2(45)	Day	46.56	46.01	-0.55	21.88	< 0.0001	Reject Ho
Treatment	WT2(45)	Night	46.24	45.19	-1.05	31.25	< 0.0001	Reject Ho
Treatment	WT2(40)	Day	43.56	43.41	-0.16	3.54	0.0004	Reject Ho
Treatment	WT2(40)	Night	42.75	42.24	-0.51	8.40	< 0.0001	Reject Ho
Treatment	Tryon1	Day	46.94	45.84	-1.10	30.45	< 0.0001	Reject Ho
Treatment	Tryon1	Night	46.38	46.40	0.02	0.39	0.699	No reject
Treatment	Tryon2	Day	39.41	39.28	-0.12	2.98	0.003	Reject Ho
Treatment	Tryon2	Night	40.53	40.93	0.40	6.32	< 0.0001	Reject Ho
Treatment	Sharon(45)	Day	39.89	38.86	-1.03	35.13	< 0.0001	Reject Ho
Treatment	Sharon(45)	Night	39.61	38.53	-1.08	26.11	< 0.0001	Reject Ho
Treatment	Sharon(35)	Day	38.44	37.72	-0.73	10.05	< 0.0001	Reject Ho
Treatment	Sharon(35)	Night	39.01	38.49	-0.52	4.52	< 0.0001	Reject Ho
Treatment	Central(35)	Day	36.57	37.97	1.40	29.62	< 0.0001	Reject Ho
Treatment	Central(35)	Night	37.26	37.17	-0.09	1.41	0.160	No reject
Treatment	Central(45)	Day	37.02	38.81	1.78	24.27	< 0.0001	Reject Ho
Treatment	Central(45)	Night	38.25	39.98	1.73	15.78	< 0.0001	Reject Ho
Treatment	Independence	Day	48.69	47.21	-1.49	61.65	< 0.0001	Reject Ho
Treatment	Independence	Night	50.13	48.16	-1.97	68.05	< 0.0001	Reject Ho
Treatment	Monroe(40)	Day	39.69	39.20	-0.48	14.54	< 0.0001	Reject Ho
Treatment	Monroe(40)	Night	40.66	39.39	-1.26	23.33	< 0.0001	Reject Ho
Treatment	Monroe(45)	Day	43.63	43.29	-0.34	10.27	< 0.0001	Reject Ho
Treatment	Monroe(45)	Night	43.85	43.06	-0.78	12.48	< 0.0001	Reject Ho
Treatment	Albemarle	Day	40.36	41.81	1.44	34.28	< 0.0001	Reject Ho
Treatment	Albemarle	Night	41.91	43.10	1.20	22.91	< 0.0001	Reject Ho
Treatment	Billy	Day	56.32	56.54	0.22	7.45	< 0.0001	Reject Ho
Treatment	Billy	Night	56.79	56.92	0.13	3.18	0.001	Reject Ho
Treatment	South(35)	Day	40.15	37.53	-2.62	34.36	< 0.0001	Reject Ho
Treatment	South(35)	Night	41.58	40.24	-1.35	10.97	< 0.0001	Reject Ho
Treatment	South(40)	Day	39.00	37.73	-1.27	29.65	< 0.0001	Reject Ho
Treatment	South(40)	Night	40.50	39.00	-1.50	22.21	< 0.0001	Reject Ho
Treatment	South(45)	Day	39.98	37.63	-2.35	49.71	< 0.0001	Reject Ho
Treatment	South(45)	Night	41.49	39.54	-1.94	28.86	< 0.0001	Reject Ho
Treatment	NC-51	Day	44.80	42.80	-2.00	95.97	< 0.0001	Reject Ho
Treatment	NC-51	Night	44.52	42.84	-1.67	45.76	< 0.0001	Reject Ho
Total lower mean speed			10 (25%)	28 (70%)				

(grey) Lower mean speed

(red) Statistically, no difference in mean speed between 'Before' and 'After' periods

1) After – Before

<Table 11> Results of t-test for Comparison Sites

Treat	Site	Time	Mean Speed (mph)			T-test	p-value	Conclude
			Before	After	Difference[1)]			
Comparison	Wilkinson	Day	46.59	47.97	1.38	32.28	< 0.0001	Reject Ho
Comparison	Wilkinson	Night	45.70	47.15	1.45	20.21	< 0.0001	Reject Ho
Comparison	Sugar(45)	Day	41.54	41.55	0.01	0.12	0.904	No reject
Comparison	Sugar(45)	Night	41.29	41.08	-0.21	3.33	0.001	Reject Ho
Comparison	Sugar(35)	Day	41.54	41.55	0.01	0.07	0.943	No reject
Comparison	Sugar(35)	Night	41.29	41.08	-0.21	2.09	0.037	Reject Ho
Comparison	Tryon	Day	45.81	44.40	-1.41	31.21	< 0.0001	Reject Ho
Comparison	Tryon	Night	44.13	43.63	-0.49	7.65	< 0.0001	Reject Ho
Comparison	Brookshire(45)	Day	47.25	46.02	-1.22	16.99	< 0.0001	Reject Ho
Comparison	Brookshire(45)	Night	47.62	47.71	0.09	0.97	0.330	No reject
Comparison	Brookshire(55)	Day	58.34	57.06	-1.28	30.23	< 0.0001	Reject Ho
Comparison	Brookshire(55)	Night	57.88	54.66	-3.22	43.20	< 0.0001	Reject Ho
Comparison	Morehead	Day	37.57	35.61	-1.96	41.20	< 0.0001	Reject Ho
Comparison	Morehead	Night	39.85	38.22	-1.63	23.23	< 0.0001	Reject Ho
Comparison	NC49	Day	46.72	45.13	-1.59	37.25	< 0.0001	Reject Ho
Comparison	NC49	Night	47.49	46.52	-0.97	17.09	< 0.0001	Reject Ho
Comparison	Graham(45)	Day	40.74	39.50	-1.24	19.89	< 0.0001	Reject Ho
Comparison	Graham(45)	Night	40.74	40.52	-0.22	2.12	0.034	Reject Ho
Comparison	Graham(35)	Day	40.15	38.85	-1.30	13.63	< 0.0001	Reject Ho
Comparison	Graham(35)	Night	40.18	39.18	-1.00	5.53	< 0.0001	Reject Ho
Comparison	Freedom	Day	41.50	41.90	0.40	8.50	< 0.0001	Reject Ho
Comparison	Freedom	Night	42.80	43.77	0.97	12.99	< 0.0001	Reject Ho
Comparison	Fairview(35)	Day	36.21	40.54	4.33	67.42	< 0.0001	Reject Ho
Comparison	Fairview(35)	Night	37.34	41.57	4.23	42.95	< 0.0001	Reject Ho
Comparison	Fairview(45)	Day	47.89	44.84	-3.04	70.30	< 0.0001	Reject Ho
Comparison	Fairview(45)	Night	47.23	43.64	-3.59	50.33	< 0.0001	Reject Ho
Comparison	Park	Day	42.03	41.44	-0.59	19.00	< 0.0001	Reject Ho
Comparison	Park	Night	40.12	40.87	0.75	12.99	< 0.0001	Reject Ho
Comparison	Old concord	Day	43.78	44.32	0.53	10.69	< 0.0001	Reject Ho
Comparison	Old concord	Night	44.13	44.02	-0.11	1.32	0.186	No reject
Total lower mean speed			8 (27%)	18 (60%)				

Lower mean speed (grey)
Statistically, no difference in mean speed between 'Before' and 'After' periods (red)

1) After – Before

Wilcoxon Paired-Sample Test

While the previous parametric tests were performed for each corridor, the Wilcoxon sign test as a nonparametric test is performed to evaluate whether there are differences in the distribution of mean speeds between 'before' and 'after' periods for the treatment and comparison sites as a whole. Two-tailed tests with significance levels of 0.05 were adopted.

Table 12 shows the results of the tests regarding whether the distributions are significantly different or not by each site. Table 12 shows that while the differences for the comparison sites were not significant, the distribution of mean speeds for the treatment sites was different. Tables 13 and 14 present the analyses of the tests by each site, as well.

<Table 12> Results of Wilcoxon Sign Test

Site	$T_{Calculated}$	Critical Value $T_{0.05(2),n}$	Result
Treatment	190	264	Rejected the null hypothesis[1)]
Comparison	150.5	137	Accepted the alternative hypothesis[2)]

1) The null hypothesis : The distribution of differences is symmetrical

2) The alternative hypothesis : The differences are different

To summarize the findings of the F-tests, t-tests, and Wilcoxon paired-sample tests, it appears that speed camera enforcement affected mean speeds and speed variances across the treatment sites as a whole compared to the comparison sites. The next section will quantify the amount by which mean speeds at the treatment sites decreased statistically compared to the comparison sites.

<Table 13> Results of Wilcoxon Sign Test for Treatment Sites

Treat	Site	Time	Mean Speed (mph)			Rank of $\|d_i\|$	Rank of d_i
			Before	After	Difference (d_i)		
Treatment	East	Day	38.99	39.30	0.31	7	7
Treatment	East	Night	38.78	39.28	0.50	12	12
Treatment	Providence	Day	40.89	39.57	-1.32	27	-27
Treatment	Providence	Night	41.83	40.94	-0.89	18	-18
Treatment	WT1	Day	41.30	40.88	-0.42	10	-10
Treatment	WT1	Night	43.65	42.36	-1.29	26	-26
Treatment	WT2(45)	Day	46.56	46.01	-0.55	15	-15
Treatment	WT2(45)	Night	46.24	45.19	-1.05	20	-20
Treatment	WT2(40)	Day	43.56	43.41	-0.16	5	-5
Treatment	WT2(40)	Night	42.75	42.24	-0.51	13	-13
Treatment	Tryon1	Day	46.94	45.84	-1.10	22	-22
Treatment	Tryon1	Night	46.38	46.40	0.02	1	1
Treatment	Tryon2	Day	39.41	39.28	-0.12	3	-3
Treatment	Tryon2	Night	40.53	40.93	0.40	9	9
Treatment	Sharon(45)	Day	39.89	38.86	-1.03	19	-19
Treatment	Sharon(45)	Night	39.61	38.53	-1.08	21	-21
Treatment	Sharon(35)	Day	38.44	37.72	-0.73	16	-16
Treatment	Sharon(35)	Night	39.01	38.49	-0.52	14	-14
Treatment	Central(35)	Day	36.57	37.97	1.40	29	29
Treatment	Central(35)	Night	37.26	37.17	-0.09	2	-2
Treatment	Central(45)	Day	37.02	38.81	1.78	35	35
Treatment	Central(45)	Night	38.25	39.98	1.73	34	34
Treatment	Independence	Day	48.69	47.21	-1.49	31	-31
Treatment	Independence	Night	50.13	48.16	-1.97	37	-37
Treatment	Monroe(40)	Day	39.69	39.20	-0.48	11	-11
Treatment	Monroe(40)	Night	40.66	39.39	-1.26	24	-24
Treatment	Monroe(45)	Day	43.63	43.29	-0.34	8	-8
Treatment	Monroe(45)	Night	43.85	43.06	-0.78	17	-17
Treatment	Albemarle	Day	40.36	41.81	1.44	30	30
Treatment	Albemarle	Night	41.91	43.10	1.20	23	23
Treatment	Billy	Day	56.32	56.54	0.22	6	6
Treatment	Billy	Night	56.79	56.92	0.13	4	4
Treatment	South(35)	Day	40.15	37.53	-2.62	40	-40
Treatment	South(35)	Night	41.58	40.24	-1.35	28	-28
Treatment	South(40)	Day	39.00	37.73	-1.27	25	-25
Treatment	South(40)	Night	40.50	39.00	-1.50	32	-32
Treatment	South(45)	Day	39.98	37.63	-2.35	39	-39
Treatment	South(45)	Night	41.49	39.54	-1.94	36	-36
Treatment	NC-51	Day	44.80	42.80	-2.00	38	-38
Treatment	NC-51	Night	44.52	42.84	-1.67	33	-33
						T_+	190
						T_-	630

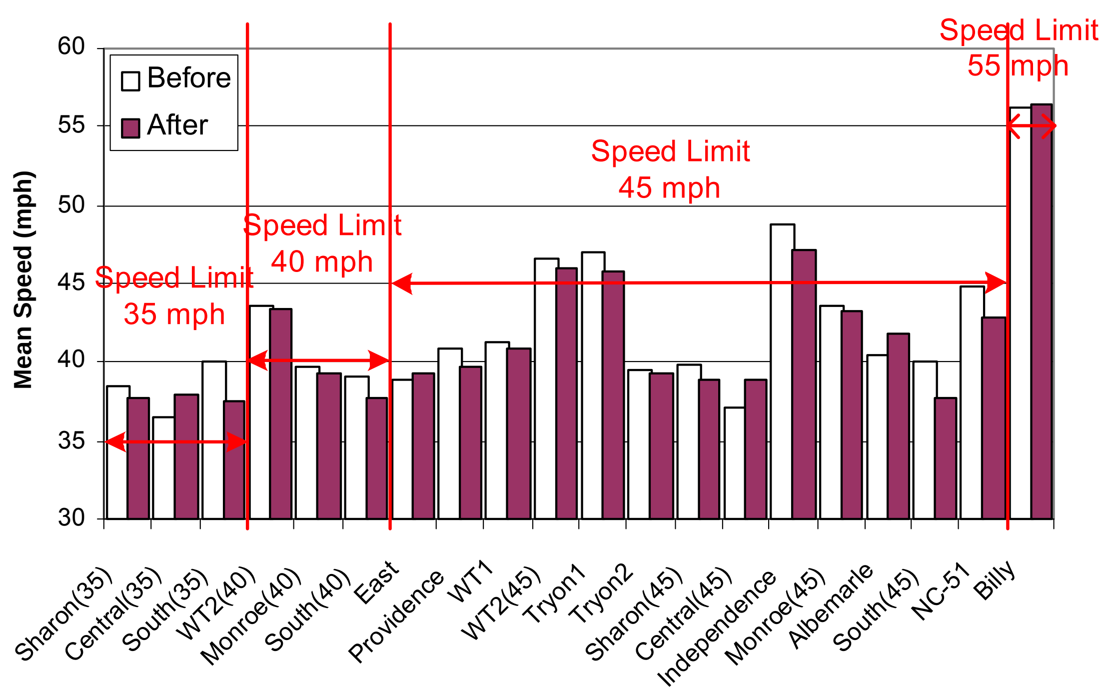
<Table 14> Results of Wilcoxon Sign Test for Comparison Sites

Treat	Site	Time	Mean Speed (mph)			Rank of $\lvert d_i \rvert$	Rank of d_i
			Before	After	Difference (d_i)		
Comparison	Wilkinson	Day	46.59	47.97	1.38	20	20
Comparison	Wilkinson	Night	45.70	47.15	1.45	22	22
Comparison	Sugar(45)	Day	41.54	41.55	0.01	1.5	1.5
Comparison	Sugar(45)	Night	41.29	41.08	-0.21	5.5	-5.5
Comparison	Sugar(35)	Day	41.54	41.55	0.01	1.5	1.5
Comparison	Sugar(35)	Night	41.29	41.08	-0.21	5.5	-5.5
Comparison	Tryon	Day	45.81	44.40	-1.41	21	21
Comparison	Tryon	Night	44.13	43.63	-0.49	9	-9
Comparison	Brookshire(45)	Day	47.25	46.02	-1.22	16	-16
Comparison	Brookshire(45)	Night	47.62	47.71	0.09	3	3
Comparison	Brookshire(55)	Day	58.34	57.06	-1.28	18	-18
Comparison	Brookshire(55)	Night	57.88	54.66	-3.22	27	-27
Comparison	Morehead	Day	37.57	35.61	-1.96	25	-25
Comparison	Morehead	Night	39.85	38.22	-1.63	24	-24
Comparison	NC49	Day	46.72	45.13	-1.59	23	-23
Comparison	NC49	Night	47.49	46.52	-0.97	13.5	-13.5
Comparison	Graham(45)	Day	40.74	39.50	-1.24	17	-17
Comparison	Graham(45)	Night	40.74	40.52	-0.22	7	-7
Comparison	Graham(35)	Day	40.15	38.85	-1.30	19	-19
Comparison	Graham(35)	Night	40.18	39.18	-1.00	15	-15
Comparison	Freedom	Day	41.50	41.90	0.40	8	8
Comparison	Freedom	Night	42.80	43.77	0.97	13.5	13.5
Comparison	Fairview(35)	Day	36.21	40.54	4.33	30	30
Comparison	Fairview(35)	Night	37.34	41.57	4.23	29	29
Comparison	Fairview(45)	Day	47.89	44.84	-3.04	26	-26
Comparison	Fairview(45)	Night	47.23	43.64	-3.59	28	-28
Comparison	Park	Day	42.03	41.44	-0.59	11	-11
Comparison	Park	Night	40.12	40.87	0.75	12	12
Comparison	Old concord	Day	43.78	44.32	0.53	10	10
Comparison	Old concord	Night	44.13	44.02	-0.11	4	-4
						T_+	314
						T_-	150.5

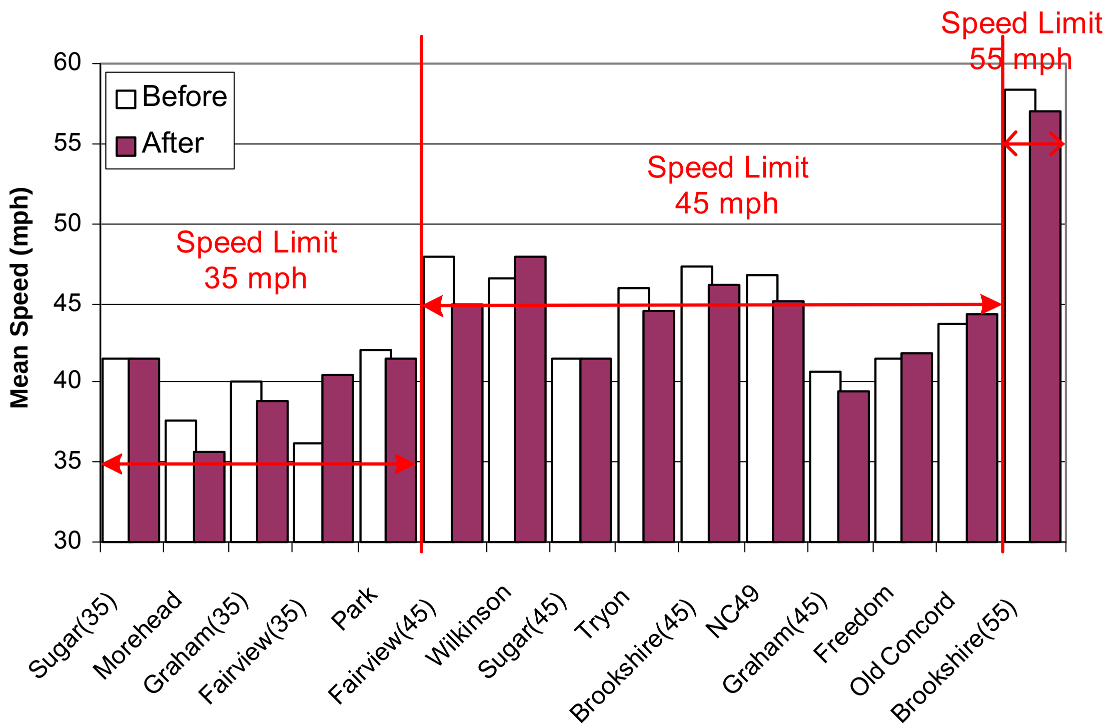
Linear Regression Model

Mean Speed

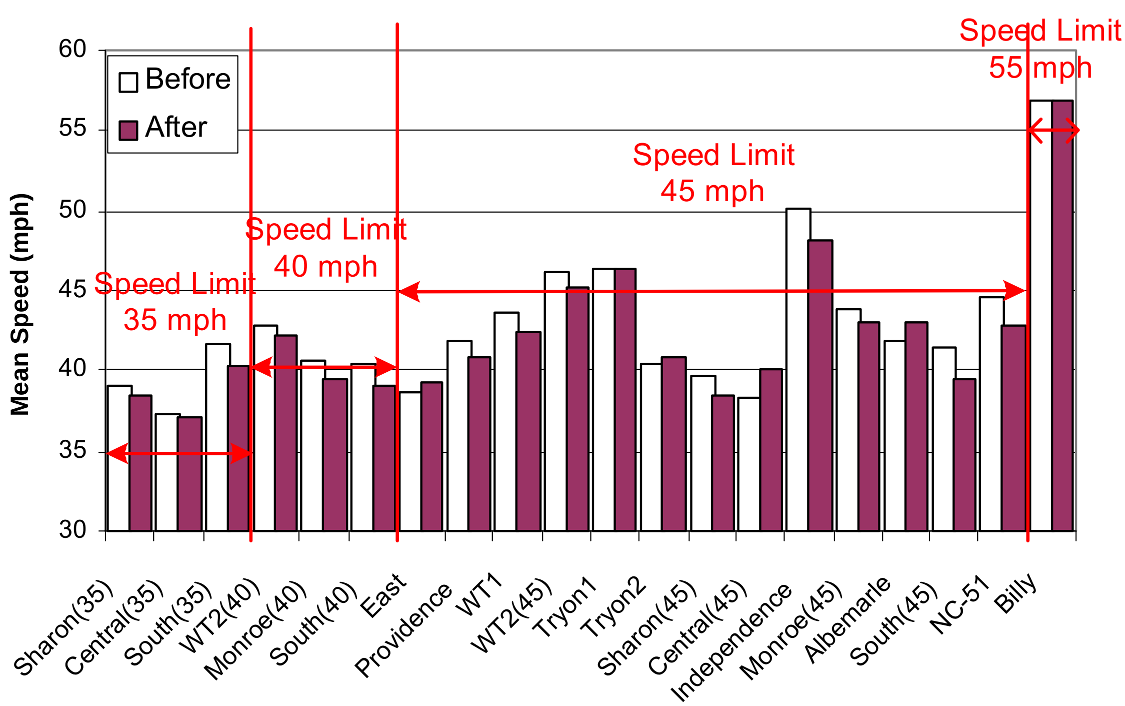
Figures 21, 22, 23, and 24 compare mean speeds in 'before' and 'after' periods for each corridor. They show that while mean speeds at most of the treatment sites decreased by 0.1 mph to 2.7 mph, a few of the sites increased by 1.8 mph or were unchanged in mean speeds compared to 'before' periods. At the comparison sites, mean speeds increased, decreased, or remained unchanged also, varying from an increase of 4.5 mph to a decrease of 3.6 mph. Overall, it appeared that declines in mean speeds and smaller variances at the treatment sites were more predominant than at the comparison sites.



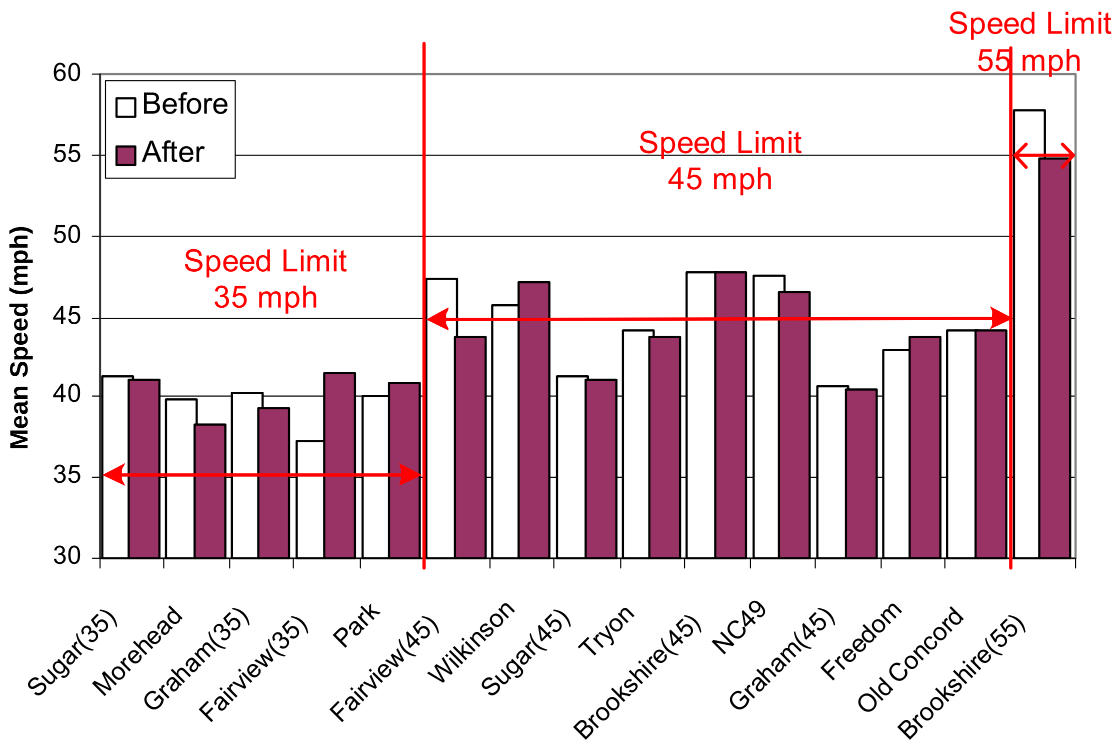
<Figure 21> Mean Speeds at Treatment Sites during Daytime



<Figure 22> Mean Speeds at Comparison Sites during Daytime



<Figure 23> Mean Speeds at Treatment Sites during Nighttime



<Figure 24> Mean Speeds at Comparison Sites during Nighttime

To quantify statistically the amount of changes in mean speed at the treatment sites due to speed camera enforcement, linear regression models were used as follows:

$$
\begin{aligned}
Mean\ Speed = {} & \beta_0 + \beta_1 \times time + \beta_2 \times period + \beta_3 \times Limit + \beta_4 \times Limit \times period + \beta_5 \times Limit \times time + \beta_6 \times period \times time \\
& + \beta_7 \times Limit \times time \times period + \beta_8 \times site(Limit)
\end{aligned}
$$

The dependent variable was mean speed. Independent variables were: site (80 speed collection points in treatment sites or 40 speed collection points in comparison sites), period ('before' and 'after'), time (day and night), and speed limit (35, 40, 45, and 55 mph). Note that there were no available comparison sites with 40 mph speed limits.

The regression model is the most appealing way to draw an inference regarding the wider population of sites assuming that site variables were considered as random effects, rather than fixed. Then, site variables are nested within levels of speed limit variables but crossed with levels of period and time variables. Using the suggested model, we could evaluate the changes in mean speed caused by speed camera enforcement. Also, we could estimate whether there are differences in the changes due to the enforcement according to the level of the other factors using interaction terms between each factor.

The suggested model for each site was fit using the Generalized Linear Model statement as implemented by the SAS procedure GLM. The significance of each independent and interaction in the full model was examined through the SAS procedure. If the independent variables and interaction terms were not statistically significant, those would be dropped from the full model, resulting in a reduced model. With the reduced model, the significance tests for the model-involved explanatory variables were performed. This repetitive process was continued to obtain the best estimates of the regression coefficients for each model. In addition, residual versus predicted values were plotted to check normal distribution assumptions. If constant patterns on the residual vs. predicted plot appeared, the assumptions with regard to the linear regression model would be appropriate to fit to our speed data.

Tables 15 and 16 summarize the results of the regression analysis for treatment sites. These results are the best of the models examined. They show that mean speeds approximately three months after speed camera enforcement began at treatment sites decreased by 0.91 mph equally during day and night times compared to 'before' periods.

The changes in mean speeds also occurred equally regardless of the speed limits because SAS indicated that there were no significant interaction relationships between any of the independent variables. The results showed that the main effects were all statistically significant at the 0.05 level.

As we can expect, the higher the posted speed limit the higher mean speeds. However, there were only small jumps from 35 mph to 45 mph, with the big jump from 45 mph to 55 mph. Also, the results show that the speeds for daytime are about 0.58 mph higher than for nighttime.

<Table 15> Analysis of Variance for Mean Speed for Treatment Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	65.913	33.75	< 0.0001
Time	1	27.268	13.96	0.0002
Speed Limit	3	1458.678	746.93	< 0.0001
Site(Speed Limit)	76	61.645	31.57	< 0.0001

<Table 16> Effect of each Factor on Mean Speed for Treatment Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.91	- 1.22 to - 0.60
Time (Day and Night)	Day – Night	- 0.58	-0.89 to - 0.28
Speed Limit (mph) (55, 45, 40, and 35)	55 – 45	13.49	12.85 to 14.13
	55 – 40	16.15	15.41 to 16.89
	55 – 35	18.73	17.81 to 19.66
	45 – 40	2.66	2.21 to 3.12
	45 – 35	5.25	4.54 to 5.96
	40 – 35	2.58	1.78 to 3.39

Tables 17 and 18 summarize the results of the best regression models for comparison sites using the same analysis process as for treatment sites. Unlike treatment sites, changes in mean speeds as the 95% confidence interval ranged from -0.80 mph to 0.22 mph and were therefore not significantly different from 0 when comparing 'before' periods with 'after' periods. The results showed that the time variable was not statistically significant. The results also indicated that there were no significant interactions between the independent variables.

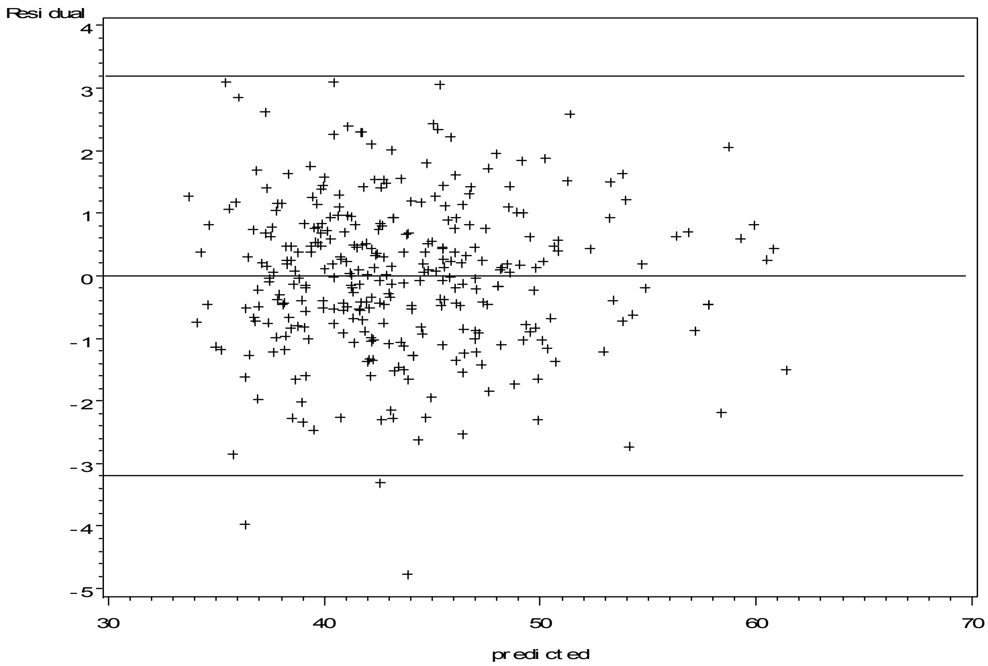
<Table 17> Analysis of Variance for Mean Speed for Comparison Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	3.334	1.23	0.2703
Time	1	0.996	0.37	0.5460
Speed Limit	2	1558.452	31.38	< 0.0001
Site(Speed Limit)	37	49.658	18.27	< 0.0001

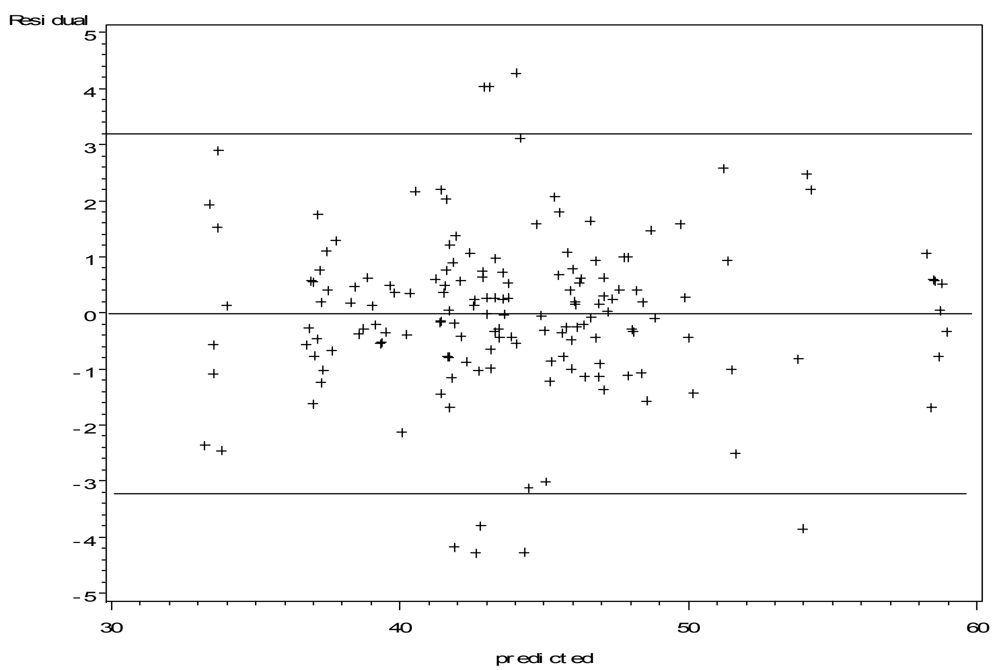
<Table 18> Effect of Each Factor on Mean Speed for Comparison Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.29	- 0.80 to 0.22
Time (Day and Night)	Day – Night	- 0.16	- 0.67 to 0.36
Speed Limit (mph) (55, 45, and 35)	55 – 45	12.54	11.55 to 13.54
	55 – 35	17.93	16.86 to 18.99
	45 – 35	5.39	4.80 to 5.97

As Figures 25 and 26 shows, the residual versus predicted plots were done for the final regression model for each site. Since the pattern appears to be constant on the plot, except for a few points, we could consider that fitting linear-regression models to the speed data was appropriate.



<Figure 25> Residual vs. Predicted Plots of Mean Speeds for Treatment Sites



<Figure 26> Residual vs. Predicted Plots of Mean Speeds for Comparison Sites

Median Speed

This analysis was to quantify statistically the changes in median speed at the treatment sites that occurred due to speed camera enforcement, compared to the comparison sites. The regression model associated with median speed is the same as for mean speeds, replacing mean speed by median speed as a dependent variable:

$$\begin{aligned} Median\ Speed = {} & \beta_0 + \beta_1 \times time + \beta_2 \times period + \beta_3 \times Limit + \beta_4 \times Limit \times period + \beta_5 \times Limit \times time + \beta_6 \times period \times time \\ & + \beta_7 \times Limit \times time \times period + \beta_8 \times site(Limit) \end{aligned}$$

The model was fit using the Generalized Linear Model technique as implemented by SAS, and the changes in median speed were finally quantified using the model that had the best estimates of the regression coefficients.

Tables 19, 20, 21, and 22 summarized the results of the regression on median speeds. SAS indicated that there were no significant interaction relationships between any of the independent variables. Tables 19 and 20 are for treatment sites and Tables 21 and 22 are for comparison sites. Although the difference in median speeds for the comparison sites was - 0.28 mph (after-before), this was not a significant difference between the two periods. Unlike the comparison sites, median speeds at treatment sites decreased significantly by 0.88 mph equally during day and night times regardless of the speed limits, compared to the 'before' periods.

<Table 19> Analysis of Variance for Median Speed for Treatment Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	62.585	33.67	< 0.0001
Time	1	9.518	5.12	0.0245
Speed Limit	3	1454.479	24.04	< 0.0001
Site (Speed Limit)	76	60.504	32.55	< 0.0001

<Table 20> Effect of each Factor on Median Speed for Treatment Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.88	- 1.18 to - 0.58
Time (Day and Night)	Day – Night	- 0.34	-0.64 to - 0.04
Speed Limit (mph) (55, 45, 40, and 35)	55 – 45	13.49	12.87 to 14.11
	55 – 40	16.13	15.41 to 16.85
	55 – 35	18.69	17.79 to 19.59
	45 – 40	2.64	2.20 to 3.08
	45 – 35	5.20	4.51 to 5.89
	40 – 35	2.56	1.78 to 3.34

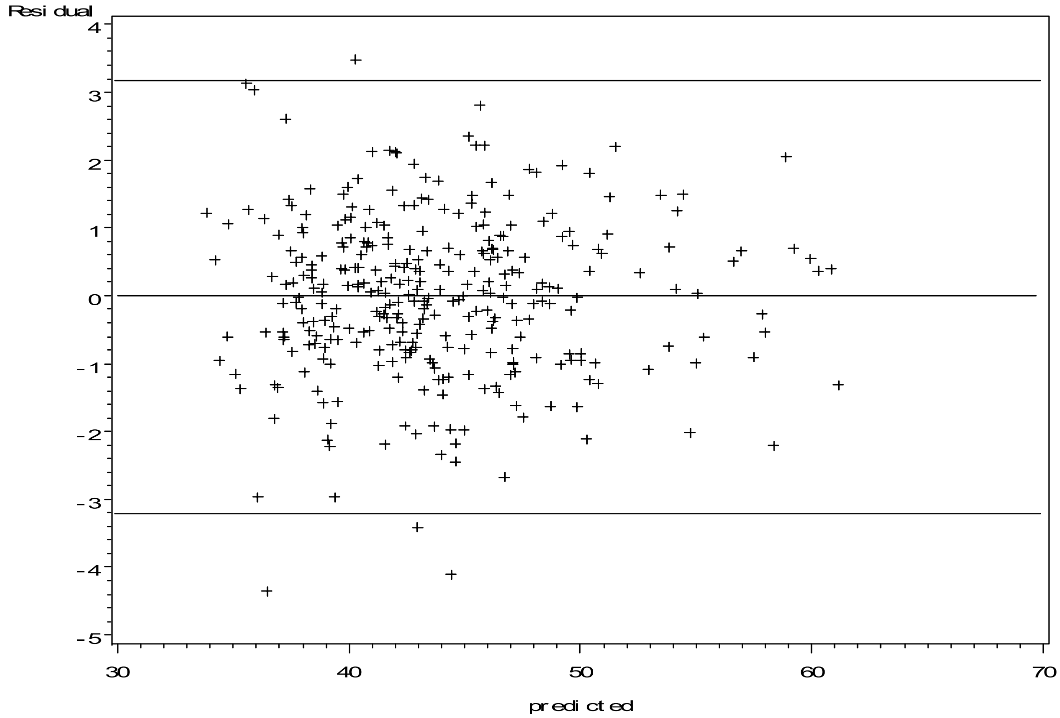
<Table 21> Analysis of Variance for Median Speed for Comparison Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	3.208	1.29	0.2587
Time	1	0.123	0.05	0.8247
Speed Limit	2	1536.132	31.70	< 0.0001
Site(Speed Limit)	37	48.461	19.46	< 0.0001

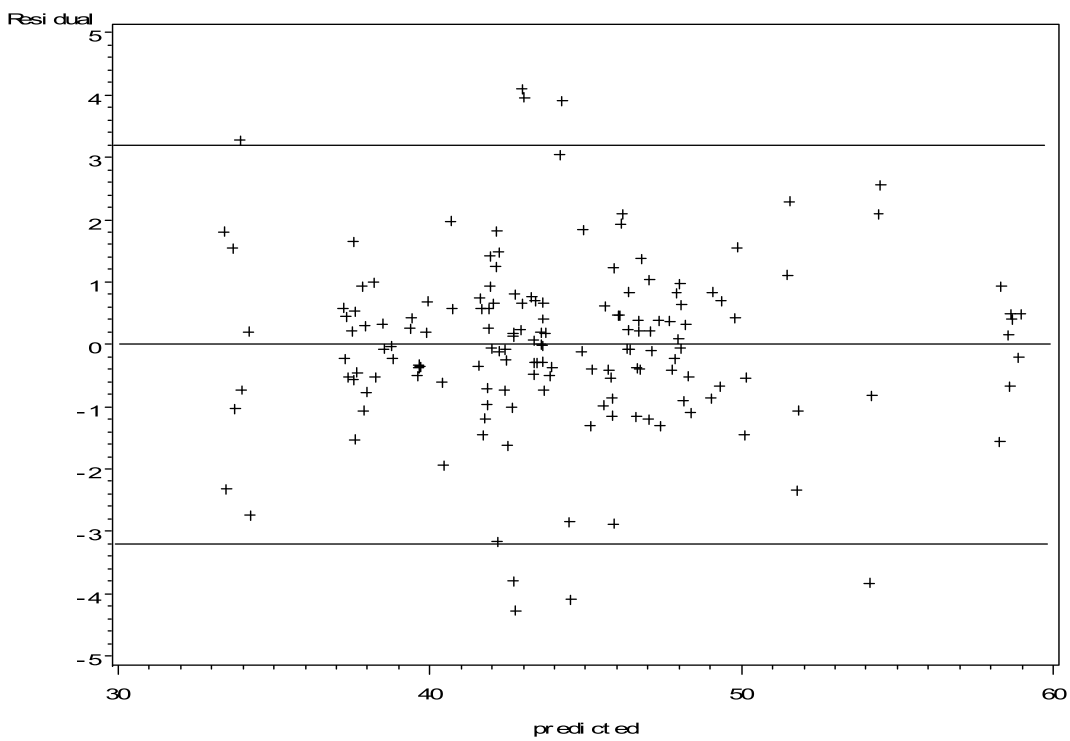
<Table 22> Effect of each Factor on Median Speed for Comparison Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.28	- 0.78 to 0.21
Time (Day and Night)	Day – Night	- 0.06	- 0.55 to 0.44
Speed Limit (mph) (55, 45, and 35)	55 – 45	12.37	11.42 to 13.33
	55 – 35	17.78	16.76 to 18.79
	45 – 35	5.40	4.84 to 5.97

We also checked whether the assumptions pertaining to normal distributions were applicable to median speeds. Since Figures 27 and 28 show a constant pattern of residual versus predicted value, assuming normal distributions for the estimated median speeds appears appropriate.



<Figure 27> Residual vs. Predicted Plots of Median Speeds for Treatment Sites



<Figure 28> Residual vs. Predicted Plots of Median Speeds for Comparison Sites

85th Percentile Speed

This analysis was to quantify statistically the changes in 85th percentile speed due to speed camera enforcement occurred at treatment sites. Like the previous regression analyses, a regression model with 85th percentile speeds as a dependent variable was also performed using the Generalized Linear Model technique as implemented by SAS:

$$85^{th}\ Speed = \beta_0 + \beta_1 \times time + \beta_2 \times period + \beta_3 \times Limit + \beta_4 \times Limit \times period + \beta_5 \times Limit \times time + \beta_6 \times period \times time \\ + \beta_7 \times Limit \times time \times period + \beta_8 \times site(Limit)$$

The regression process associated with 85th percentile speeds is the same as for mean speeds, and the changes in 85th percentile speeds were finally quantified with model that had the best estimates of the regression coefficients.

Tables 23, 24, 25, and 26 summarize the results of the regression against 85th percentile speeds. There were no significant interaction relationships between the independent variables. Tables 23 and 24 are for treatment sites and Tables 25 and 26 are for comparison sites. Like mean speeds and median speeds, the results show that while there are no significant differences in 85th percentile speeds between the two periods at the comparison sites, 85th percentile speeds at treatment sites decreased significantly by 0.99 mph compared to the 'before' periods. The results also indicated that there were marginal significant differences in the speeds between the two times (day and night) at the treatment sites.

<Table 23> Analysis of Variance for 85^{th} Percentile Speed for Treatment Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	78.054	51.23	< 0.0001
Time	1	4.934	3.24	0.0732
Speed Limit	3	1552.429	28.22	< 0.0001
Site(Speed Limit)	76	55.005	36.10	< 0.0001

<Table 24> Effect of Each Factor on 85^{th} Percentile Speed for Treatment Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.99	- 1.26 to - 0.72
Time (Day and Night)	Day – Night	- 0.25	-0.524 to 0.02
Speed Limit (mph) (55, 45, 40, and 35)	55 – 45	13.77	13.20 to 14.33
	55 – 40	16.85	16.19 to 17.50
	55 – 35	19.12	18.30 to 19.93
	45 – 40	3.08	2.68 to 3.48
	45 – 35	5.35	4.72 to 5.98
	40 – 35	2.27	1.56 to 2.98

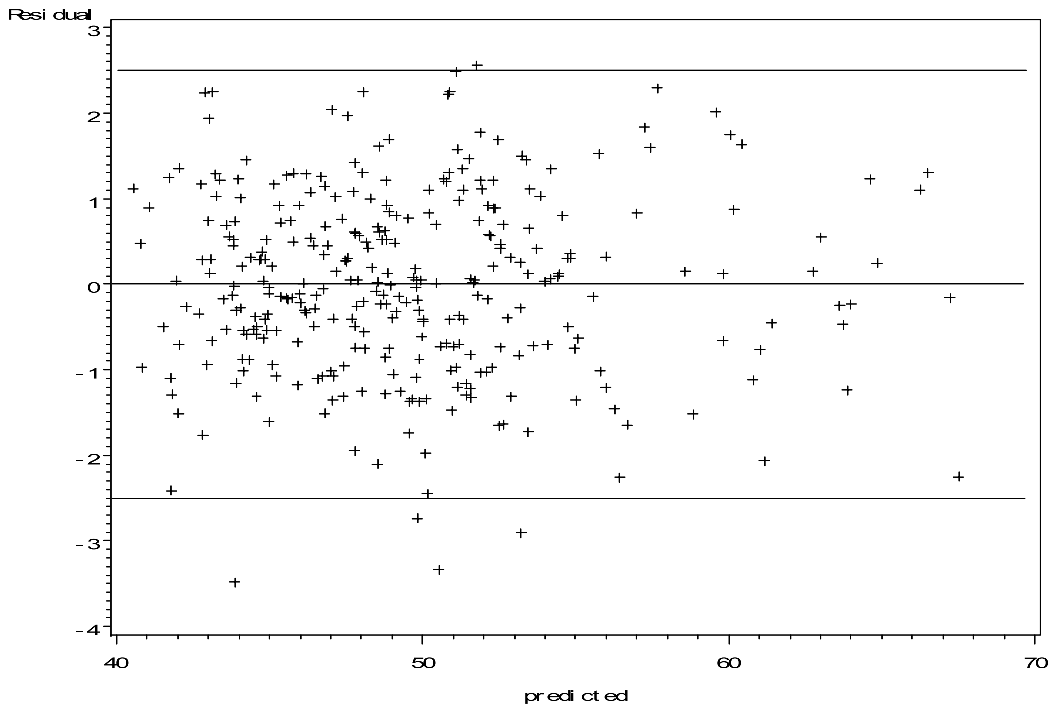
<Table 25> Analysis of Variance for 85th Percentile Speed for Comparison Sites

Effect	Degree of Freedom	Mean Square	F-value	p-value
Period	1	3.653	1.45	0.2312
Time	1	1.124	0.45	0.5056
Speed Limit	2	1582.467	36.32	< 0.0001
Site(Speed Limit)	37	43.568	17.27	< 0.0001

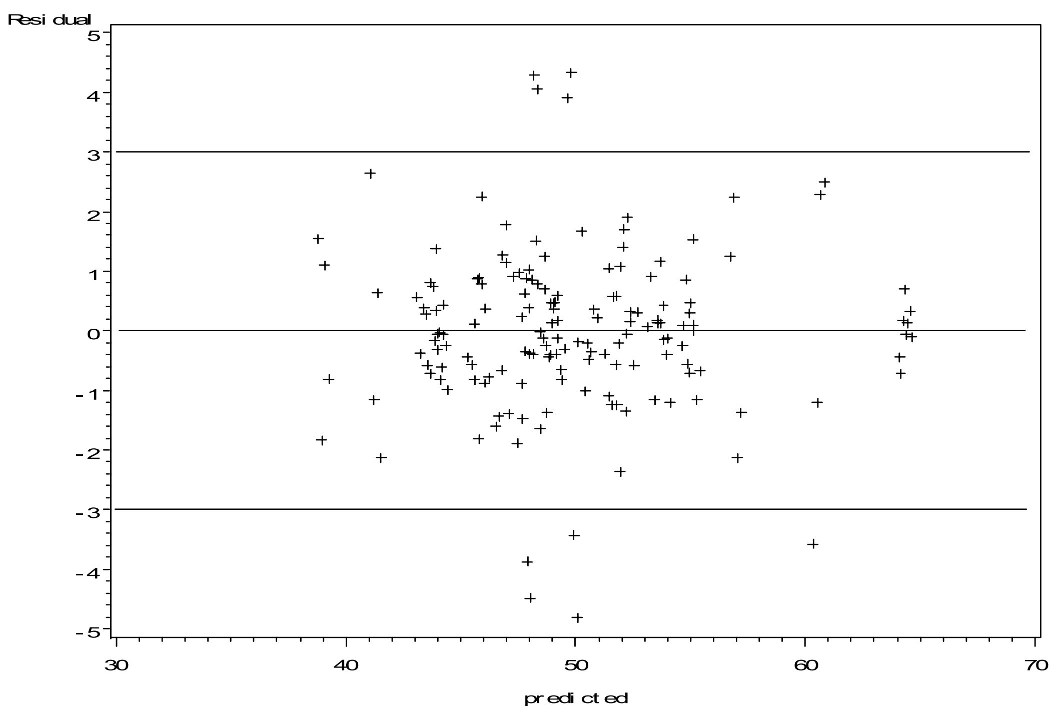
<Table 26> Effect of Each Factor on 85th Percentile Speed for Comparison Sites

Effect	Difference	Estimate (mph)	95% confidence (mph)
Period (Before and After)	After – Before	- 0.30	- 0.80 to 0.20
Time (Day and Night)	Day – Night	- 0.16	- 0.66 to 0.33
Speed Limit (mph) (55, 45, and 35)	55 – 45	12.58	11.62 to 13.54
	55 – 35	18.05	17.03 to 19.07
	45 – 35	5.47	4.90 to 6.03

As before, we checked whether normal distributions were appropriate or not, shown in Figures 29 and 30. Since the plot shows a constant pattern of residual versus predicted value, we considered the assumption of normal distribution as being appropriate.



<Figure 29> Residual vs. Predicted Plots for Treatment Sites

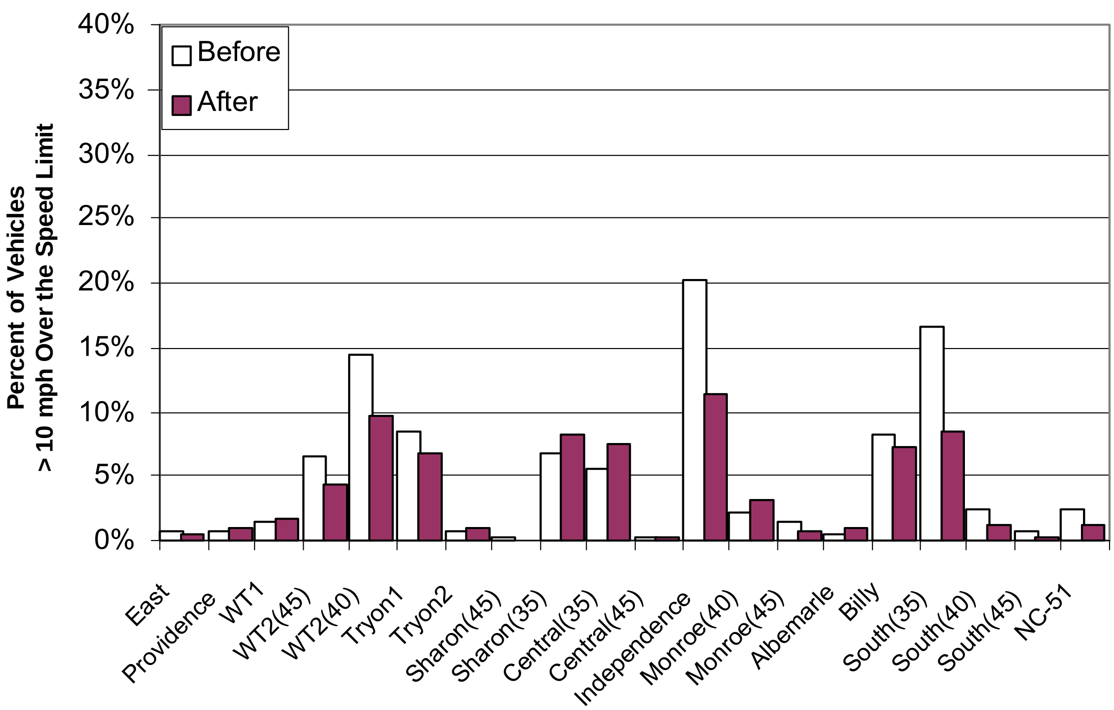


<Figure 30> Residual vs. Predicted Plots for Comparison Sites

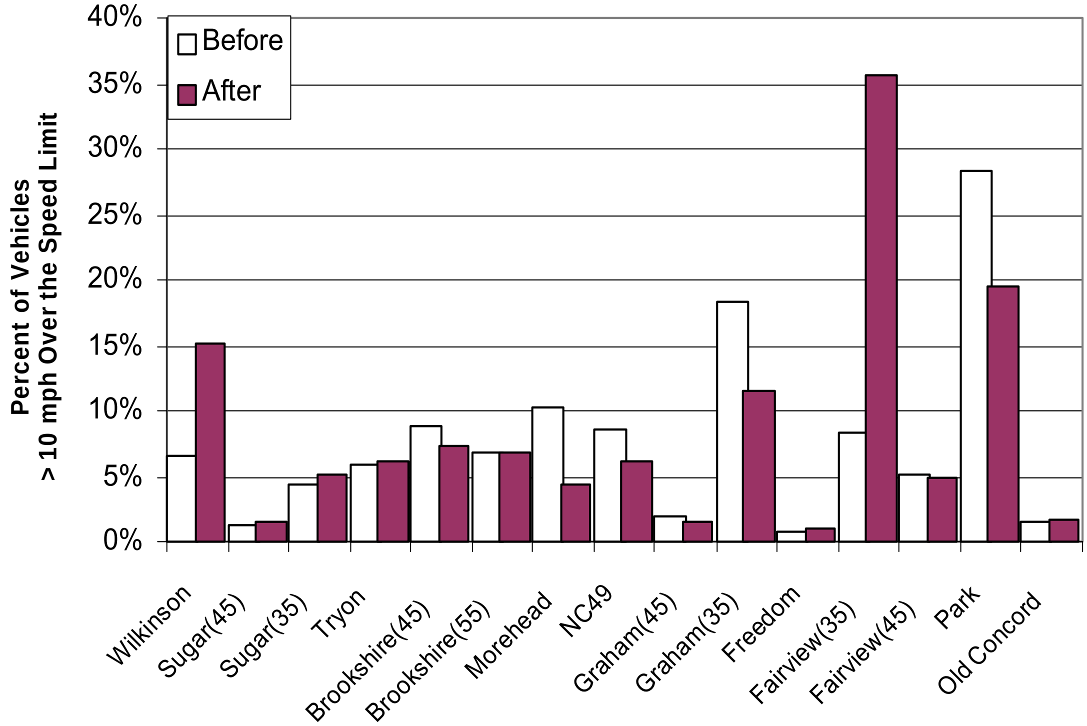
Logistic Regression Model

Percentage Vehicles more than 10 mph over Speed Limit

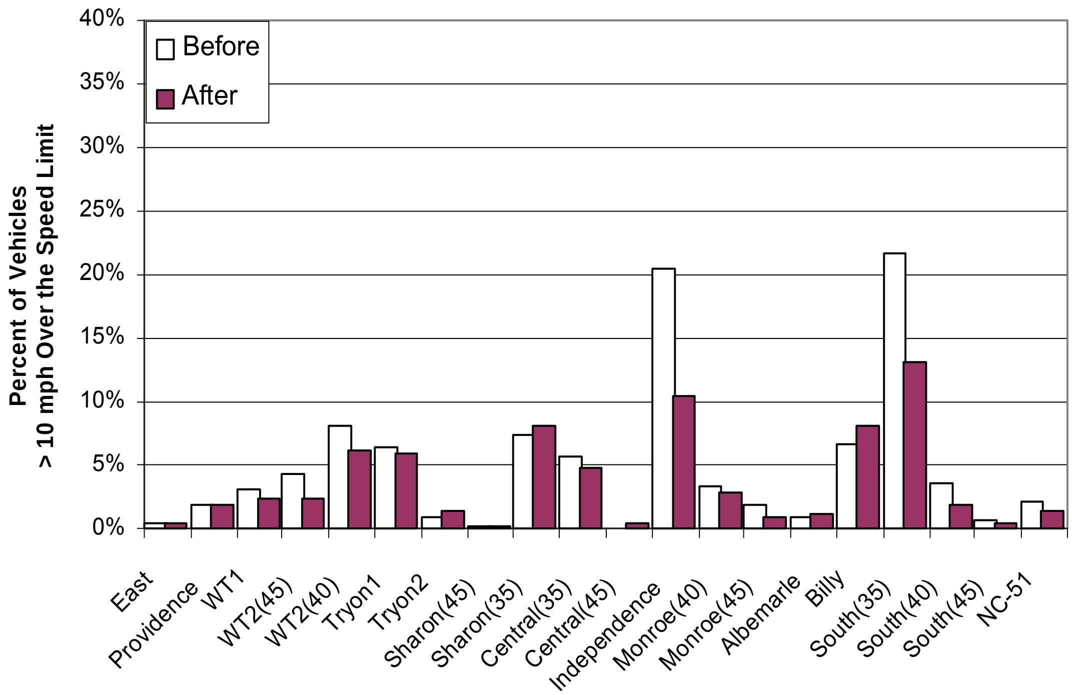
Figures 31, 32, 33, and 34 show the percentages of vehicles more than 10 mph over the speed limit for the 'before' and 'after' periods for the fourteen treatment corridors and eleven comparison corridors. The figures show that while small increases in the percentages occurred at a few of the treatment corridors, the speeding percentages in the 'after' periods for daytime and nighttime decreased at most of the treatment sites compared to the 'before' periods. Of the treatment corridors, the Independence corridor and the South corridor with the 35 speed limit appeared to have substantial decreases in the speeding percentages. There were about the same numbers of sites with increased speeding percentages as with decreased speeding percentages. Of the comparison sites, the increase in the speeding percentage in the Fairview corridor was the largest.



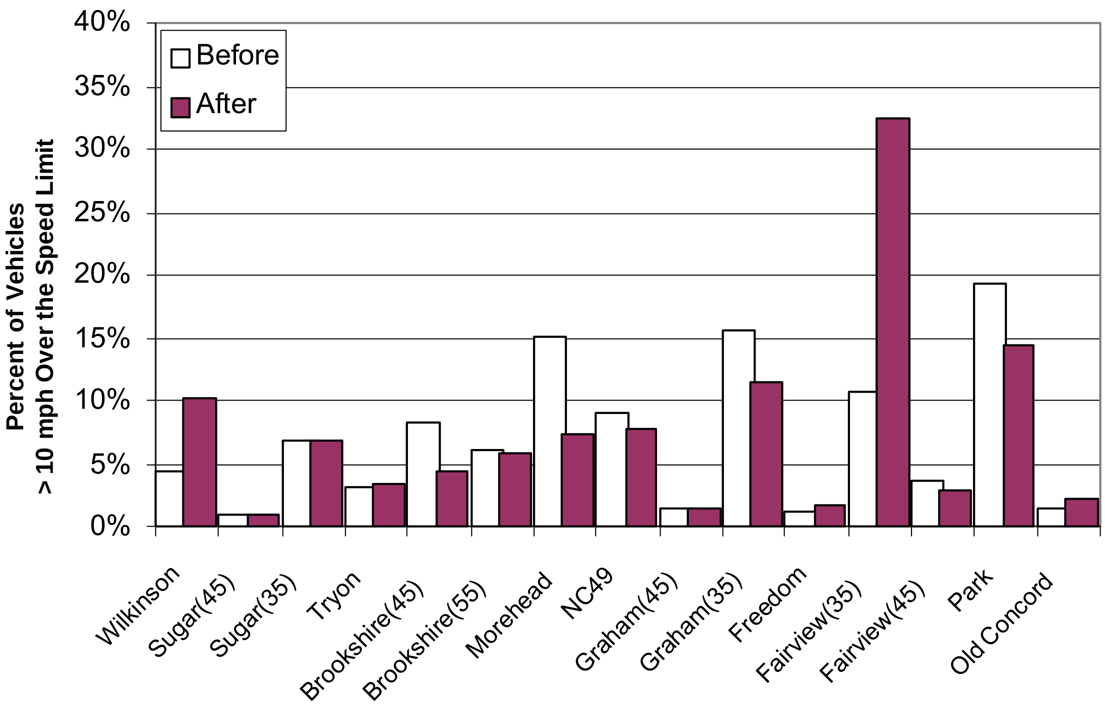
<Figure 31> Percentage of Vehicles More than 10 mph over Speed Limit at Treatment Sites during Daytime



<Figure 32> Percentage of Vehicles More than 10 mph over Speed Limit at Comparison Sites during Daytime



<Figure 33> Percentage of Vehicles More than 10 mph over Speed Limit at Treatment Sites during Nighttime



<Figure 34> Percentage of Vehicles More than 10 mph over Speed Limit at Comparison Sites during Nighttime

To quantify statistically the changes in speeding percentages at the treatment sites and comparison sites between the two periods, logistic regression models were used because the dependent variable is a percentage. The applied model was:

$$Logit(\pi) = \beta_0 + \beta_1 \times time + \beta_2 \times period + \beta_3 \times test + \beta_4 \times test \times period + \beta_5 \times test \times time$$
$$+ \beta_6 \times time \times period + \beta_7 \times test \times time \times period + \beta_8 \times site(test)$$

The dependent variable was the percentages of vehicles more than 10 mph over the speed limit and independent variables were: site (20 corridors in treatment sites and 15 corridors in comparison sites), period ('before' and 'after'), time (day and night), and test (treatment and comparison).

The site variables were considered as a random effect factor, nested within the levels of the test variable (treatment sites and comparison sites). We also evaluated whether there are differences in speeding percentages according to the level of the other factors using interaction terms between each factor.

The logistic model was performed using PROC GENMOD (a generalized linear model procedure) in SAS. The built-in link function was given as a logit function and a binomial distribution was adopted in the SAS procedure. Like the previous regressions, if the independent variables and interaction terms were not statistically significant, those would be dropped from the full model, and the process continued to obtain the best model.

Tables 27 and 28 summarize the results of the logistic regression using SAS. A large deviance or large p-value (> 0.75) indicates either that the model is inappropriate or the test is not powerful enough to pick up the inadequacies. So, Table 27 shows that there is no evidence that the model is inadequate because of large deviances. Table 28 shows the estimation of each factor on the speeding percentages through the logit model. The best estimated logistic model from Table 28 is as follows:

$$\begin{aligned} Logit(\pi) = {} & -2.444 + 0.0829 \times time + 0.4384 \times period + 0.0902 \times test - 0.4450 \times test \times period \\ & + 0.1271 \times test \times time + \beta_8 \times site(test) \end{aligned}$$

The relative changes of speeding percentages between the treatment sites and comparisons sites could be calculated by simply taking the exponent for the best estimated logistic model. This effort was performed through the "Contrast Estimate" function in SAS. As Table 29 shows, the percentage of speeding for the 'before' periods was evaluated as 1.55 times the percentage of speeding for 'after' periods at the treatment sites. This means that the percentage of speeding for 'after' periods reduced by 55% compared to 'before' periods. The 95% confidence limits of the decrease are between

56% and 54%. For the comparison sites, it was estimated that the speeding percentage in the 'before' periods was 0.993 times the percentage of speeding for 'after' with 95% confidence interval ranging from 0.983 to 1.003, so that change is not significant statistically.

<Table 27> Criteria for Assessing Goodness of Fit

Criterion	DF	Value	Value / DF
Deviance	94	20105.5386	203.0862
Scaled Deviance	94	20089.6471	203.0862
Pearson Chi-Square	94	20089.6471	203.0862
Scaled Deviance	94	20089.6471	203.0862

<Table 28> Effect of each Factor on Speeding Percentage

Variable	DF	Coefficient	Standard Error	95% Confidence Limit		Pr > ChiSq
Intercept	1	-2.4437	0.0100	-2.4634	-2.4241	< 0.0001
Time (Day=1, Night=0)	1	0.0829	0.0049	0.0734	0.0925	< 0.0001
Period (Before=1, After=0)	1	0.4384	0.0045	0.4295	0.4473	< 0.0001
Test (Comparison =1, Treatment =0)	1	0.0902	0.0144	0.0619	0.1184	< 0.0001
Test*period	1	-0.4450	0.0070	-0.4588	-0.4313	< 0.0001
Test*time	1	0.1271	0.008	0.1114	0.1428	< 0.0001

<Table 29> Contrast Estimate Results

Label	Estimate	Standard Error	Confidence Limits (95%)		Pr > Chisq
Exp ('Before' vs. 'After' for treatment sites)	1.5502	0.0070	1.5365	1.5640	< 0.0001
Exp ('Before' vs. 'After' for comparison sites)	0.9934	0.0053	0.9830	1.0038	0.2125

SUMMARY AND DISCUSSION

Speed data were collected at 80 points along the treatment corridors and 40 points in the comparison corridors approximately one year before implementing speed cameras and then approximately two months after speed cameras began enforcing. Through GLM and Logistic Regression models, the following were analyzed: mean speeds, median speeds, 85^{th} percentile speeds, and the percentage of vehicles exceeding the speed limit by more than 10 mph after implementing speed camera enforcement. The following patterns have emerged:

- Most of the corridors had significant differences in variance between the 'before' and 'after' periods, but there were no consistent patterns in whether the lower variance was found in the 'before' or the 'after' period.
- Most of the treatment sites had mean speed reduction experience after camera installation while the comparison sites did not demonstrate a consistent pattern of mean speed change.
- While there were no significant mean speed differentials between 'before' and 'after' periods at the comparison sites, mean speeds in the treatment sites declined significantly by an average of 0.91 mph.
- Median and 85^{th} percentile speeds decreased significantly by 0.88 mph and 0.99 mph, respectively, at the treatment sites in the 'after' period.
- The percentage of vehicles exceeding the speed limit by 10 mph or more decreased significantly by an average of 55 % at the treatment sites compared to the comparison sites.

ANALYSIS OF COLLISIONS

INTRODUCTION

This chapter reports on our evaluation of police reported collisions at treatment and comparison sites before and after kick-off of the automated speed enforcement program. As mentioned previously, we evaluated the automated speed enforcement program using the methodology presented in Chapter 9 of Ezra Hauer's text, "Observational Before-After Studies in Road Safety *(37)*." This study method was determined to be the most appropriate method for this case provided that the comparison sites were appropriately tested for similarity to the treatment sites before the analysis.

Following the collision analysis, trend analyses were conducted to answer such questions as how the collision frequency varies over time for each site, how many collisions occurred in each type of site by collision type, what was crash severity during day and night time period, etc. The trend analysis is reported in the next chapter of the report.

STUDY SITE AND COLLISION DATA

As described above, fourteen segments were chosen as treatment sites and eleven segments as comparison sites. These sites were dispersed throughout the City. The collision data were the counts of police reported accidents in the City of Charlotte between 2000 and 2004. Collision data for treatment sites and comparison sites are categorized into "before" periods and "after" periods; the "before" period covered January 2000 to July 2004 and the "after" period was from September 2004 to December 2004. Since August 2004 was the period when the speed cameras were deployed at treatment sites, this month was excluded from the collision analyses. At the time of this report collision data were not available for 2005. The collision analysis will be updated using 2005 collision data in a follow-up report in the near future.

Collision data were provided in a Microsoft Access database format by Charlotte. Queries and unions were made to the data to sub-divide the data properly into treatment and comparison groups. One of the problems our group encountered involved the disposition of a collision that happened at an intersection of two different corridors (i.e., where a treatment corridor crosses a comparison corridor). We decided that a single collision at an intersection of this type would be counted once in each corridor grouping. In addition, we had a problem with different names for one particular roadway. Our group decided to combine collisions along a corridor with different names into a single roadway name that could be depicted for any one of the various names (i.e., Hwy. 51 = Hwy. 51 (Pineville-Mathews Road). This was important in completing our collision trend analysis (reported in the next chapter) because it looked at each corridor individually to identify where trends were taking place. Appendix D gives a diagram of the logic in making each of the queries and unions from the original queries and provides tables showing how to overcome these problems should Charlotte choose to further analyze trends in the future.

USING A COMPARISON GROUP

Understanding of Potential Problems

The research team conducted a "before and after with comparison sites" type of analysis on the collision data. This analysis method is found in Chapter 9 of Ezra Hauer's text, "Observational Before-After Studies in Road Safety *(37)*." Data from the "before program" time periods will be used to estimate what the collision patterns would have been in the "after program" period without the program in place. The comparison sites will be needed to help make adjustments to those estimates for historical and seasonality biases.

A history bias occurs when some event not connected with the evaluation affects the chosen measures during the evaluation period. For instance, a rise in gasoline prices may lead to less travel which may lead in turn to fewer collisions during the study period. We would assume that both comparison and treatment sites would be affected in the same manner by an event such as this. We are not sure whether there have been or will be such events during this evaluation period, but comparison sites are a good safeguard against them should they occur.

An important subset of history bias is seasonality bias, which occurs when collision trends are affected by changes in weather and similar patterns. Collision data collected in an "after" period of only four months (as is the case in our study) during the Fall and Winter of 2004 could be biased because collision frequencies are likely higher during those months than the previous months of 2004. Or, there could have been an important change in the weather from year to year (i.e., 2003 may have had more snow and ice occurrences than 2004). However, seasonality is virtually eliminated using comparison sites because all sites in the City of Charlotte would likely be affected by any variation in the normal weather pattern.

One of the biggest issues with using a comparison group methodology is the potential for affects caused by regression-to-the-mean. As noted in the evaluation plan chapter above, we will provide justification for use of this methodology by showing that regression-to-the-mean effects are limited, at best. To do this, the research team analyzed a subset of the before data that includes only the time from January 2003 to July 2004. This data set does not include collisions that the Charlotte DOT used in determining treatment locations (January 1999 – December 2001). We did not include collision data from 2002 simply to provide additional buffer. An analysis of the data from only 2003 and 2004 should give an indication if the effects of regression-to-the-mean are present in our overall analysis using data from 2000 to 2004. If findings are similar, we can assume that regression-to-the-mean was likely negligible.

We tested the comparison sites using odds ratios to see if they had similar collision trends through time during the before period as the treatment sites. As readers will see, the comparison sites did have similar trends to the treatment sites, so they will likely account for any history bias very well.

At the time we began our evaluation, the City of Charlotte had already chosen comparison sites for the evaluation and collected collision and speed data for them. Our team thought at the onset of the project that we might want more of them. However, at this point, having carefully examined the speed and collision data from the treatment and comparison sites from the lengthy before period, we have concluded that no additional sites are necessary. In almost all aspects that we examined, the comparison sites acted similarly (with respect to collisions) to the treatment sites. Therefore, we determined that the analysis methodology chosen was fair given the constraints of the project.

Adjustments Needed

Besides using the data from comparison sites to account for history biases in the evaluation, Hauer recommends that we account for many factors directly. Two of these factors are traffic volume and time duration from before and after periods. However, having looked at the available data, we have determined that we will account for these factors indirectly using comparison sites for the following reasons:

- Traffic volumes are typically good indicators of traffic safety on roadways. As traffic volumes increase, the likelihood of a collision increases. Although the exact correlation of traffic to collisions varies from site to site, the relationship does exist and we should attempt to account for it. In this study, reliable traffic volumes were not available in the before and after periods for all sites in the treatment and comparison groups. We did not want to make adjustments using unreliable data. Instead, our group assumed that traffic flows changed within the comparison and treatment groups at a similar rate during the study period, and the comparison sites accounted for the change in traffic flow indirectly. A look at a map of the city displaying the treatment and comparison corridors shows that it would hardly be possible for significant changes in traffic flow to occur at one type of site without also affecting the other type of site.
- Time duration is one of the easiest factors to account for directly. Collisions in the after period are multiplied by a ratio of before to after time period duration in an attempt to correct for smaller sample sizes in the after period. Because our sample in the after period included only data from September 1 to December 31st 2004, our team would have had to pare down data in the before period during the same months in order to analyze like months and eliminate seasonality biases. As with traffic volumes, our team thought that it would be better to account for

changes in time indirectly instead of essentially eliminating large amounts of data. Seasonality will not be a problem because comparison sites should be affected in the same way as treatment sites by seasonal variability.

Calculating the Sample Odds Ratios

Following meetings with officials from the City of Charlotte and the Charlotte Department of Transportation, our group decided that the comparison group methodology was the likely study of choice, provided that comparison and treatment sites were comparable. As Hauer (37) suggests, we calculated sample odds ratios (o) to check whether the selected comparison group is suitable to compare to the treatment group, or whether other comparison sites are needed. Odds ratios were calculated from the collision counts using the following equation:

$$o = \frac{\frac{(KN)}{(LM)}}{\left(1 + \frac{1}{L} + \frac{1}{M}\right)}$$

where,

K = the collision counts for treatment sites (previous time period)
L = the collision counts for treatment sites (current time period)
M = the collision counts for comparison sites (previous time period)
N = the collision counts for comparison sites (current time period)

The primary indicator of similarity between both groups of sites is total collisions. Collisions by year in the before time period can be found in Table 30. The first odds ratio calculation in this table, between the years 2000 and 2001, for total collisions is shown below for clarity.

$$o = \frac{\frac{(KN)}{(LM)}}{\left(1 + \frac{1}{L} + \frac{1}{M}\right)} = \frac{\frac{(7{,}015 * 2{,}646)}{(7{,}132 * 2{,}471)}}{\left(1 + \frac{1}{7{,}132} + \frac{1}{2{,}471}\right)} = 1.053$$

Table 30 shows odds ratios by year and the mean of the odds ratios, *m(o)*. The mean of the odds ratios is very close to 1 with a suitably small standard deviation about the mean. Therefore, the selected comparison group appears appropriate for use with the treatment group relative to implementing speed cameras. Since both groups are apparently following the same trends, whatever causes changes in safety at the treatment sites in the after period will also most likely do so at the comparison sites.

<Table 30> Mean of Odds Ratios for Collision Frequency

Year	Treatment sites	Comparison sites	Odds ratio
2000	7,015	2,471	-
2001	7,132	2,646	1.053
2002	7,018	2,513	0.965
2003	6,710	2,396	0.997
Average			1.0047
Std. Dev.			0.02228

This step in the comparison group methodology is important to the validity of this choice of study. One cannot state, with any certainty, whether a countermeasure implemented at treatment sites decreases or increases the probability of a collision by association to a pool of comparison sites unless they are proven comparable.

Calculations and Significance Testing

Before a before-after study can be completed, an understanding of the measures of effectiveness (MOE) is needed. All before-after studies consist of two primary tasks:

prediction of expected collisions (π), and estimation (λ) of the collision effect. These are used to calculate the two MOE's.

The first MOE is the reduction in the expected number of collisions, δ. The expected number of collisions (π) is found by multiplying the collisions in the before period at treatment sites by a factor r_c. This factor approximately represents the ratio of after collisions divided by before collisions at comparison sites. Since comparison sites were found to act in a similar manner to that of treatment sites in the previous section, we can use this factor to determine the collisions that would have been expected to take place in the after period had the countermeasure not been implemented. This is calculated as:

$$\delta = \pi - \lambda \text{ , where}$$

$$\pi = K \cdot r_c \text{ and } \lambda = L$$

The variance, VAR {δ}, assuming π and λ are statistically independent, is calculated as:

$$VAR\{\delta\} = VAR\{\pi\} + VAR\{\lambda\}$$

The second MOE is the index of effectiveness, θ. This is calculated as the ratio of what safety was with the treatment to what it would have been without the treatment, and is calculated as:

$$\theta = (\lambda / \pi) / [1 + VAR\{\pi\} / \pi^2]$$

The variance, VAR {θ}, is calculated as:

$$VAR\{\theta\} = \theta^2 [(VAR\{\lambda\}) / \lambda^2 + (VAR\{\pi\}) / \pi^2)] / [1 + VAR\{\pi / \pi^2)]^2$$

Both δ and θ were computed for this analysis and are shown in the next section.

Analysis Results

Prediction using a comparison group accounts for many of the problems associated with numerous studies using a simple before-after analysis method. It is also an improvement on the prediction method using causal factors because it accounts for flaws such as seasonality and historical effects. Although random selection of treatment and control sites was not possible, as discussed above it is likely that the effects of regression-to-the-mean bias are negligible in this study. We will attempt to account for any of these affects following an overall analysis.

Table 31 shows a screen shot of the analysis worksheet we provided to Charlotte. Four main sections define this worksheet, and are explained below.

- The top left section represents the number of police reported collisions in the before and after periods for treatment and comparison groups. The letters "K, L, M, and N" are denoted in red and are used in many of the equations in this figure.
- The upper right section refers to the calculation of the sample odds ratio. This calculation lets us know whether our comparison group is comparable to the treatment group and was defined in a previous section.
- The bottom left section calculates the expected and predicted numbers of collisions and the actual number of collisions in the after period for treatment sites. This was explained in the previous section.
- The bottom right section calculates the net effect on safety based on predicted and actual number of collisions. This was explained in the previous section.

<Table 31> Findings using a Comparison Group Methodology –Total Collisions from January 2000 to December 2004

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	Treatment	**Comparison**
Before	31185 - **(K)**	11275 - **(M)**
After	1767 - **(L)**	725 - **(N)**

Sample Odds Ratio	
m(*o*) =	1.0047
$s^2(o)$ =	0.001985
s(o) =	0.022276
VAR (ω) =	0.000

Estimates	
$\lambda_{treatment}$ =	1767
r_c =	0.064
π =	2005
VAR (λ) =	1767
VAR (π) =	6031

Effect on Safety	
δ =	238.1
Θ =	0.880
σ (δ) =	88.3
σ (Θ) =	0.040

Reduction of	**238**	**+/-**	**88.3**	**collisions**	**or**
reduction of	**12%**	**+/-**	**4.0%**	**from the**	
expected # of collisions					

The final result is an estimate that overall, the automated speed enforcement program reduced total collisions by 12% from what they would have been in the treatment corridors from September to December of 2004. These findings are based on a before and after data set from January 2000 to December 2004. This is an important reduction, but readers must keep in mind the serious limitations of the study (such as short duration of the after period, intense media attention on the program, and others) before attempting to generalize this finding.

As noted previously, one of the shortfalls of the comparison group methodology is its ability to account for regression-to-the-mean. An analysis of data from January 2003 to December 2004 likely excludes the effects that regression-to-the-mean would have on the overall analysis. Table 32 shows the same analysis as before; however, it does not include data from January 2000 to December 2002.

<Table 32> Findings using a Comparison Group Methodology –Total Collisions from January 2003 to December 2004 –Accounting for Regression-to-the-Mean

CHAP 9 - USING A COMPARISON GROUP

	Treatment	Comparison
Before	10020 - **(K)**	3645 - **(M)**
After	1767 - **(L)**	725 - **(N)**

Sample Odds Ratio	
m(*o*) =	1.0047
$s^2(o)$ =	0.001985
s(o) =	0.022276
VAR (ω) =	0.000

Estimates	
$\lambda_{treatment}$ =	1767
r_c =	0.199
π =	1992
VAR (λ) =	1767
VAR (π) =	6961

Effect on Safety	
δ =	225.5
Θ =	0.885
σ (δ) =	93.4
σ (Θ) =	0.043

Reduction of	**225**	**+/-**	**93.4**	**collisions**	**or**
reduction of	**11%**	**+/-**	**4.3%**	**from the**	
expected # of collisions					

The analysis of collisions excluding the 2000-2002 data seems to indicate a very similar finding to the previous overall analysis. It was estimated that there was an 11% decrease in total collisions from what would have been expected along treatment corridors from September to December 2004. The similarity in this analysis accounting for potential affects caused by regression-to-the-mean seems to indicate that our initial thoughts in our evaluation plan were correct – that is, that the data set was sufficiently large and covered a sufficiently large enough time period to dampen the effects, other factors were included in the selection process, and the early selection of treatment sites allowed for a sufficient amount of time in the before period following the selection of treatment sites. Based on this analysis, the affects of regression-to-the-mean in this case appear negligible. As noted in the previous overall analysis, readers must keep in mind the serious limitations of the study (such as short duration of the after period, intense media attention on the program, and others) before attempting to generalize this finding.

Specific analysis of the five most heavily-enforced corridors also appeared justified. These five corridors were discussed in a previous section outlining Charlotte's automated enforcement program. Specifically, it was noted that Independence Boulevard, Tryon Street, South Boulevard, Central Avenue, and Billy Graham Parkway accounted for approximately 90.4% of all citations issued by Charlotte. Table 33 shows an analysis using data from January 2000 to December 2004 with collision data from only the five sites mentioned above.

<Table 33> Findings using a Comparison Group Methodology –Total Collisions at Five Highly Enforced Corridors

CHAP 9 - USING A COMPARISON GROUP

	Treatment	Comparison
Before	14699 **(K)**	11275 **(M)**
After	810 **(L)**	725 **(N)**

14699 11275
810 725

Estimates	
$\lambda_{treatment}$ =	810
r_c =	0.064
π =	945
VAR (λ) =	810
VAR (π) =	1372

Sample Odds Ratio	
m(*o*) =	1.0284
s^2(*o*) =	0.000527
s(o) =	0.011481
VAR (ω) =	0.000

Effect on Safety	
δ =	135.1
Θ =	0.856
σ (δ) =	46.7
σ (Θ) =	0.045

Reduction of 135 +/- 46.7 collisions or
reduction of 14% +/- 4.5% from the
expected # of collisions

Analyzing these highly-enforced sites, it is estimated that automated speed enforcement reduced collisions by 14% from what they would have been in the treatment corridors from September to December of 2004. It appears that the extra enforcement of these sites led to a slightly bigger reduction in collisions than at the other sites, although the difference is not very significant. Again, readers must keep in mind the serious limitations of the study (such as short duration of the after period, intense media attention on the program, and others) before attempting to generalize this finding.

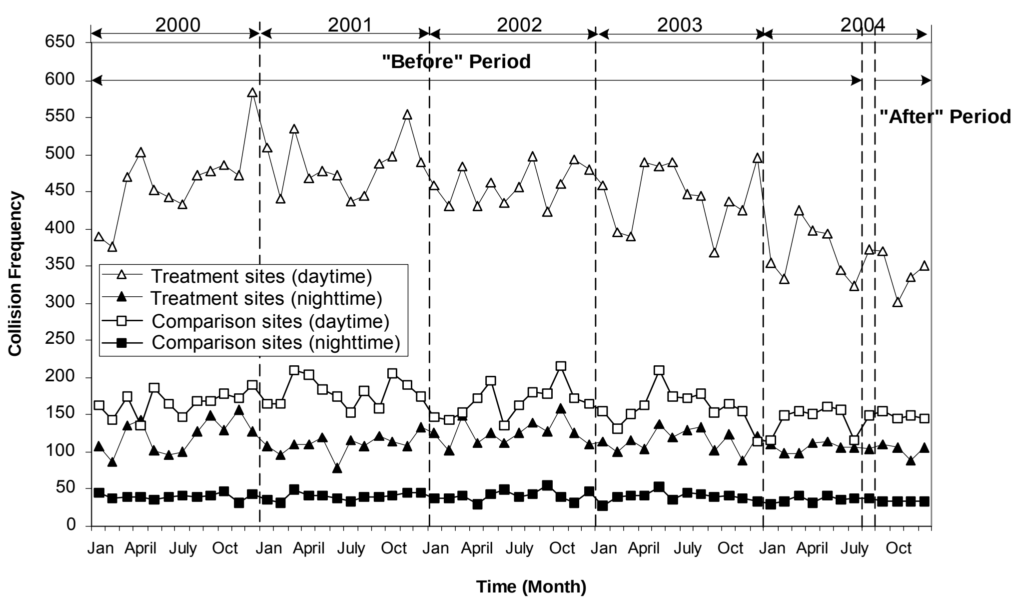
COLLISION TRENDS

INTRODUCTION

This section of the report describes patterns in collisions that occurred at treatment and comparison sites between 2000 and 2004. After completing the analysis of collisions described above, simple comparisons and trends in collision patterns were examined to see if we could better understand the effects of automated speed enforcement.

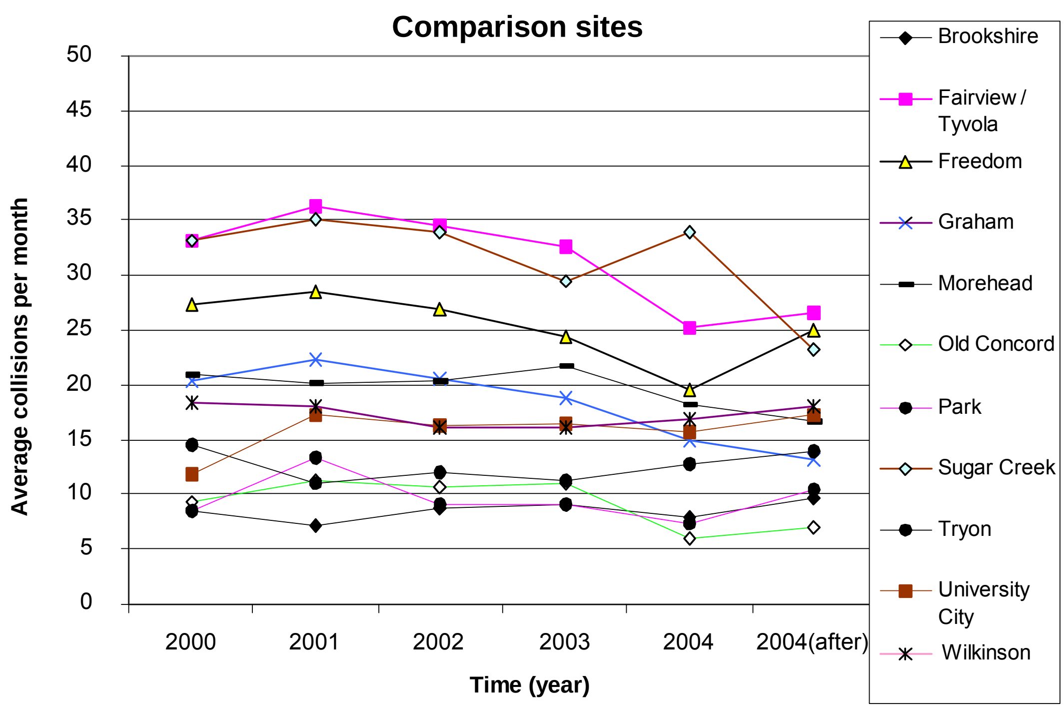
AVERAGE COLLISIONS

Figure 36 displays monthly collision patterns between the "before" period and the "after" period for daytime and nighttime for comparison and treatment sites. As shown in Figure 36, while the monthly collision pattern associated with nighttime for comparison sites were fairly constant, the patterns for the other conditions fluctuated. The monthly collision pattern for the treatment sites during daytime hours fluctuated heavily; monthly collisions appeared to decrease gradually at the beginning of 2004.



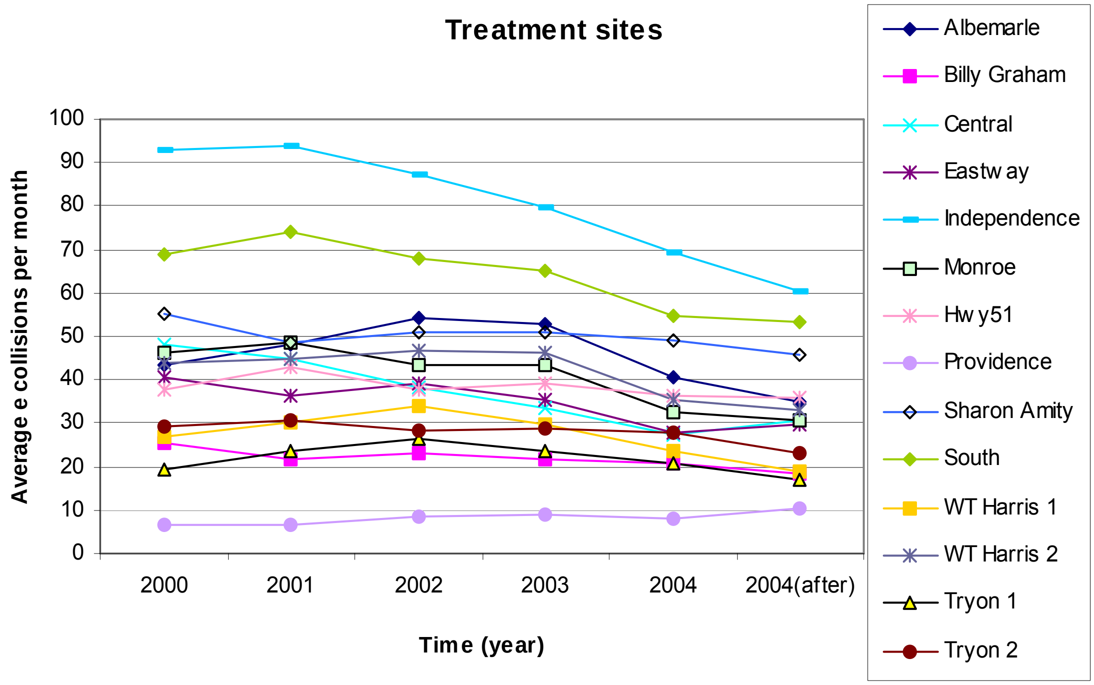
<Figure 35> Monthly Patterns of Collision Frequency

Figures 37 and 38 and Table 34 show average collisions per month by site. Figure 37 and Table 34 show that while average collisions for the "after" period had increased compared to the "before" period in five of comparison sites, the average collisions at the other sites had decreased. It also shows that while average collisions in the Park corridor was the lowest among comparison sites, the Fairview/Tyvola corridor and Sugar Creek were the highest, followed by the Freedom, Graham, Morehead/Queens/Providence, and other corridors.



<Figure 36> Collision Frequency of Each Comparison Site over Each Year

For treatment sites, Figure 38 and Table 34 show that the average collisions at all treatment sites, except the Providence corridor, had decreased in the "after" period compared to the "before" period, but the average collisions of some sites had decreased gradually during the study years. Figure 38 and Table 34 also indicate that the average collisions in the Independence corridor were the highest followed by the South, Sharon Amity, Albemarle, Monroe, WT Harris 2, and other corridors.



<Figure 37> Collision Frequency of Each Treatment Site over Each Year

<Table 34> Average Collisions per Month for All the Sites

	Before period						After period
Treatment site \ Year	2000	2001	2002	2003	2004	Average	2004
Albemarle	43.33	48.00	54.17	52.67	40.43	47.72	35.00
Billy Graham	25.58	21.92	23.00	21.92	20.57	22.6	18.25
Central	48.17	44.75	38.00	33.58	27.14	38.33	30.75
Eastway	40.33	36.42	39.33	35.17	27.86	35.82	29.75
Hwy51	37.67	42.92	37.83	39.17	36.29	38.78	35.75
Independence	93.00	93.83	87.17	79.67	69.43	84.62	60.25
Monroe	46.42	48.42	43.17	43.50	32.57	42.82	30.75
Providence	6.50	6.83	8.58	8.75	8.00	7.73	10.25
Sharon Amity	55.25	48.50	50.75	51.00	48.86	50.87	45.75
South	68.83	73.92	67.83	65.25	54.57	66.08	53.25
Tryon 1	19.33	23.58	26.33	23.75	20.57	22.71	16.75
Tryon 2	29.42	30.50	28.25	28.92	27.86	28.99	23.25
WT Harris 1	27.00	30.00	33.75	29.75	23.43	28.79	19.00
WT Harris 2	43.83	44.75	46.67	46.00	35.29	43.31	33.00
Comparison site \ Year	2000	2001	2002	2003	2004	Average	2004
Brookshire	8.58	7.25	8.67	9.08	7.86	8.29	9.75
Fairview / Tyvola	33.17	36.17	34.50	32.50	25.29	32.33	26.50
Freedom	27.33	28.58	27.00	24.42	19.57	25.38	25.00
Graham	20.33	22.25	20.58	18.75	14.86	19.35	13.25
Morehead	20.92	20.17	20.42	21.67	18.14	20.26	16.75
Old Concord	9.25	11.17	10.67	11.00	6.00	9.62	7.00
Park	8.50	13.33	9.08	9.08	7.43	9.48	10.50
Sugar Creek	33.17	35.17	33.92	29.50	34.00	33.15	23.25
Tryon	14.50	11.00	12.08	11.17	12.71	12.29	14.00
University	11.75	17.33	16.33	16.50	15.71	15.52	17.25
Wilkinson	18.42	18.08	16.17	16.00	16.86	17.11	18.00

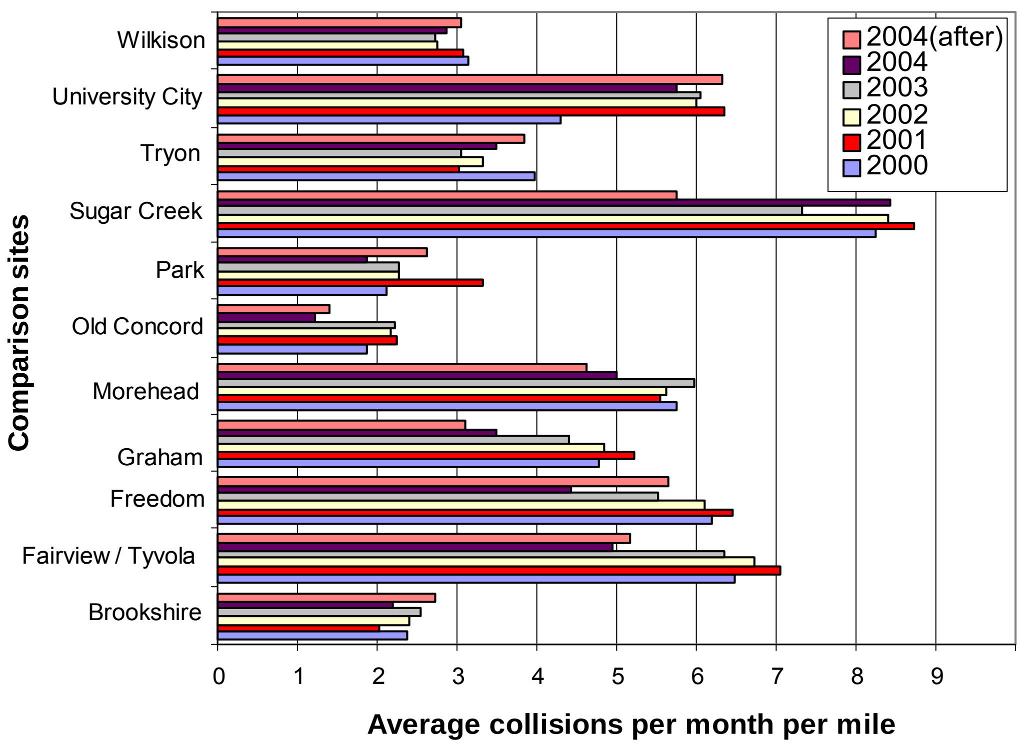
(shaded) Higher average collisions

COLLISION RATE AND INTERSECTION DENSITY

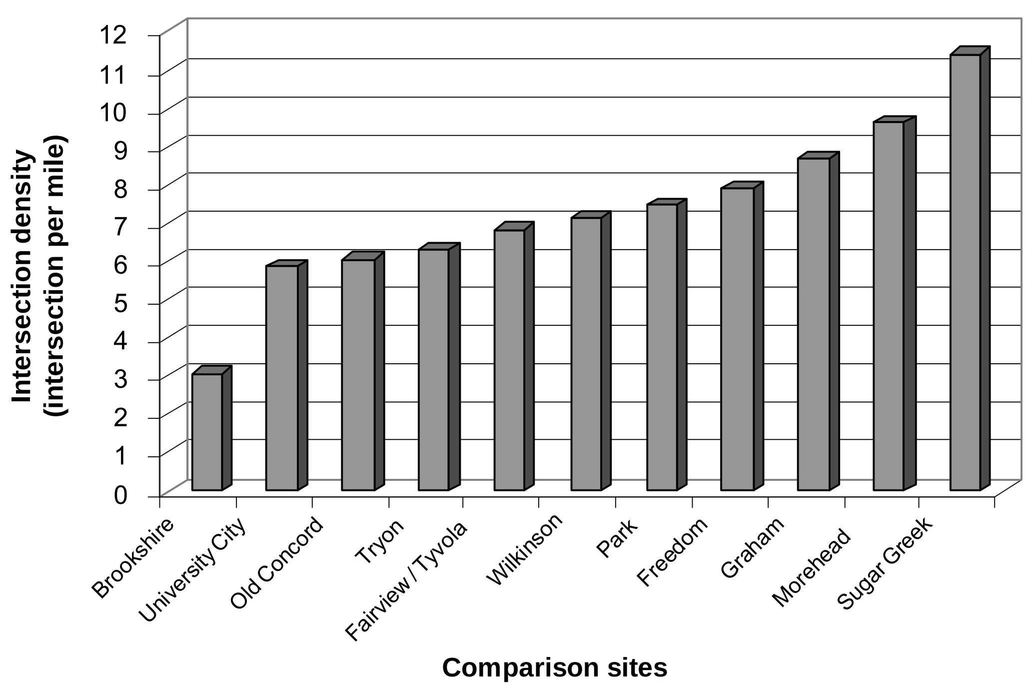
Figures 39 and 40 and Table 35 describe the average collisions per month divided by the length of each corridor. In addition to this collision rate, we also estimated the intersection density as the number of intersections in each corridor divided by the segment length and provide these data in Figures 41 and 42 and Table 35.

Figure 39 and Table 35 show that the highest collision rate over the study time for comparison sites was on the Sugar Creek corridor, followed by Fairview/Tyvola, Freedom, and University City corridors. The Old Concord corridor had the lowest rate among comparison sites at 1.85 average collisions/month/mile over the study period. In addition, Table 35 indicates that five of the comparison sites had higher average collision rates for the "after" period than for the "before" period. Figure 41 shows that most of the comparison sites have intersection densities above 6.0 intersections/mile, while the intersection density of the Brookshire corridor is the lowest.

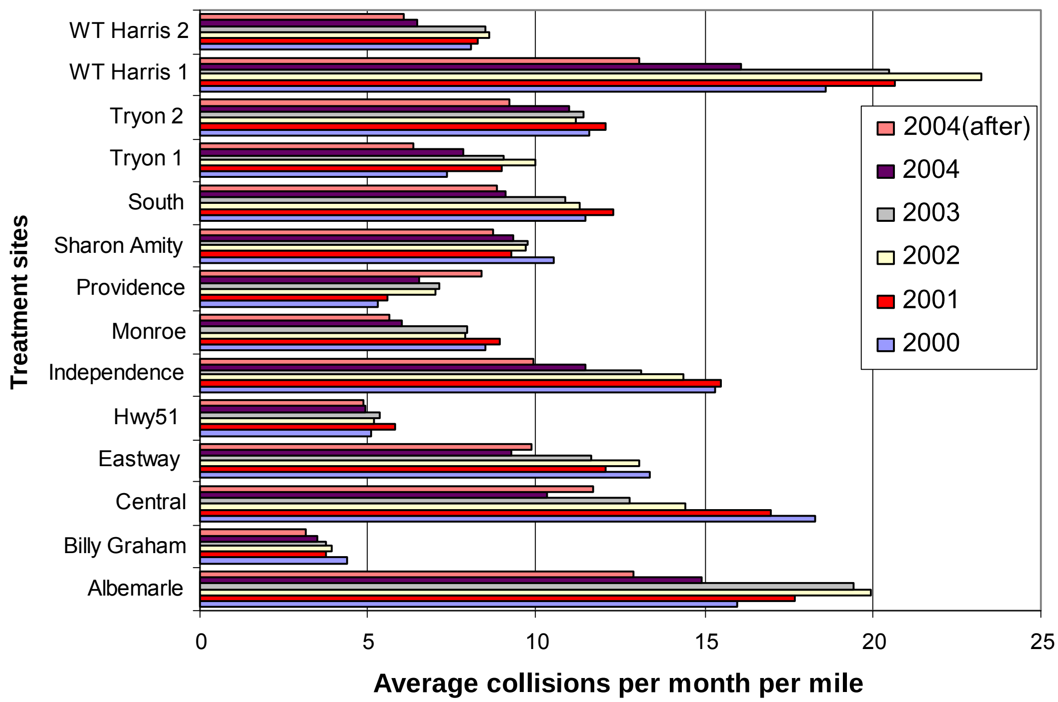
For treatment sites, Figure 40 and Table 32 show that most of the corridors have collision rates above 5.0 collisions/month/mile. All the treatment sites but the Providence, Eastway, and Central corridors had decreasing tendencies for the average collision rates in the "after" period compared to the "before" period. While the Billy Graham corridor has the lowest average collision rate of the treatment sites, the WT Harris 1 corridor has the highest average collision rate followed by the Albemarle, Central, Independence and Eastway corridors. Figure 42 shows that most of the treatment sites have intersection densities above 6.0 intersections/mile. It also indicates that the Billy Graham and the Tryon 1 corridor have the lowest intersection densities at 5.0 and 4.9, respectively.



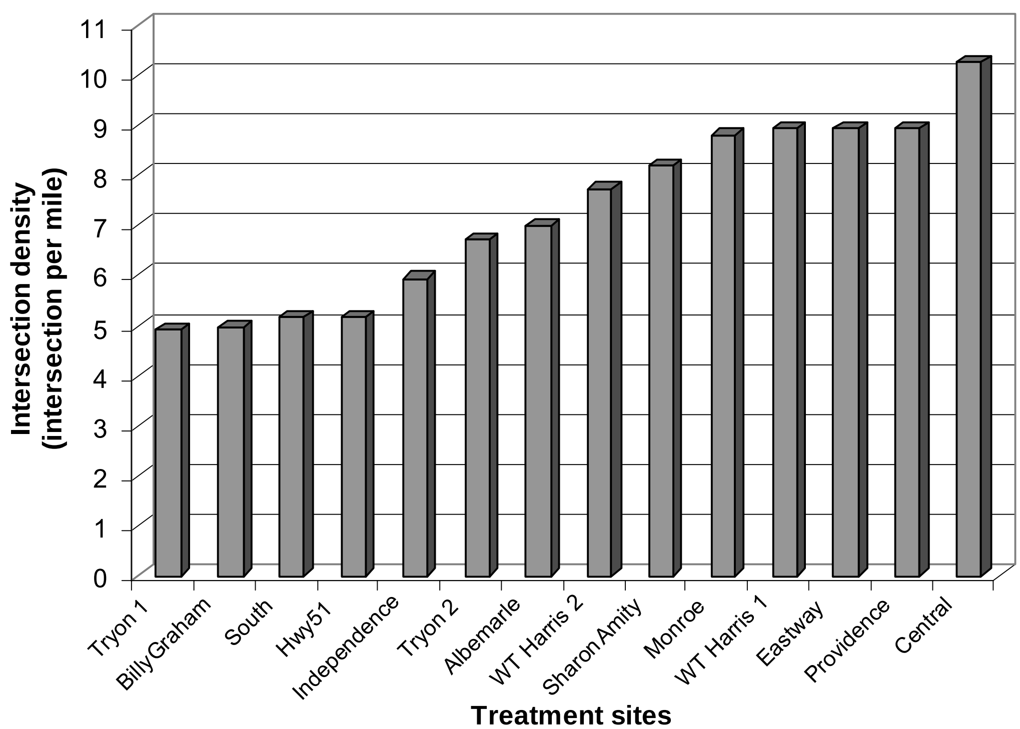
<Figure 38> Collision per Mile for Each Comparison Site



<Figure 39> Intersection Density for Each Comparison Site



<Figure 40> Collision per Mile for Each Treatment Site



<Figure 41> Intersection Density for Each Treatment Site

<Table 35> Collision Rate and Intersection Density for Each Site

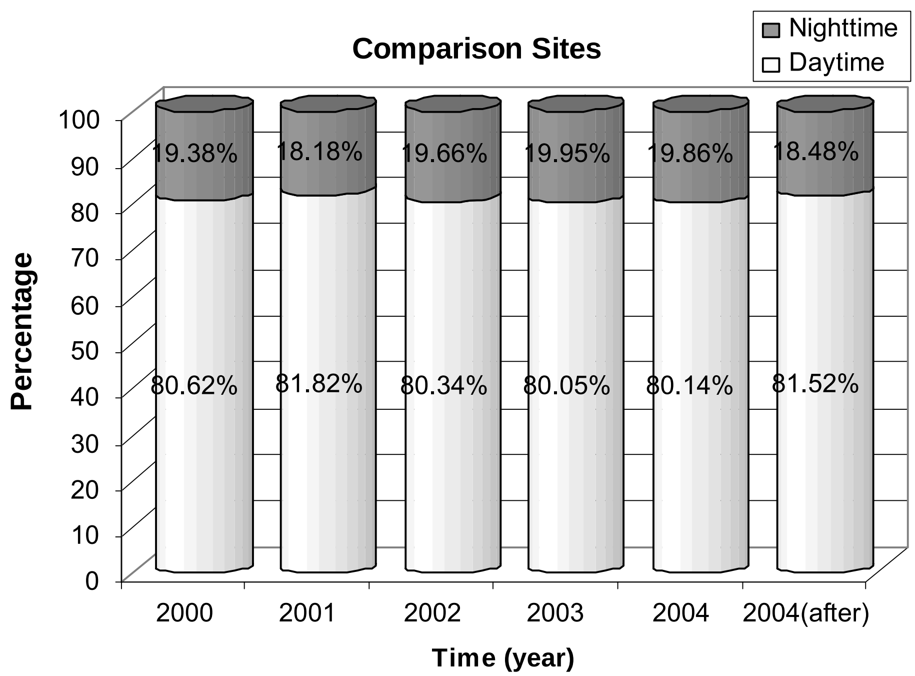
Site	Corridor	Intersection density	Average collisions per month per mile						
			Before period						After period
			2000	2001	2002	2003	2004	Average	2004
Treatment	Central	10.3	18.30	17.00	14.43	12.76	10.31	14.56	11.68
	Providence	9.0	5.30	5.57	6.99	7.13	6.52	6.30	8.35
	Eastway	9.0	13.37	12.07	13.04	11.66	9.24	11.88	9.86
	WT Harris 1	8.9	18.57	20.64	23.22	20.47	16.12	19.80	13.07
	Monroe	8.8	8.52	8.88	7.92	7.98	5.98	7.86	5.64
	Sharon Amity	8.2	10.52	9.24	9.66	9.71	9.30	9.69	8.71
	WT Harris 2	7.7	8.07	8.24	8.59	8.47	6.50	7.97	6.08
	Albemarle	7.0	15.97	17.69	19.97	19.41	14.90	17.59	12.90
	Tryon 2	6.7	11.61	12.04	11.15	11.41	10.99	11.44	9.17
	Independence	5.9	15.35	15.48	14.38	13.15	11.46	13.96	9.94
	Hwy51	5.2	5.13	5.84	5.15	5.33	4.94	5.28	4.86
	South	5.2	11.46	12.31	11.30	10.87	9.09	11.01	8.87
	Billy Graham	5.0	4.39	3.76	3.94	3.76	3.53	3.88	3.13
	Tryon 1	4.9	7.34	8.96	10.00	9.02	7.81	8.63	6.36
Comparison	Sugar Creek	11.4	8.23	8.73	8.42	7.32	8.44	8.23	5.77
	Morehead	9.6	5.76	5.55	5.62	5.97	5.00	5.58	4.61
	Graham	8.7	4.77	5.22	4.83	4.40	3.49	4.54	3.11
	Freedom	7.9	6.18	6.46	6.11	5.52	4.43	5.74	5.65
	Park	7.5	2.12	3.32	2.26	2.26	1.85	2.36	2.62
	Wilkinson	7.1	3.13	3.07	2.74	2.72	2.86	2.90	3.06
	Fairview /Tyvola	6.8	6.47	7.06	6.73	6.34	4.94	6.31	5.17
	Tryon	6.3	3.98	3.02	3.31	3.06	3.49	3.37	3.84
	Old Concord	6.1	1.87	2.25	2.15	2.22	1.21	1.94	1.41
	University City	5.9	4.31	6.36	5.99	6.05	5.76	5.69	6.33
	Brookshire	3.1	2.39	2.02	2.41	2.53	2.19	2.31	2.72

(shaded) Higher average collisions

OVERALL COLLISION FREQUENCY

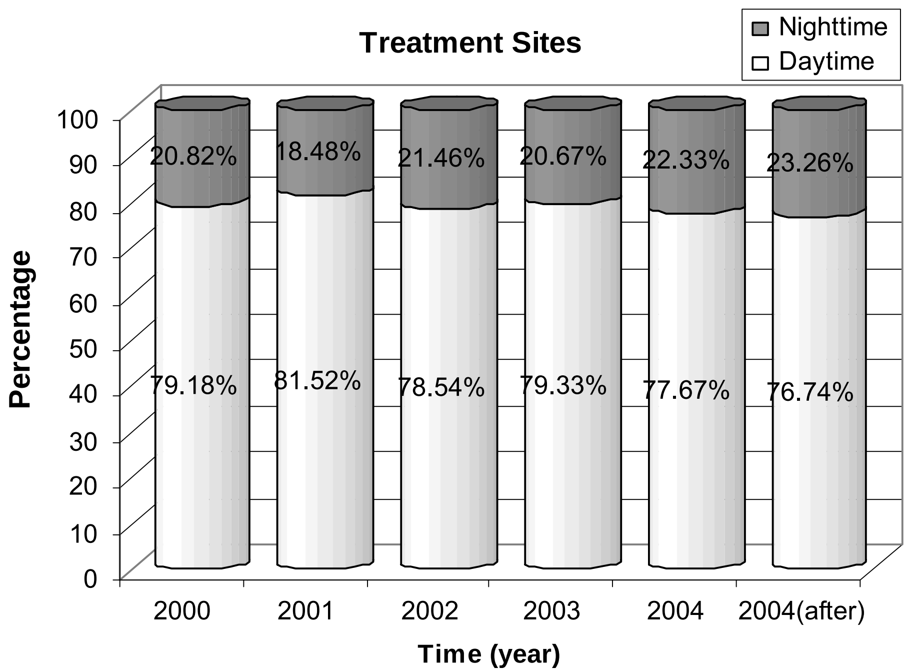
Figures 42 and 43 show the proportion of collisions occurring between daytime and nighttime hours across all the subject sites over the study years, and Table 36 displays collision frequencies with the collision percentages by time of day.

As shown in Figure 42 and Table 36, the collision proportion by daytime and nighttime in comparison sites held roughly constant over the study years. It also shows that just over 80% of collisions at comparison sites occurred during the daytime.



<Figure 42> Overall Collision Frequency by Time Period for Comparison Sites

Figure 43 and Table 36 show that, like the comparison sites, the collision proportion by each time of day at treatment sites held fairly constant over the study years. Figure 43 and Table 36 also show that just under 80% of collisions at the treatment sites occurred during daytime.



<Figure 43> Overall Collision Frequency by Time Period for Treatment Sites

<Table 36> Overall Collision Frequency

Site	Year	Total Collisions	Collision Frequency		Collision Percentage	
			Daytime	Nighttime	Daytime	Nighttime
Treatment Sites	2000	7,016	5,555	1,461	79.18	20.82
	2001	7,132	5,814	1,318	81.52	18.48
	2002	7,018	5,512	1,506	78.54	21.46
	2003	6,709	5,322	1,387	79.33	20.67
	2004	3,310	2,571	739	77.67	22.33
	2004 (after)	1,767	1,356	411	76.64	23.26
Comparison Sites	2000	2,471	1,992	479	80.62	19.38
	2001	2,646	2,165	481	81.82	18.18
	2002	2,513	2,019	494	80.34	19.66
	2003	2,396	1,918	478	80.05	19.95
	2004	1,249	1,001	248	80.14	19.86
	2004 (after)	725	591	134	81.52	18.48

As noted in a previous chapter describing Charlotte's automated enforcement program, automated speed enforcement was estimated by Charlotte officials to be enforcing much more heavily during daytime hours (approximately 75% of citations).

Comparing percentage of collisions during daytime and nighttime hours between treatment and comparison sites, it appears that daytime collisions at treatment sites are slightly lower than at comparison sites. However, this cannot be directly attributed to automated enforcement because the overall trend of daytime collisions at treatment sites before and after indicates this was true before the system was in place.

However, when looking at the difference (Δ) between daytime and nighttime collisions for treatment and comparison sites every year, the change in the after period of 2004 (4.78) when automated enforcement took place appears to be greatest among all years (Table 37). The greater difference during this period could support claims that greater daytime enforcement leads to decreases in collisions, however it is not definitive.

<Table 37> Comparing Differences Between Percentage of Daytime Collisions at Comparison and Treatment Corridors

	2000	2001	2002	2003	2004	2004 (after)
Comparison Corridors	80.62	81.82	80.34	80.05	80.14	81.52
Treatment Corridors	79.18	81.52	78.54	79.33	77.67	76.74
Change (Δ)	1.44	0.30	1.80	0.72	2.47	4.78

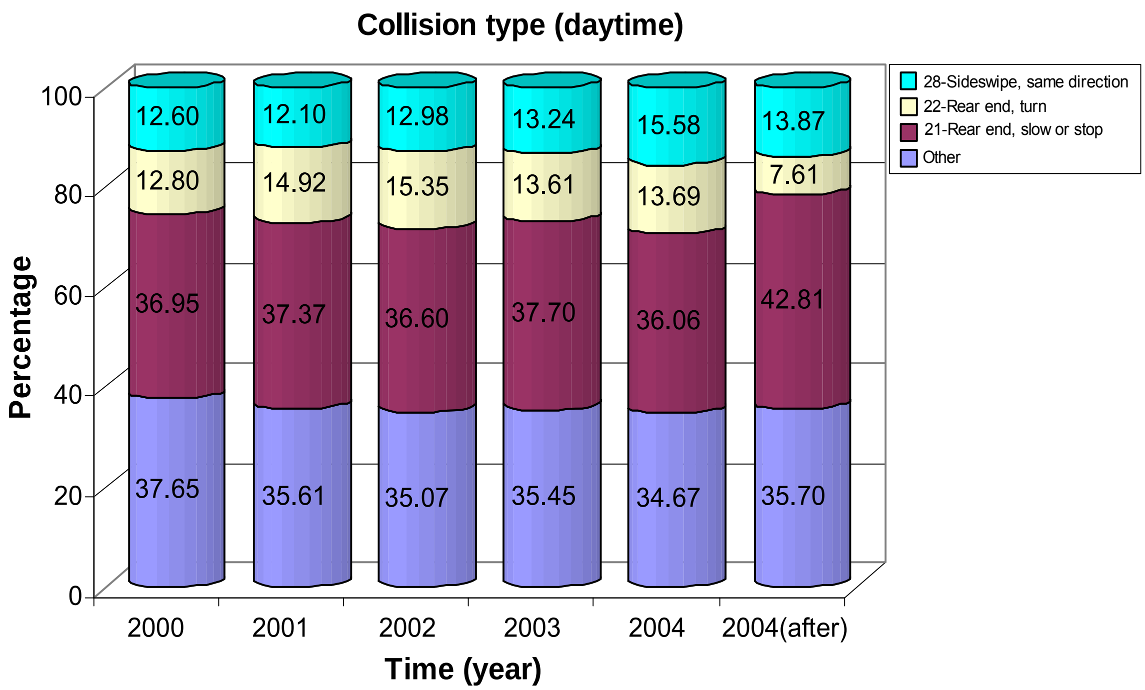
COLLISION TYPES

Figures 44-45 and Tables 38-39 show the collision types that occurred during daytime at each type of site. As shown in Figure 44 and Table 38, the most common collision types for the "before" period at comparison sites were rear end, slow or stop (average 37%), rear end, turning vehicles (average 14%), and sideswipe in same direction (average 13%). For the "after" period, the proportion of the rear end, slow or stop increased by 7% and other major types decreased compared to the "before" period.

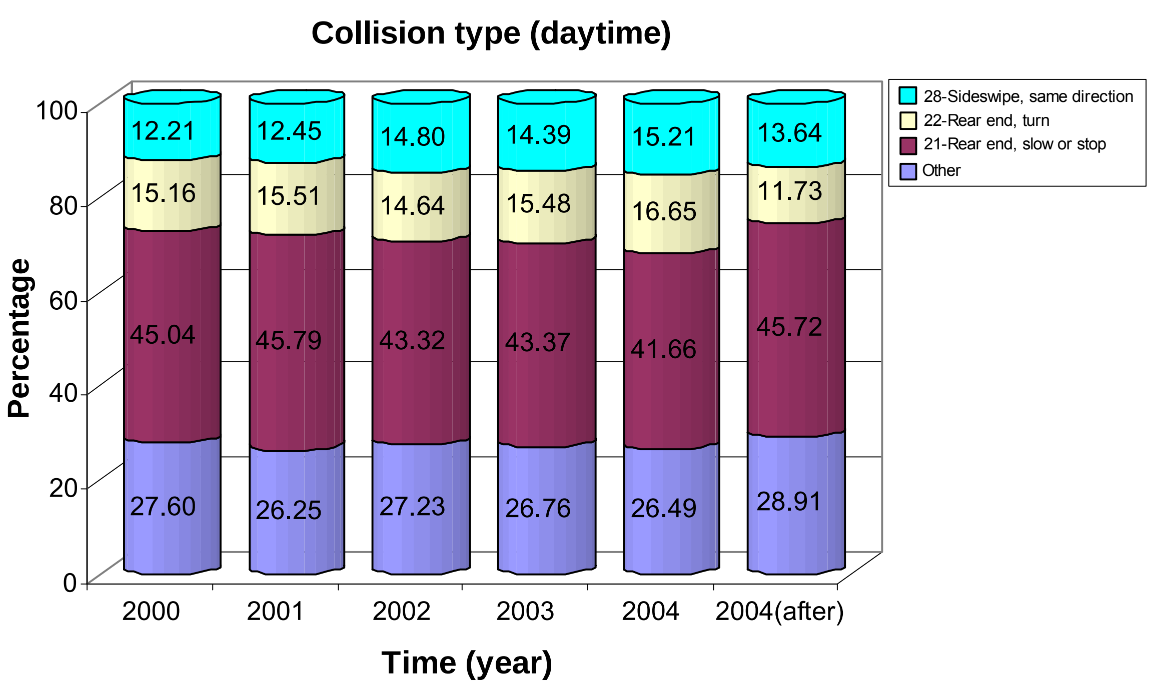
Figure 45 and Table 39 show that rear end, slow or stop collisions (average 44%), rear end, turning vehicles collisions (average 15%), and sideswipe in same direction (average 13%) occurred frequently at treatment sites during daytime in the "before" period. For the "after" period, the proportion of the rear end, turning vehicle increased by about 4% and the other major types decreased compared to the "before" period.

Figures 46 and 47 and Tables 40 and 41 show the collision types that occurred during nighttime at each type of site. For comparison sites, shown in Figure 46 and Table 40, rear end, slow or stop (average 25%) is the most frequent of the collision types, while rear end, turning vehicles (average 13%) and sideswipe in same direction (average 10%) were also frequent at night for the "before" period. For the "after" period at comparison sites, the proportion of rear end, turning vehicles and ran off road collisions decreased, while the proportion of other types increased.

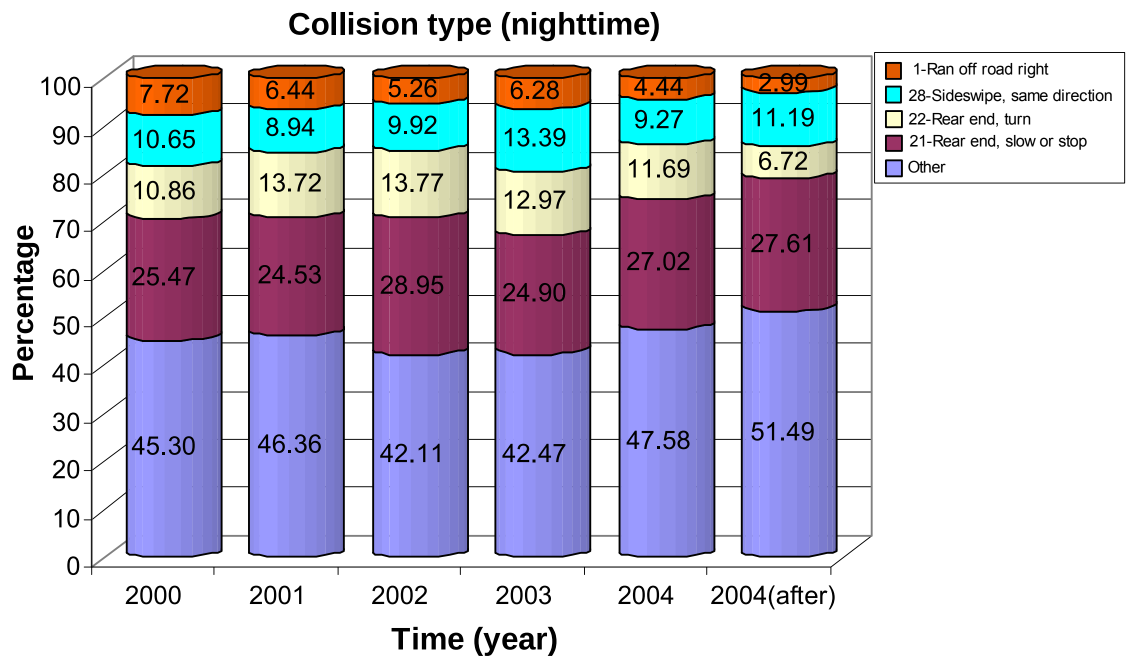
Figure 47 and Table 41 show that rear end, slow or stop (average 33%), rear end, turning vehicles (average 15%), and sideswipe in same direction (average 13%) were the most frequent collision types at treatment sites during nighttime for the "before" period. In the "after" period, the proportions of the most common collision types decreased and the proportion of the other types increased.



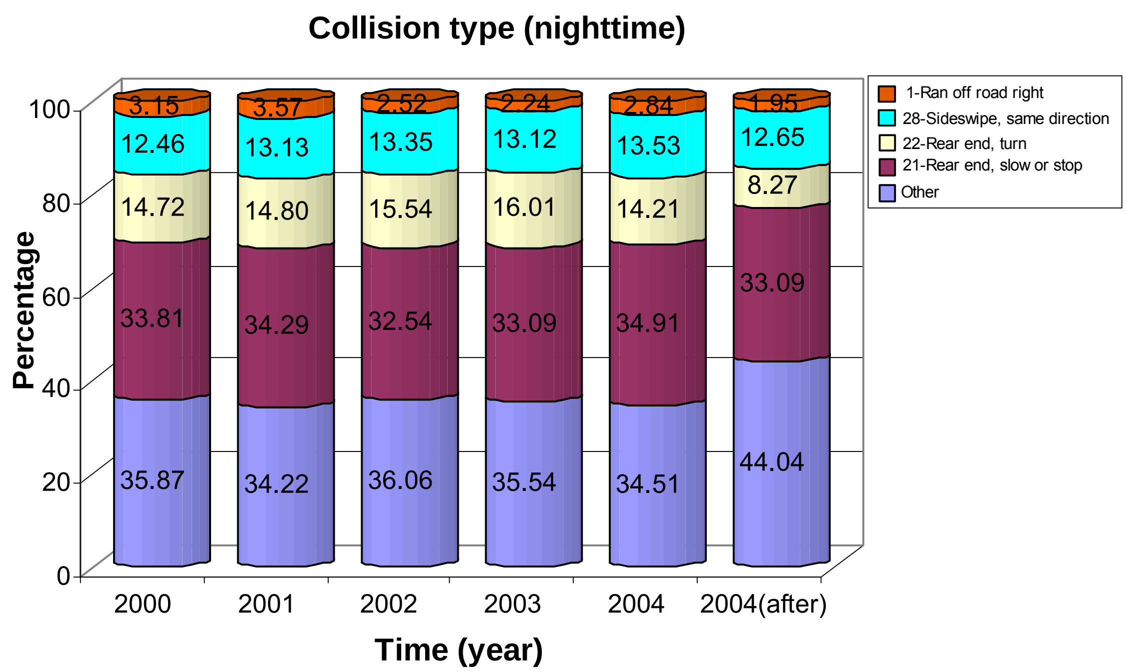
<Figure 44> Collision Type during Daytime at Comparison Sites



<Figure 45> Collision Type during Daytime at Treatment Sites



<Figure 46> Collision Type during Nighttime at Comparison Sites



<Figure 47> Collision Type during Nighttime at Treatment Sites

<Table 38> Types of Collisions for Comparison Sites (Daytime)

Collision type	2000	2001	2002	2003	2004	2004 ("After")
1 (Ran off road right)	27 (1.4%)	28 (1.3%)	26 (1.3%)	31 (1.6%)	19 (1.90%)	3 (0.5%)
2 (Ran off road left)	12 (0.6%)	9 (0.4%)	15 (0.7%)	13 (0.7%)	5 (0.50%)	1 (0.2%)
3 (Ran off road straight ahead)	-	-	1 (0.1%)	-	-	-
4 (Jackknife)	-	-	1 (0.1%)	-	-	-
5 (Overturn / rollover)	-	1 (0.1%)	2 (0.2%)	4 (0.2%)	-	1 (0.2%)
11 (Equipment failure)	-	-	-	-	-	-
12 (Separation units)	-	-	1 (0.1%)	-	-	-
13 (Other non-collision)	7 (0.4%)	13 (0.6%)	5 (0.2%)	8 (0.4%)	2 (0.20%)	2 (0.3%)
14 (Pedestrian)	9 (0.5%)	5 (0.2%)	6 (0.3%)	14 (0.7%)	5 (0.50%)	1 (0.2%)
15 (Pedal-cyclist)	5 (0.3%)	11 (0.5%)	1 (0.1%)	4 (0.2%)	2 (0.2%)	1 (0.2%)
16 (RR train, engine)	1 (0.1%)	-	-	-	-	-
17 (Animal)	1 (0.1%)	-	4 (0.2%)	2 (0.1%)	-	2 (0.3%)
18 (Movable object)	3 (0.2%)	6 (0.3%)	8 (0.4%)	1 (0.1%)	3 (0.30%)	1 (0.2%)
19 (Fixed object)	19 (1.0%)	18 (0.8%)	17 (0.8%)	15 (0.8%)	10 (1.0%)	6 (1.0%)
20 (Parked motor vehicle)	9 (0.5%)	9 (0.4%)	9 (0.4%)	3 (0.2%)	1 (0.1%)	1 (0.2%)
21 (Rear end, slow or stop)	736 (37.0%)	809 (37.3%)	739 (36.6%)	723 (37.7%)	361 (36.1%)	253 (42.8%)
22 (Rear end, turn)	255 (12.8%)	323 (14.9%)	310 (15.4%)	261 (13.6%)	137 (13.70%)	45 (7.6%)
23 (Left turn, same roadway)	203 (10.2%)	210 (9.7%)	167 (8.3%)	157 (8.2%)	83 (8.3%)	51 (8.6%)
24 (Left turn, different roadways)	190 (9.5%)	177 (8.2%)	200 (9.9%)	168 (8.8%)	103 (10.3%)	70 (11.8%)
25 (Right turn, same roadway)	36 (1.8%)	44 (2.0%)	27 (1.3%)	23 (1.2%)	13 (1.3%)	11 (1.9%)
26 (Right turn, different roadways)	70 (3.5%)	77 (3.6%)	54 (2.7%)	74 (3.9%)	25 (2.5%)	16 (2.7%)
27 (Head on)	7 (0.4%)	2 (0.1%)	6 (0.3%)	5 (0.3%)	6 (0.6%)	3 (0.5%)
28 (Sideswipe, same direction)	251 (12.6%)	262 (12.1%)	262 (13.0%)	254 (13.2%)	156 (15.6%)	82 (13.9%)
29 (Sideswipe, opposite direction)	12 (0.6%)	11 (0.5%)	15 (0.7%)	9 (0.5%)	5 (0.5%)	3 (0.5%)
30 (Angle)	83 (4.2%)	98 (4.5%)	97 (4.8%)	96 (5.0%)	38 (3.8%)	24 (4.1%)
31 (Backing up)	47 (2.4%)	47 (2.2%)	40 (2.0%)	36 (1.9%)	19 (1.9%)	7 (1.2%)
32 (Other collision with vehicle)	9 (0.5%)	5 (0.2%)	6 (0.3%)	17 (0.9%)	8 (0.8%)	7 (1.2%)
Total	1,992 (100%)	2,165 (100%)	2,019 (100%)	1,918 (100%)	1,001 (100%)	591 (100%)

<Table 39> Types of Collisions for Treatment Sites (Daytime)

Collision type	2000	2001	2002	2003	2004	2004 ("After")
1 (Ran off road right)	58 (1.0%)	51 (0.9%)	60 (1.1%)	53 (1.0%)	26 (1.0%)	12 (0.9%)
2 (Ran off road left)	13 (0.2%)	24 (0.4%)	25 (0.5%)	15 (0.3%)	12 (0.5%)	4 (0.3%)
3 (Ran off road straight ahead)	2 (0.1%)	-	1 (0.1%)	3 (0.1%)	-	-
4 (Jackknife)	-	4 (0.1%)	2 (0.1%)	1 (0.1%)	-	-
5 (Overturn / rollover)	4 (0.1%)	1 (0.1%)	4 (0.1%)	2 (0.1%)	1 (0.1%)	1 (0.1%)
11 (Equipment failure)	-	1 (0.1%)	-	-	-	-
12 (Separation units)	-	1 (0.1%)	1 (0.1%)	-	-	-
13 (Other non-collision)	17 (0.3%)	15 (0.3%)	26 (0.5%)	23 (0.4%)	11 (0.4%)	7 (0.5%)
14 (Pedestrian)	31 (0.6%)	22 (0.4%)	36 (0.7%)	34 (0.6%)	17 (0.7%)	5 (0.4%)
15 (Pedal-cyclist)	17 (0.3%)	10 (0.2%)	11 (0.2%)	7 (0.1%)	8 (0.3%)	1 (0.1%)
16 (RR train, engine)	-	-	-	-	-	-
17 (Animal)	2 (0.1%)	3 (0.1%)	7 (0.1%)	9 (0.2%)	2 (0.1%)	5 (0.4%)
18 (Movable object)	11 (0.2%)	17 (0.3%)	17 (0.3%)	16 (0.3%)	4 (0.2%)	2 (0.2%)
19 (Fixed object)	28 (0.5%)	27 (0.5%)	18 (0.3%)	19 (0.4%)	25 (1.0%)	4 (0.3%)
20 (Parked motor vehicle)	13 (0.2%)	7 (0.1%)	12 (0.2%)	7 (0.1%)	6 (0.2%)	-
21 (Rear end, slow or stop)	2,502 (45.0%)	2,662 (45.8%)	2,388 (43.3%)	2,308 (43.4%)	1071 (41.7%)	620 (45.7%)
22 (Rear end, turn)	842 (15.2%)	902 (15.5%)	807 (14.6%)	824 (15.5%)	428 (16.7%)	159 (11.7%)
23 (Left turn, same roadway)	409 (7.4%)	441 (7.6%)	384 (7.0%)	366 (6.9%)	164 (6.4%)	88 (6.5%)
24 (Left turn, different roadways)	333 (6.0%)	371 (6.4%)	368 (6.7%)	347 (6.5%)	164 (6.4%)	89 (6.6%)
25 (Right turn, same roadway)	63 (1.1%)	61 (1.1%)	43 (0.8%)	39 (0.7%)	23 (0.9%)	30 (2.2%)
26 (Right turn, different roadways)	212 (3.8%)	196 (3.4%)	176 (3.2%)	206 (3.9%)	97 (3.8%)	52 (3.8%)
27 (Head on)	16 (0.3%)	11 (0.2%)	18 (0.3%)	20 (0.4%)	6 (0.2%)	6 (0.4%)
28 (Sideswipe, same direction)	678 (12.2%)	724 (12.5%)	816 (14.8%)	766 (14.4%)	391 (15.2%)	185 (13.6%)
29 (Sideswipe, opposite direction)	15 (0.3%)	11 (0.2%)	12 (0.2%)	19 (0.4%)	4 (0.2%)	2 (0.2%)
30 (Angle)	187 (3.4%)	179 (3.1%)	172 (3.1%)	120 (2.3%)	50 (1.9%)	48 (3.5%)
31 (Backing up)	73 (1.3%)	61 (1.1%)	85 (1.5%)	73 (1.4%)	38 (1.5%)	24 (1.8%)
32 (Other collision with vehicle)	29 (0.5%)	12 (0.2%)	23 (0.4%)	45 (0.9%)	23 (0.9%)	12 (0.9%)
Total	5,555 (100%)	5,814 (100%)	5,512 (100%)	5,322 (100%)	2,571 (100%)	1,356 (100%)

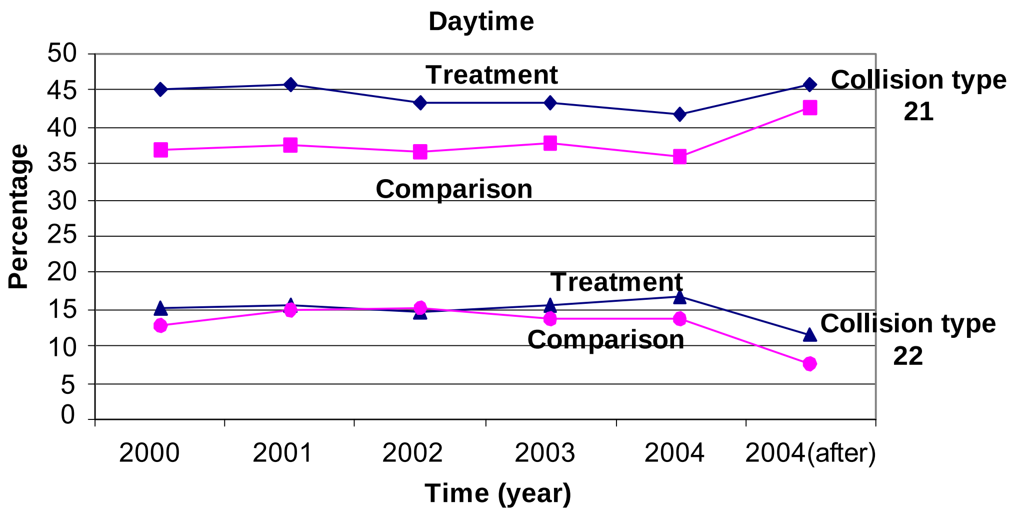
<Table 40> Types of Collisions for Comparison Sites (Nighttime)

Collision type	2000	2001	2002	2003	2004	2004 ("After")
1 (Ran off road right)	37 (7.7%)	31 (6.4%)	26 (5.3%)	30 (6.3%)	11 (4.4%)	4 (3.0%)
2 (Ran off road left)	11 (2.3%)	14 (2.9%)	15 (3.0%)	9 (1.9%)	8 (3.2%)	6 (4.5%)
3 (Ran off road straight ahead)	4 (0.8%)	3 (0.6%)	2 (0.4%)	2 (0.4%)	2 (0.8%)	1 (0.8%)
4 (Jackknife)	-	-	1 (0.2%)	-	-	-
5 (Overturn / rollover)	-	3 (0.6%)	3 (0.6%)	4 (0.8%)	-	-
13 (Other non-collision)	4 (0.8%)	2 (0.4%)	-	1 (0.2%)	-	-
14 (Pedestrian)	4 (0.8%)	5 (1.0%)	2 (0.4%)	8 (1.7%)	5 (2.0%)	4 (3.0%)
15 (Pedal-cyclist)	2 (0.4%)	-	2 (0.4%)	2 (0.4%)	2 (0.8%)	-
17 (Animal)	3 (0.6%)	3 (0.6%)	4 (0.8%)	7 (1.5%)	1 (0.4%)	3 (2.2%)
18 (Movable object)	2 (0.4%)	3 (0.6%)	6 (1.2%)	2 (0.4%)	3 (1.2%)	3 (2.2%)
19 (Fixed object)	15 (3.1%)	8 (1.7%)	10 (2.0%)	9 (1.9%)	6 (2.4%)	9 (6.7%)
20 (Parked motor vehicle)	3 (0.6%)	5 (1.0%)	-	3 (0.6%)	1 (0.4%)	2 (1.5%)
21 (Rear end, slow or stop)	122 (25.5%)	118 (24.5%)	143 (29.0%)	119 (24.9%)	67 (27.0%)	37 (27.6%)
22 (Rear end, turn)	52 (10.9%)	66 (13.7%)	68 (13.8%)	62 (13.0%)	29 (11.7%)	9 (6.7%)
23 (Left turn, same roadway)	49 (10.2%)	68 (14.1%)	58 (11.7%)	56 (11.7%)	22 (8.9%)	12 (9.0%)
24 (Left turn, different roadways)	32 (6.7%)	42 (8.7%)	29 (5.9%)	31 (6.5%)	18 (7.3%)	9 (6.7%)
25 (Right turn, same roadway)	12 (2.5%)	6 (1.3%)	4 (0.8%)	3 (0.6%)	7 (2.8%)	2 (1.5%)
26 (Right turn, different roadways)	19 (4.0%)	12 (2.5%)	12 (2.4%)	12 (2.5%)	14 (5.7%)	3 (2.2%)
27 (Head on)	4 (0.8%)	3 (0.6%)	-	7 (1.5%)	1 (0.4%)	-
28 (Sideswipe, same direction)	51 (10.7%)	43 (8.9%)	49 (9.9%)	64 (13.4%)	23 (9.3%)	15 (11.2%)
29 (Sideswipe, opposite direction)	3 (0.6%)	4 (0.8%)	5 (1.0%)	4 (0.8%)	-	1 (0.8%)
30 (Angle)	38 (7.9%)	37 (7.7%)	38 (7.7%)	25 (5.2%)	16 (6.5%)	13 (9.7%)
31 (Backing up)	12 (2.5%)	4 (0.8%)	14 (2.8%)	12 (2.5%)	1 (0.4%)	1 (0.8%)
32 (Other collision with vehicle)	-	1 (0.2%)	3 (0.6%)	6 (1.2%)	11 (4.4%)	-
Total	479 (100%)	481 (100%)	494 (100%)	478 (100%)	248 (100%)	134 (100%)

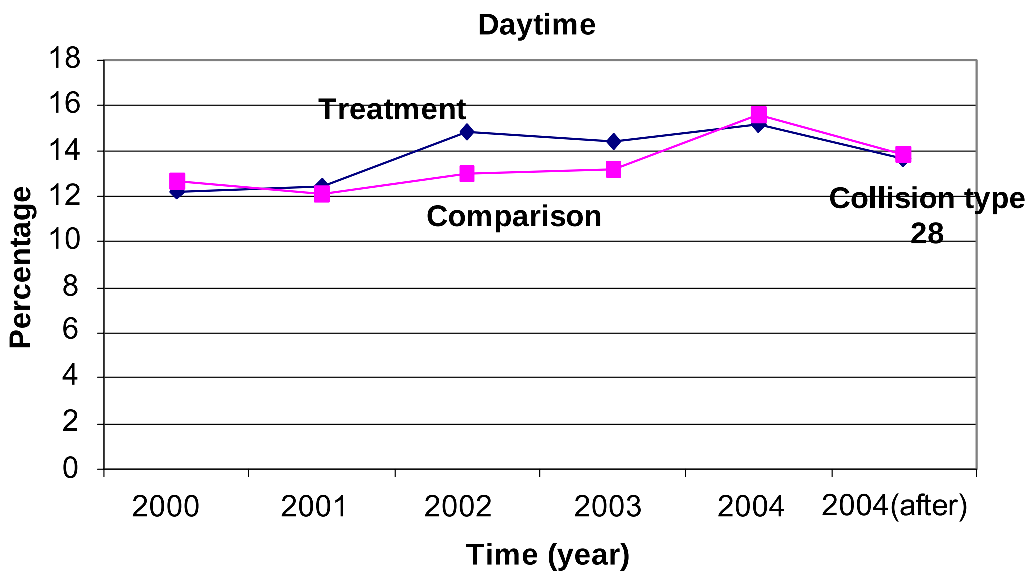
<Table 41> Types of Collisions for Treatment Sites (Nighttime)

Collision type	2000	2001	2002	2003	2004	2004 ("After")
1 (Ran off road right)	46 (3.2%)	47 (3.6%)	38 (2.5%)	31 (2.2%)	21 (2.8%)	8 (2.0%)
2 (Ran off road left)	24 (1.6%)	21 (1.6%)	29 (1.9%)	24 (1.7%)	9 (1.2%)	3 (1.0%)
3 (Ran off road straight ahead)	2 (0.1%)	-	1 (0.1%)	4 (0.3%)	1 (0.1%)	-
4 (Jackknife)	1 (0.1%)	-	-	1 (0.1%)	-	-
5 (Overturn / rollover)	1 (0.1%)	-	5 (0.3%)	3 (0.2%)	3 (0.3%)	1 (0.2%)
13 (Other non-collision)	2 (0.1%)	4 (0.3%)	3 (0.2%)	3 (0.2%)	-	2 (0.5%)
14 (Pedestrian)	21 (1.4%)	16 (1.2%)	23 (1.5%)	21 (1.5%)	8 (1.1%)	13 (3.2%)
15 (Pedal-cyclist)	4 (0.3%)	6 (0.5%)	4 (0.3%)	6 (0.4%)	5 (0.7%)	3 (0.7%)
17 (Animal)	7 (0.5%)	5 (0.4%)	9 (0.6%)	4 (0.3%)	3 (0.4%)	11 (2.7%)
18 (Movable object)	6 (0.4%)	3 (0.2%)	7 (0.5%)	4 (0.3%)	4 (0.5%)	7 (1.7%)
19 (Fixed object)	27 (1.9%)	16 (1.2%)	34 (2.3%)	30 (2.2%)	20 (2.7%)	16 (3.9%)
20 (Parked motor vehicle)	4 (0.3%)	6 (0.5%)	12 (0.8%)	10 (0.7%)	5 (0.7%)	4 (1.0%)
21 (Rear end, slow or stop)	494 (33.8%)	452 (34.3%)	490 (32.5%)	459 (33.1%)	258 (34.9%)	136 (33.1%)
22 (Rear end, turn)	215 (14.7%)	195 (14.8%)	234 (15.5%)	222 (16.0%)	105 (14.2%)	34 (8.3%)
23 (Left turn, same roadway)	122 (8.4%)	123 (9.3%)	149 (9.9%)	118 (8.5%)	58 (7.9%)	46 (11.2%)
24 (Left turn, different roadways)	100 (6.8%)	90 (6.8%)	97 (6.4%)	83 (6.0%)	43 (5.8%)	23 (5.6%)
25 (Right turn, same roadway)	31 (2.1%)	15 (1.1%)	9 (0.6%)	16 (1.2%)	15 (2.0%)	9 (2.2%)
26 (Right turn, different roadways)	54 (3.7%)	57 (4.3%)	44 (2.9%)	50 (3.6%)	27 (3.7%)	11 (2.7%)
27 (Head on)	11 (0.8%)	12 (0.9%)	8 (0.5%)	11 (0.8%)	-	7 (1.7%)
28 (Sideswipe, same direction)	182 (12.5%)	173 (13.1%)	201 (13.4%)	182 (13.1%)	100 (13.5%)	52 (12.7%)
29 (Sideswipe, opposite direction)	6 (0.4%)	6 (0.5%)	11 (0.7%)	5 (0.4%)	5 (0.7%)	1 (0.2%)
30 (Angle)	64 (4.4%)	46 (3.5%)	63 (4.2%)	66 (4.8%)	25 (3.4%)	14 (3.4%)
31 (Backing up)	28 (1.9%)	23 (1.8%)	21 (1.4%)	25 (1.8%)	7 (1.0%)	4 (1.0%)
32 (Other collision with vehicle)	9 (0.6%)	2 (0.2%)	14 (0.9%)	9 (0.7%)	17 (2.3%)	6 (1.5%)
Total	1,461 (100%)	1,318 (100%)	1,506 (100%)	1,387 (100%)	739 (100%)	411 (100%)

For the most common collision types, we examined simple comparisons to see if there are differences in the patterns of these types over the years between treatment and comparison sites. As shown in Figures 48 and 49, it seems like that there are no major differences in the trends for the common types of collisions between the two types of sites in the daytime.

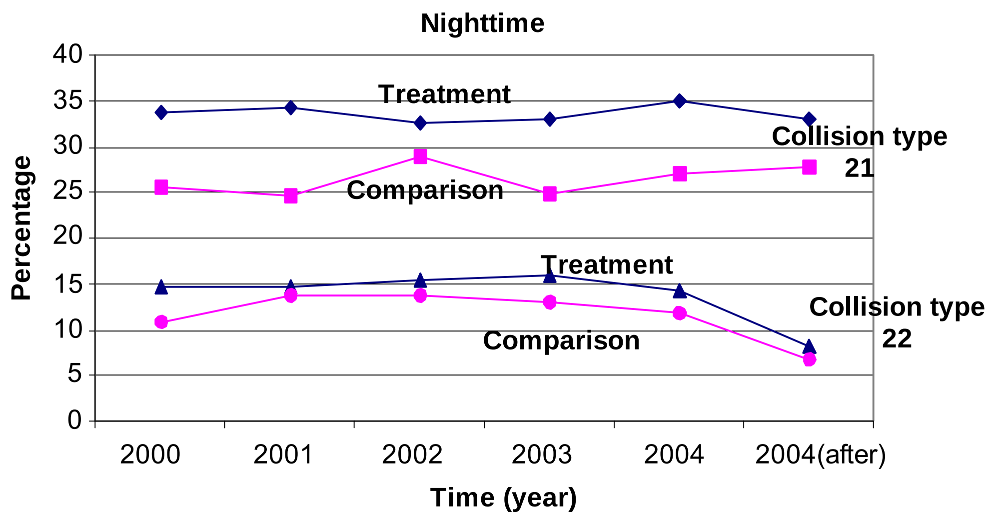


<Figure 48> Comparing Collision Types 21 and 22 between Treatment and Comparison Sites during Daytime

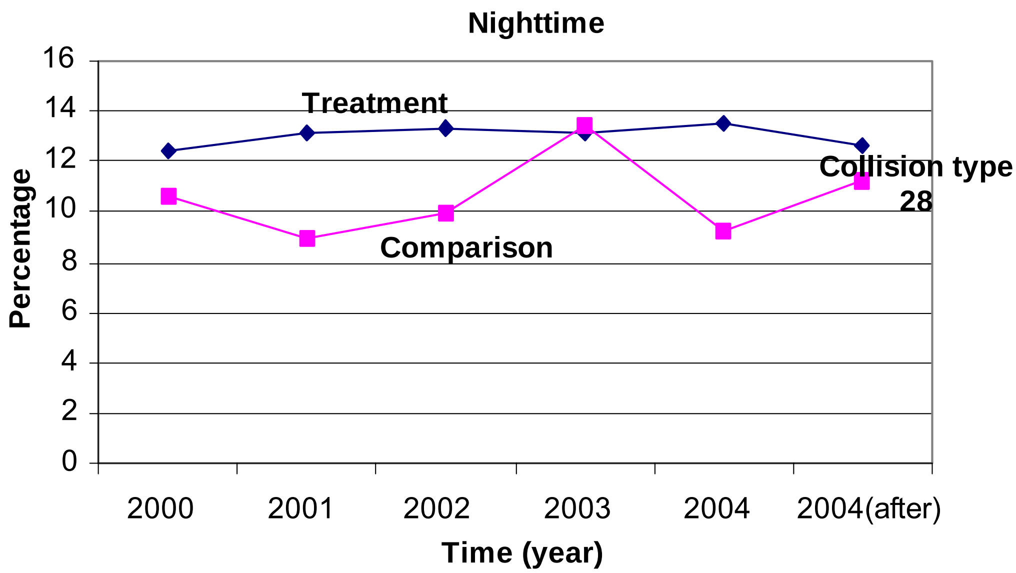


<Figure 49> Comparing Collision Type 28 between Treatment and Comparison Sites during Daytime

On the other hand, rear end (21), slow or stop (22) and sideswipe in same direction (28) exhibited different tendencies between the two types of sites during nighttime hours. When comparing the "after" period with the "before" period, treatment sites had a decreasing tendency and the comparison sites had an increasing tendency or stayed constant. These are shown in Figures 50 and 51.



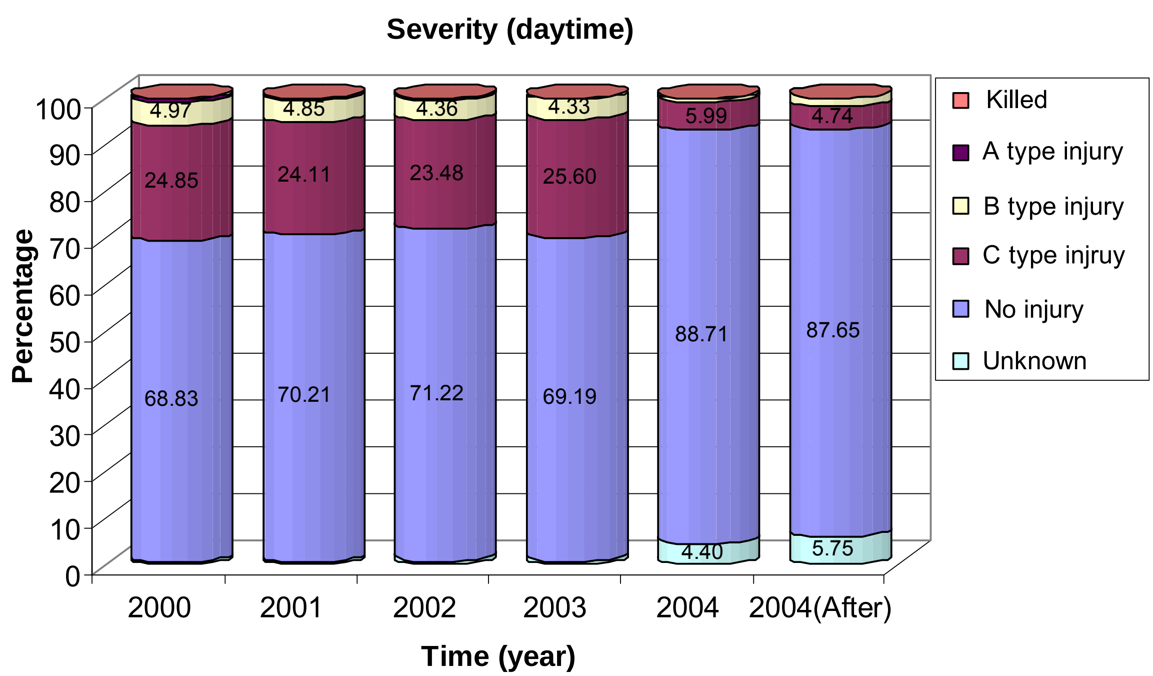
<Figure 50> Comparing Collision Types 21 and 22 between Treatment and Comparison Sites during Nighttime



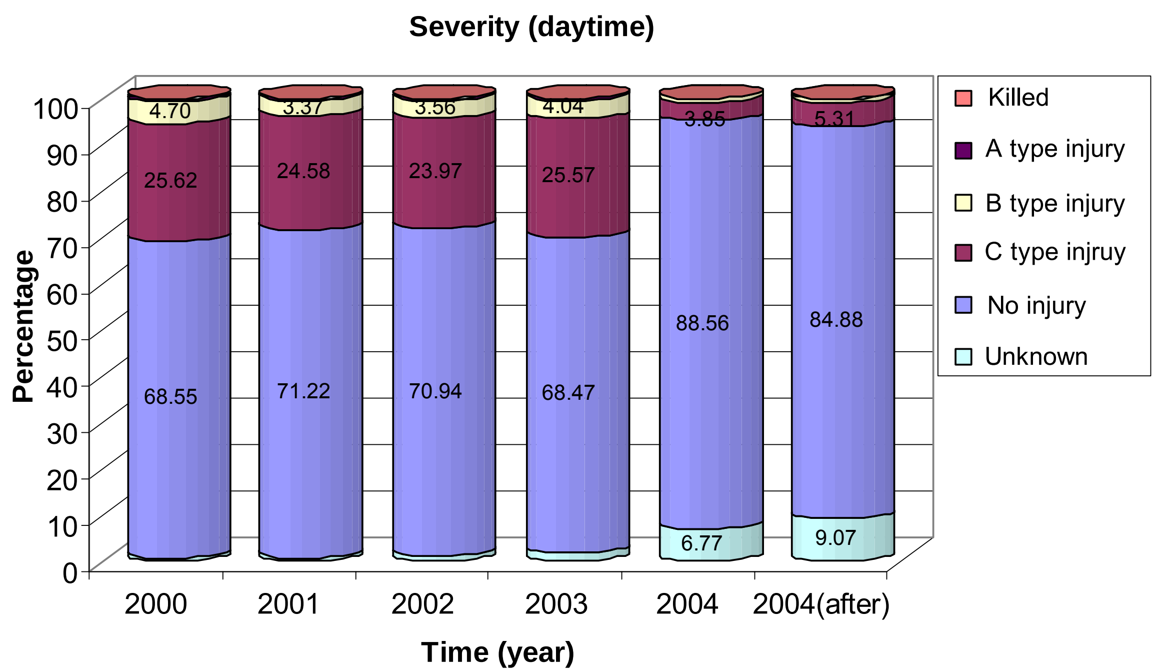
<Figure 51> Comparing Collision Type 28 between Treatment and Comparison Sites during Nighttime

CRASH SEVERITY

Figures 52 and 53 and Table 44 present crash severity data during daytime for the each type of site over the study years. Figure 52 and Table 42 show that for comparison sites, while "no injury" crashes from 2000 to 2003 made up about 70 percent of the sample, this crash type jumped to about 87 percent for 2004. It also shows that the proportion of "unknown" crashes for 2004 increased to about 5 percent compared to very small values in the previous years and the proportion of "C" type injuries decreased noticeably to about 5 percent. Figure 53 and Table 44 show that there was little difference in this severity distribution at the treatment sites compared to the comparison sites during daytime over the study years.



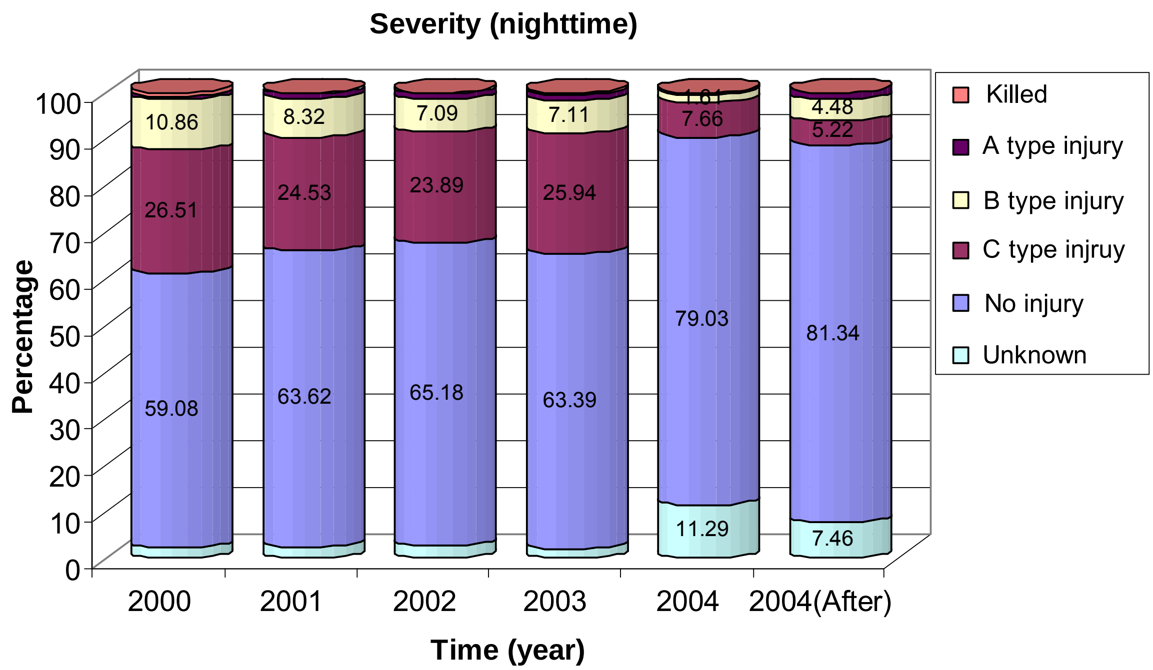
<Figure 52> Crash Severities for Comparison Sites during Daytime



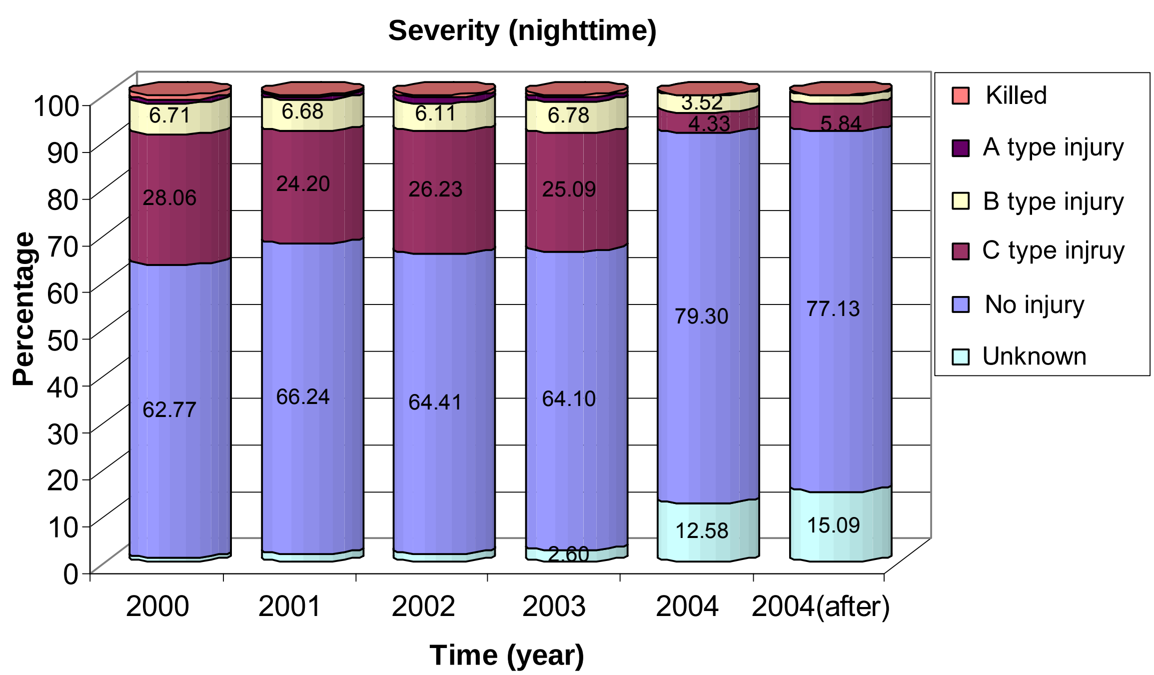
<Figure 53> Crash Severities for Treatment Sites during Daytime

Figures 54 and 55 and Table 44 indicate crash severities during nighttime for the each type of site over the study years. Figure 54 and Table 44 show that for comparison sites, while the average proportion of "no injury" crashes was about 63 percent between 2000 and 2003, the proportion of this crash type for 2004 increased to about 80 percent. In addition, the proportion of the "C" type injuries decreased noticeably to about 6 percent for 2004, while the proportion of "unknown" crashes rose considerably in 2004 compared to the previous years. Figure 55 and Table 44 indicate that the same trends were apparent for treatment sites.

One feasible explanation for these trends is that the Charlotte-Mecklenburg Police Department replaced paper crash report forms by digital crash reporting software during 2004 *(35)*. Adopting the new reporting system likely contributed to the noticeable changes in severity proportions between 2004 and the other years. While the paper forms did not include all the definitions with regard to crash severities, the digital reporting system included actual definitions associated with the crash severities.



<Figure 54> Crash Severities for Comparison Sites during Nighttime



<Figure 55> Crash Severities for Treatment Sites during Nighttime

Therefore, the important comparisons for severity are between the "before" months and the "after" months for 2004; the "before" months covered January to July and the "after" months from September to December. This allows for a more true comparison by eliminating data sets that are known to differ for reasons other than speed cameras. Tables 42 and 43 show changes in differing collision types from before and after periods in 2004 for comparison and treatment corridors. For example, 'Unknown' collisions at comparison corridors during daytime hours increased by 1.4% after implementing speed cameras. The same collisions at treatment corridors increased by 2.3%. The net change in "Unknown" collisions at treatment corridors is estimated to have increased by 0.9% during daytime hours.

Because sample sizes are so small (see Table 44) for Fatal and Type-A collisions, we have to be careful with the estimates shown in Tables 42 and 43. Ignoring Fatal and Type-A collisions, it appears that there are some differences between night and day collision estimates for comparison and treatment sites, noted below.

- Unknown collisions increased 0.9% during daytime vs. an increase of 6.3% during nighttime.
- No Injury collisions decreased 3.7% during daytime vs. a decrease of 4.5% during nighttime.
- Type-C collisions increased 2.7% during daytime vs. an increase of 4.0% during nighttime.
- Type-B collisions decreased 1.6% during daytime vs. a decrease of 5.1% during nighttime.

<Table 42> Difference in Collisions from Before to After 2004 at Comparison and Treatment Corridors (Daytime)

	Unknown	No Injury	C	B	A	Fatal
Comparison Corridors	+1.4	-1.1	-1.3	+1.3	-0.2	-0.1
Treatment Corridors	+2.3	-3.7	+1.4	-0.3	+0.1	0
Change (Δ)	+0.9	-2.6	+2.7	-1.6	+0.3	+0.1

<Table 43> Difference in Collisions from Before to After 2004 at Comparison and Treatment Corridors (Nighttime)

	Unknown	No Injury	C	B	A	Fatal
Comparison Corridors	-3.8	+2.3	-2.5	+3.3	+1.1	0
Treatment Corridors	+2.5	-2.2	+1.5	-1.8	-0.1	0
Change (Δ)	+6.3	-4.5	+4.0	-5.1	-1.2	0

<Table 44> Crash Severity

Daytime

Crash Severity \ Year	Comparison 2000	Comparison 2001	Comparison 2002	Comparison 2003	Comparison 2004	Comparison 2004 (after)	Treatment 2000	Treatment 2001	Treatment 2002	Treatment 2003	Treatment 2004	Treatment 2004 (after)
1 (Killed)	3 (0.2%)	1 (0.1%)	2 (0.1%)	1 (0.1%)	1 (0.1%)	0 (0.0%)	6 (0.1%)	6 (0.1%)	6 (0.1%)	1 (0.1%)	0 (0.0%)	0 (0.0%)
2 (A type, disabling)	14 (0.7%)	8 (0.4%)	6 (0.3%)	3 (0.2%)	2 (0.2%)	0 (0.0%)	26 (0.5%)	14 (0.2%)	19 (0.3%)	15 (0.3%)	1 (0.1%)	2 (0.2%)
3 (B type, evident)	99 (5.0%)	105 (4.9%)	88 (4.4%)	83 (4.3%)	6 (0.6%)	11 (1.9%)	261 (4.7%)	196 (3.4%)	196 (3.6%)	215 (4.0%)	20 (0.9%)	8 (0.6%)
4 (C type, possible)	495 (24.9%)	522 (24.1%)	474 (23.5%)	491 (25.6%)	60 (6.0%)	28 (4.7%)	1,423 (25.6%)	1,429 (24.6%)	1,321 (24.0%)	1,361 (25.6%)	99 (3.9%)	72 (5.3%)
5 (No injury)	1,371 (68.8%)	1,520 (70.2%)	1,438 (71.2%)	1,327 (69.2%)	888 (88.7%)	518 (87.6%)	3,808 (68.6%)	4,141 (71.2%)	3,910 (70.9%)	3,644 (68.5%)	2,277 (88.6%)	1,151 (84.9%)
6 (Unknown)	10 (0.5%)	9 (0.4%)	11 (0.5%)	13 (0.7%)	44 (4.4%)	34 (5.8%)	31 (0.6%)	28 (0.5%)	60 (1.1%)	86 (1.6%)	174 (6.8%)	123 (9.1%)
Total	1,992 (100%)	2,165 (100%)	2,019 (100%)	1,918 (100%)	1,001 (100%)	591 (100%)	5,555 (100%)	5,814 (100%)	5,512 (100%)	5,322 (100%)	2,571 (100%)	1,356 (100%)

Nighttime

Crash Severity \ Year	Comparison 2000	Comparison 2001	Comparison 2002	Comparison 2003	Comparison 2004	Comparison 2004 (after)	Treatment 2000	Treatment 2001	Treatment 2002	Treatment 2003	Treatment 2004	Treatment 2004 (after)
1 (Killed)	4 (0.8%)	1 (0.2%)	1 (0.2%)	2 (0.4%)	0 (0.0%)	0 (0.0%)	14 (1.0%)	5 (0.4%)	8 (0.5%)	9 (0.7%)	0 (0.0%)	0 (0.0%)
2 (A type, disabling)	3 (0.6%)	5 (1.0%)	6 (1.2%)	6 (1.2%)	1 (0.4%)	2 (1.5%)	10 (0.7%)	10 (0.8%)	16 (1.1%)	11 (0.8%)	2 (0.3%)	1 (0.2%)
3 (B type, evident)	52 (10.9%)	40 (8.3%)	35 (7.1%)	34 (7.1%)	4 (1.6%)	6 (4.9%)	98 (6.7%)	88 (6.7%)	92 (6.1%)	94 (6.8%)	26 (3.5%)	7 (1.7%)
4 (C type, possible)	127 (26.5%)	118 (24.5%)	118 (23.9%)	124 (25.9%)	19 (7.7%)	7 (5.2%)	410 (28.1%)	319 (24.2%)	395 (26.2%)	348 (25.1%)	32 (4.3%)	24 (5.8%)
5 (No injury)	283 (59.1%)	306 (63.6%)	322 (65.2%)	303 (63.4%)	196 (79.0%)	109 (81.3%)	917 (62.8%)	873 (66.2%)	970 (64.4%)	889 (64.1%)	586 (79.3%)	317 (77.1%)
6 (Unknown)	10 (2.1%)	11 (2.3%)	12 (2.4%)	9 (1.9%)	28 (11.3%)	10 (7.5%)	12 (0.8%)	23 (1.8%)	25 (1.7%)	36 (2.6%)	93 (12.6%)	62 (15.1%)
Total	479 (100%)	481 (100%)	494 (100%)	478 (100%)	248 (100%)	134 (100%)	1,461 (100%)	1,318 (100%)	1,506 (100%)	1,387 (100%)	739 (100%)	411 (100%)

SUMMARY AND DISCUSSION

For the pattern of the reported collisions for treatment and comparison sites, overall, the results showed that collisions were more frequent, and more frequent per mile, at treatment sites than comparison sites. It also appeared that higher collision frequency was associated with higher intersection density for the sample corridors and collisions tended to be more severe at night than during the day. Although collision patterns over five years were similar between treatment and comparison sites, collisions at the treatment sites seemed to have decreased by a small amount compared to the comparison sites, which were fairly constant.

In a previous chapter discussing citation issuance by Charlotte-Mecklenburg Police Department, an interesting detail surfaced. Police department officials noted that approximately 75% of all automated enforcement was done during daytime hours. Looking at the difference between daytime and nighttime collisions between treatment and comparison sites every year, the change in the after period for 2004 of 4.48% could support claims that greater daytime enforcement leads to greater decreases in collisions, however it is not definitive.

When examining collision types, rear end, slow or stop, and sideswipe in same direction exhibited different tendencies between the two types of sites during nighttime hours: when comparing the "after" period with the "before" period, treatment sites had a decreasing tendency and the comparison sites had an increasing tendency or stayed constant. Daytime analysis of the same collision types showed no changes.

A noticeable change in severity proportions between 2004 and the other years was obvious. One feasible explanation for the trends is that CMPD replaced paper crash report forms by a digital crash reporting software during 2004. Examining crash severity between before and after periods at comparison and treatment sites during before and after periods in 2004,

- Unknown collisions increased 0.9% to 6.3% from daytime to nighttime.
- No Injury collisions decreased 3.7% to 4.5% from daytime to nighttime.
- Type-C collisions increased 2.7% to 4.0% from daytime to nighttime.
- Type-B collisions decreased 1.6% to 5.1% from daytime to nighttime.

SUMMARY

The goal of this research effort was to evaluate the speed camera program conducted by the City of Charlotte. Four tasks were identified to help in this endeavor. These included a literature review, conducting focus groups, a before-after collision study, and an analysis of speeds.

CONCLUSION

The purpose of this report was to summarize the work the ITRE team has performed during the two-year analysis of Charlotte's automated speed camera project. This report should serve to inform GHSP, the City of Charlotte, the NC Legislature, and other municipalities of our findings so that they can make informed decisions about speed camera systems in the future.

There has been previous research on automated speed enforcement in the U.S.; however, those programs differ in their operational details from the Charlotte program. In addition, prior speed enforcement camera projects have not been evaluated very rigorously. It is not at all clear that the previous programs have generally led to collision reductions.

Four focus groups were conducted in Charlotte and Raleigh, N.C. The automated speed camera program was popular with the two Charlotte-based focus groups we conducted. If these groups are representative of other Charlotte residents and professionals, the program is likely to be generally popular in Charlotte. The focus groups all emphasized the need for continuous driver education to increase the effectiveness of the program. The groups felt that drivers need to be aware of program motives, operational details, and statistics through web sites, media, and perhaps other methods.

Two measures of effectiveness, speeds and collisions, were used in our analysis of the speed camera system in Charlotte. Speeds are indirectly related to safety; however, they are obvious indicators of conformity to posted speed limits. An analysis of speed data in the before and after periods using a Generalized Linear model and a Linear Regression model indicated the following patterns:

- Most of the corridors had significant differences in variance between the 'before' and 'after' periods, but there were no consistent patterns in whether the lower variance was found in the 'before' or the 'after' period.
- Most of the treatment sites had mean speed reduction experience after camera installation while the comparison sites did not demonstrate a consistent pattern of mean speed change.
- While there were no significant mean speed differentials between 'before' and 'after' periods at the comparison sites, mean speeds in the treatment sites declined significantly by an average of 0.91 mph.
- Median and 85^{th} percentile speeds decreased significantly by 0.88 mph and 0.99 mph, respectively, at the treatment sites in the 'after' period.
- The percentage of vehicles exceeding the speed limit by 10 mph or more decreased significantly by an average of 55 % at the treatment sites compared to the comparison sites.

The primary measure of effectiveness was collisions. Collisions are the ideal measure for traffic-related countermeasures because they are directly related to safety. Odds ratio calculations showed that the comparison sites and the treatment sites tracked each other very well through the before period. Therefore, an analysis of collisions using a comparison group methodology was completed. An estimated reduction of 12% in total collisions was attributed to automated speed enforcement cameras. Regression to the mean bias does not appear to be a significant threat in this case. In addition to this analysis, a subset of collisions from the treatment sites was analyzed. This subset included data from five heavily enforced corridors. Analyzing these sites, it is estimated that automated speed enforcement reduced collisions by 14 % from what they would have been in the treatment corridors from September to December of 2004. It appears that the extraneous enforcement of these sites has had a slightly bigger reduction in collisions. Although both of these analyses show reductions in collisions, readers must keep in mind the serious limitations of the study (such as short duration of the after period, intense media attention on the program, and others) before attempting to generalize this finding.

Following the collision analysis, collision trends were analyzed to help determine any specific areas that collision reductions may have taken place. Some of the findings are:

- Collisions at the treatment sites seemed to have decreased by a small amount compared to the comparison sites, which were fairly constant.
- Trends seem to indicate that Charlotte's higher enforcement during daytime hours (approximately 75%) is decreasing collisions at a slightly higher rate during daytime hours.
- When examining collision types, rear end, slow or stop, and sideswipe in same direction exhibited different tendencies between comparison and treatment sites during nighttime hours. When comparing the "after" period with the "before" period, treatment sites had a decreasing trend and the comparison sites had an increasing trend or stayed constant. Daytime analysis of the same collision types showed no changes.

- Examining crash severity between before and after periods at comparison and treatment sites during before and after periods in 2004,
  - Unknown collisions increased 0.9% to 6.3% from daytime to nighttime.
  - No Injury collisions decreased 3.7% to 4.5% from daytime to nighttime.
  - Type-C collisions increased 2.7% to 4.0% from daytime to nighttime.
  - Type-B collisions decreased 1.6% to 5.1% from daytime to nighttime.

Based on findings from both speed and collisions analyses, it appears that Charlotte's automated speed enforcement program is successful at reducing speeds and collisions. Further analysis of collision data from 2005 should be completed in the near future to help solidify safety related findings given in this report.

RECOMMENDATIONS TO CHARLOTTE AND OTHER CITIES

We recommend that the City of Charlotte keep the current mobile automated speed enforcement program and expand to other similar corridors. Other cities across the state should also consider this countermeasure in similar corridors with similar speed-related safety issues to help keep drivers compliant with posted speed limits. We do like the idea of the mobile automated speed enforcement unit because it can be moved easily to enforce multiple, specific zones. Speed enforcement cameras should be used to supplement patrolling officers, not take their place. Other violations such as driving under the influence (DUI) would likely be missed without one-on-one contact with the driver of the vehicle. In addition, public information should remain a priority for city officials involved in speed camera programs. The public should be made aware of the costs and benefits of this and other countermeasures so that support does not erode and so the effects are spread as widely as possible.

RECOMMENDATIONS FOR FUTURE RESEARCH

Future research on speed cameras should, if at all possible, include a before-after analysis of collisions using a control group. To date, no studies of this type have been conducted. If this is not possible, an evaluation using high-quality reference sites could provide better safety estimates by eliminating possible regression-to-the-mean bias. We apparently did not have a regression-to-the-mean issue during this study, because of the lag between site selection and program initiation, but other studies may not be so fortunate. Cities wishing to conduct evaluations of countermeasure such as automated speed enforcement should involve the research team as early as possible to set up the most promising study methodology. One other potential evaluation could be a meta-analysis using other studies done across the U.S., allowing more general conclusions to be drawn.

This study of automated speed cameras was more rigorous than most studies conducted because comparison sites were shown to act similarly to treated sites based on previous collision counts. However, a larger sample size of collisions in the after period would provide a much better indication of the actual effects cameras have on driver behavior in the Charlotte area. We strongly urge the City of Charlotte to continue analyzing their program using the framework we have established.

Lastly, we would like to see speed enforcement cameras tried in other locations such as freeways, rural roads, residential streets, school zones, work zones, or downtown areas. Focus groups indicated that they would like to see cameras used in a variety of areas to keep drivers in compliance with posted speeds and reduce the potential for dangerous collisions.

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Appendix A:

Legislative Bill 562

GENERAL ASSEMBLY OF NORTH CAROLINA

SESSION 2003

SESSION LAW 2003-280
HOUSE BILL 562

AN ACT TO AUTHORIZE THE CITY OF CHARLOTTE TO USE PHOTOGRAPHIC SPEED-MEASURING SYSTEMS DURING A THREE-YEAR PILOT PROGRAM IN DESIGNATED CORRIDORS; TO AUTHORIZE THE CITY OF CHARLOTTE TO ESTABLISH CIVIL PENALTIES FOR SPEED LIMIT AND SCHOOL ZONE SPEED LIMIT VIOLATIONS; AND TO AUTHORIZE THE NORTH CAROLINA CRIMINAL JUSTICE EDUCATION AND TRAINING STANDARDS COMMISSION AND THE SECRETARY OF CRIME CONTROL AND PUBLIC SAFETY TO APPROVE STANDARDS FOR THE PHOTOGRAPHIC SPEED-MEASURING SYSTEMS.

The General Assembly of North Carolina enacts:

SECTION 1. Chapter 160A of the General Statutes is amended by adding a new section to read:

"**§ 160A-300.4. Use of photographic speed-measuring systems.**

(a) A photographic speed-measuring system is a speed-measuring system that works in conjunction with a photographic, video, or electronic camera to automatically measure the speed and produce photographs, video, or digital images of vehicles violating a speed limit or speed restriction.

(b) A photographic speed-measuring system shall be approved, calibrated, and tested for accuracy in accordance with G.S. 8-50.3.

(c) A photographic speed-measuring system shall be monitored by a sworn law enforcement officer at all times that the system is actively in use.

(d) Any photographic speed-measuring system installed or in use on a street or highway shall be identified by appropriate advance warning signs conspicuously posted not more than 1,000 feet from the location of a photographic speed-measuring system. All advance warning signs shall be consistent with a statewide standard adopted by the Department of Transportation.

(e) A municipality may adopt ordinances for the civil enforcement of G.S. 20-141 and G.S. 20-141.1 by means of a photographic speed-measuring system. Notwithstanding the provisions of G.S. 20-141, 20-141.1, and 20-176, in the event that a municipality adopts an ordinance pursuant to this section, a violation of G.S. 20-141 or G.S. 20-141.1 detected by a photographic speed-measuring system shall not be an infraction or misdemeanor. An ordinance authorized by this subsection shall provide that:

(1) The owner of a vehicle shall be responsible for a violation unless the owner can furnish evidence that the vehicle was, at the time

of the violation, in the care, custody, or control of another person. The owner of the vehicle shall not be responsible for the violation if the owner of the vehicle furnishes, within 21 days of notification of the violation, to the officials or agents of the municipality that issued the citation either of the following:

a. The name and address of the person or company who leased, rented, or otherwise had the care, custody, or control of the vehicle.

b. An affidavit stating that the vehicle involved was, at the time of the violation, stolen or in the care, custody, or control of some person who did not have permission of the owner to use the vehicle.

(2) A violation detected by a photographic speed-measuring system shall be deemed a noncriminal violation for which a civil penalty of fifty dollars ($50.00) shall be assessed and for which no points authorized by G.S. 20-16(c) or G.S. 58-36-65 shall be assigned to the owner or driver of the vehicle.

(3) The owner of the vehicle shall be issued a citation, written in both English and Spanish, clearly stating the manner in which the violation may be challenged and containing both a street address within the municipality and a local or toll-free telephone number at which the owner may challenge the citation. The citation shall be processed by officials or agents of the municipality and shall be forwarded by personal service or certified mail to the address given on the motor vehicle registration. If the owner fails to pay the civil penalty or to respond to the citation within the time period specified on the citation, the owner shall have waived the right to contest responsibility for the violation and shall be subject to an additional penalty not to exceed fifty dollars ($50.00). The municipality may establish procedures for the collection of these penalties and may recover the penalties by civil action in the nature of debt.

(4) The municipality shall provide a nonjudicial administrative hearing process to review objections to citations or penalties issued or assessed under this section. The administrative hearing process shall include methods for challenging the violation or penalty either in person, at the street address provided on the citation, or through the telephone, at the telephone number provided on the citation. The municipality shall ensure that a Spanish-speaking person is available both at the street address and through the telephone number to assist Spanish-speaking persons. An administrative hearing decision shall be subject to review by the superior

court by proceedings in the nature of certiorari. Any petition for review by the superior court shall be filed with the clerk of superior court within 30 days after the administrative hearing decision.

(5) The clear proceeds from the citations issued pursuant to the ordinance authorized by this section shall be paid to the county school fund. The clear proceeds from the citations shall mean the funds remaining after paying for the lease, lease-purchase, or purchase of the photographic speed-measuring system; paying for operation of the system, either by the municipality or by a contractor; paying for a program to provide public awareness of the system; and paying any administrative costs incurred by the municipality related to the use of the system."

SECTION 2. Chapter 8 of the General Statutes is amended by adding a new section to read:

"**§ 8-50.3. Results of photographic speed-measuring instruments; admissibility.**

(a) The results of the use of a photographic speed-measuring system as described in G.S. 160A-300.4 shall be admissible as evidence in a nonjudicial administrative hearing held pursuant to G.S. 160A-300.4(e)(4) for the purpose of establishing the speed of the vehicle detected.

(b) Notwithstanding the provisions of subsection (a) of this section, the results of a photographic speed-measuring system are not admissible unless all of the following are established:

(1) The photographic speed-measuring system employed was approved for use by the North Carolina Criminal Justice Education and Training Standards Commission and the Secretary of Crime Control and Public Safety pursuant to G.S. 17C-6.

(2) The photographic speed-measuring system had been calibrated and tested for accuracy in accordance with the standards established by the North Carolina Criminal Justice Education and Training Standards Commission and the Secretary of Crime Control and Public Safety for that particular system.

(3) At the time the results were obtained, the photographic speed-measuring system was being operated by a sworn law enforcement officer who has been certified by the North Carolina Criminal Justice Education and Training Standards Commission under G.S. 17-6(a).

(c) All photographic speed-measuring systems shall be calibrated and tested in accordance with standards established by the North Carolina Criminal Justice Education and Training Standards Commission and the Secretary of Crime Control and Public Safety. A written certificate by a technician certified by the North Carolina Criminal Justice Education and Training Standards Commission showing that a test was made within the required testing period and that the system was accurate shall be competent and prima facie evidence of those facts in a nonjudicial administrative hearing held pursuant to G.S. 160A-300.4(e)(4).

(d) In every nonjudicial administrative hearing held pursuant to G.S. 160A-300.4(e)(4), where the results of a photographic speed-measuring system are sought to be admitted, notice shall be taken of the rules approving the photographic speed-measuring system and the procedures for calibration or testing for accuracy of the system."

SECTION 3. G.S. 17C-6(a) reads as rewritten:

"(a)In addition to powers conferred upon the Commission elsewhere in this Chapter, the Commission shall have the following powers, which shall be enforceable through its rules and regulations, certification procedures, or the provisions of G.S. 17C-10:

...

(13a) In conjunction with the Secretary of Crime Control and Public Safety, approve use of specific models and types of photographic speed-measuring systems as described in G.S. 160A-300.4(a) and establish the standards for calibration and testing for accuracy of each approved system."

SECTION 4. Section 1 of this act applies to the City of Charlotte only, and the photographic speed-measuring systems may only be used in the following corridors:

(1) South Boulevard between Interstate 485 and Scaleybark.
(2) Independence between Briarcreek and Sardis Road North.
(3) East W.T. Harris between The Plaza and Idlewild.
(4) Tryon Street from 36th to Orr Road.
(5) Tryon Street between Mallard Creek Church Road and University City Boulevard.
(6) Eastway between Independence and Sugar Creek.
(7) West W.T. Harris between North Tryon Street and Technology Drive.
(8) Albemarle Road between Independence and Lawyers.
(9) Central between Albemarle and Briar Creek.
(10) Monroe Road between Sardis Road North and Wendover.
(11) Providence between McKee and Providence Country Club.
(12) Highway 51 between Park Road and Alexander Road.
(13) Sharon Amity between Lyttleton Drive and East W.T. Harris.
(14) Billy Graham Parkway between Interstate 85 and Woodlawn.

SECTION 5. This act becomes effective July 1, 2003, and expires June 30, 2006.

In the General Assembly read three times and ratified this the 18th day of June, 2003.

s/ Beverly E. Perdue
President of the Senate

s/ Richard T. Morgan
Speaker of the House of Representatives

This bill having been presented to the Governor for his signature on the 19th day of June, 2003 and the Governor having failed to approve it within the time prescribed by law, the same is hereby declared to have become a law.

This 30th day of June, 2003

s/ Leigh A. Goodman
Enrolling Clerk

Appendix B:

Charlotte Flyer on Automated Speed Enforcement

Why do we need Safe Speed?

In 2003 when the City and the Charlotte Mecklenburg Police Department sought the legislative approval for Safe Speed, the city had experienced nearly 27,000 crashes. Speed was the primary factor in 26 of 53 fatalities and more than 2700 people were injured in speed related crashes. Numbers that high place a tremendous resource drain not only on the CMPD, but Fire and Medic as well. Although new to this area, automated speed enforcement has been in use for more than 25 years and has shown to effectively reduce the incidents of speeding and vehicle crashes, and frees up public safety resources to address other safety issues.

Will I get a citation for going 2-3 mph over the speed limit?

No. The established thresholds speeds are reasonable and based on factors such as the number and severity of crashes in the areas where Safe Speed is deployed. However, the speed limit is just that – the Limit. And motorists who drive within that limit are less likely to be involved in a crash that injures themselves, their loved ones, or other motorists.

How do I know it was my vehicle clocked by Safe Speed?

Safe Speed utilizes laser speed measuring technology. This technology is target-specific and many times more precise than conventional radar systems. At 500 feet, the laser beam is only 18 inches wide. To further confirm the vehicle targeted, the laser signal is encrypted on the photograph of the speeding vehicle. And to insure accuracy, Safe Speed technology is checked daily for calibration.

How is Safe Speed funded?

Safe Speed is self-funded through citation revenue at no cost to local government. The contractor, Peek Traffic, supplies all equipment and processes citations for a share of the citation revenue. The City's share of citation revenue pays for items such as fuel costs, public education, adjudicator fees, and speed studies.

Doesn't Safe Speed violate my rights?

No. Speeding is a violation of State law and City ordinance, and motorists who exceed the speed limit are subject to enforcement action by police officers. Those officers employ a variety of techniques and technologies to detect speeding vehicles, including pacing and the use of RADAR and VASCAR. The Safe Speed legislation allows for the use of Laser to detect speeding vehicles. Safe Speed is simply another tool used to act on the authority to enforce speed regulations, and to help the CMPD reduce the number of vehicle crashes.

Why has no money been sent to the school system?

The Safe Speed legislation requires revenue generated by the program to go to the school system after all operating costs are paid. Since citation revenues pay for those costs, no expenses are passed on the taxpayers, and none of the proceeds go to the City or the CMPD. Once operating costs have been paid, any and all additional revenue will be sent to the school system. But it's important to remember that Safe Speed is, first and foremost, a safety program.

Where can Safe Speed be deployed?

Safe Speed can only be deployed along 14 designated high crash corridors. These corridors constitute less than 2% of our total road mileage but account more than 30% of speed related crashes.

What warning signs are required?

The Safe Speed legislation requires a warning sign prior to and within 1000 feet of the enforcement vehicle. To meet this requirement, the City placed a supplemental Photo Enforced sign under each speed limit sign along the designated corridors. These signs alone meet the legislative requirement and there are 298 of them in the designated corridors. In addition, to raise public awareness about the program and make motorists more attentive to the speed limit, a portable sign is placed prior to the enforcement vehicle. The enforcement vehicle is also marked. Although these additional steps were not required by the legislation it is the City's and CMPD's intent to provide citizens with every opportunity to voluntarily comply with the speed limits.

Can I appeal a citation?

Yes. A citizen can appeal a citation in writing, by phone or in person. An Adjudicator will review the evidence and make a ruling to uphold or dismiss the citation.

Are the police officers using Safe Speed trained?

The officers deploying Safe Speed receive the same type of training as they do for other speed measuring devices, and must hold certifications issued by the North Carolina Criminal Justice Education and Training Standards division.

What do citizens think about automated enforcement?

A 2004 UNCC Urban Institute poll shows 67% of residents favor the use of automated enforcement to control incidents of speeding. In addition, 70% of residents believed speeding was a major threat to their personal safety and 89% were aware of the Safe Speed program. More than 70% of AAA members polled in North Carolina and South Carolina favored the use of automated enforcement to control speeding and red light running.

DRIVE LIKE YOUR LIFE DEPENDS ON IT.

Traffic Safety Advisory Committee

CHARLOTTE.

SAFE SPEED

Questions and Answers about Charlotte's Automated Speed Enforcement Program

Appendix C:

Citation History Along Fourteen Treatment Corridors

Citation History August 2, 2004 to September 19, 2005			
Intersection	Site Name	Incidents	Citations
8700 Block Highway 51 east	511	0	0
5400 Block Highway 51 east	512	8	5
Highway 51 at McPearson east	513	49	30
Highway 51at Reverby Lane east	514	10	5
2600 Highway 51 west	515	82	56
7132 Highway 51 west	516	18	2
Highway 51 at Charter Oaks Rd. west	517	0	0
5426 Highway 51 west	518	0	0
4200 Block East of McPearson west	519	36	26
5800 Albemarle Road east bound	A01	9	5
5525 Albemarle Road west bound	A02	12	6
4855 Albemarle Road west bound	A03	22	7
5411 Albemarle Road west bound	A04	0	0
6030 Albemarle Road east bound	A05	0	0
6810 Albemarle Road east bound	A06	0	0
6835 Albemarle Road west bound	A07	0	0
6025 Albemarle Road west bound	A08	0	0
Billy Graham Pky at J Birmingham west	BG1	29	14
Billy Graham Pky at J Birmingham east	BG2	272	151
Billy Graham Pky at Tyvola Rd. east	BG3	3127	2032
Billy Graham Pky at Tyvola Rd. west	BG4	122	57
Billy Graham Pky at Farmers Market east	BG5	70	23
Billy Graham Pky at Westmont west	BG6	17	6
4633 Central Ave west	C01	3892	2521
Central Ave at Central Terrace Apt east	C02	47	29
4019 Central Ave west bound	C03	135	68
Central Ave at Methodist Ch east bound	C04	228	55
Central Ave at Episcopal Ch east bound	C05	186	120
3534 Central Ave west bound	C06	41	19
Eastway Dr at Bentley Pl south	E01	26	12
2415 Eastway Dr north	E02	11	6
1720 Eastway Dr north	E03	0	0
Eastway Dr at Hilliard Dr south	E04	0	0
Eastway Dr at Audrey St north	E05	0	0
1100 Eastway Dr south	E06	25	15
East W T Harris at Hickory Grove east	EH1	0	0
8922 East W T Harris east	EH2	18	15
7000 East W T Harris west	EH3	0	0
9710 East W T Harris east	EH4	55	41
8032 East W T Harris east	EH5	71	37
7705 East W T Harris west	EH6	9	3
East W T Harris at Wallace Ave east	EH7	0	0
6601 East W T Harris west	EH8	4	1

4620 East W T Harris east	EH9	901	565
8109 Independence Blvd west	I01	93	58
Independence Blvd at Krefeld Dr west	I02	55	35
7500 Independence Blvd west	I03	3	1
6625 Independence Blvd west	I04	193	139
6191 Independence Blvd west	I05	169	97
6100 Independence Blvd east	I06	309	88
5201 Independence Blvd west	I07	1	0
5226 Independence Blvd east	I08	32	17
3600 Independence Blvd 3600 east	I09	4972	2601
3500-3700 Independence Blvd west	I10	12646	7271
3001 Independence Blvd west	I11	4311	2560
6316 Independence Blvd east	I12	0	0
4732 Monroe Rd east	M01	36	18
5037 Monroe Rd west	M02	21	14
Monroe Rd at Sardis Rd east	M03	3	2
5800 Monroe Rd east	M04	26	11
7301 Monroe Rd west	M05	9	5
8100 Monroe Rd west	M06	0	0
8800 Monroe Rd west	M07	0	0
9315 Monroe Rd west	M08	8	3
Monroe Rd at McAlpine Park east	M09	0	0
Providence Rd at Ardrell Kell Rd.north	P01	2	2
Providence Rd at Ardrell Kell Rd.south	P02	1	0
Providence Rd at Allison Woods north	P03	1	0
Providence Rd at Allison Woods south	P04	9	6
4240 South Blvd north	S01	5302	2821
4240 South Blvd south	S02	2951	1827
4800 South Blvd north	S03	9	6
4800 South Blvd south	S04	0	0
5400 Soth Blvd north	S05	26	18
5400 South Blvd south	S06	137	88
6200 South Blvd south	S07	7	4
6424 South Blvd south	S08	581	357
6547 South Blvd north	S09	122	85
1229 Sharon Amity Rd south	SA1	996	589
Sharon Amity Rd at Clearmont Ave. north	SA2	0	0
Sharon Amity Rd at Wiloria Lake north	SA3	6	2
Sharon Amity Rd at Kimberly Glen north	SA4	1	1
Sharon Amity Road NB	SA5	558	381
7925 Tryon Street south	TM1	172	125
7706 Tryon Street north	TM2	4704	2942
9624 Tryon Street north	TM3	3733	2743
9701 Tryon Street south	TM4	176	107
4200 Tryon Street south	TO1	10	8
4500 Tryon Street north	TO2	17	8
4709 Tryon Street south	TO3	69	37
5410 Tryon Street north	TO4	5	2

1000 West W.T. Harris Blvd west	WH1	301	152
1400 West W.T. Harris Blvd east	WH2	31	20
	Totals	**52346**	**31183**

Appendix D:

Queries and Unions Used to Gather Collision Data from Access Database

Qry Dep Modified All Crashes

- Qry Dep Hwy51 Crashes
  - Qry Dep All Crashes
- Qry Dep Tryon 1 Crashes
  - Qry Dep All Crashes
- Qry Dep Tryon 2 Crashes
  - Qry Dep All Crashes
- Qry Dep WT Harris 1 Crashes
  - Qry Dep All Crashes
- Qry Dep WT Harris 2 Crashes
  - Qry Dep All Crashes
    - Qry Dep Segment Crashes
      - *ControlLinkTable*
      - *tAccAllData*
    - Qry Dep Intersection Crashes
      - Qry Dep Nodes
        - Qry Dep Nodes (Intermediate)
          - NodeTable
          - LinkTable
      - *tAccAllData*
- Qry Dep All other Crashes
  - Qry Dep All Crashes

Note: Red (italicized) tables and queries were base data provided by Charlotte

Qry Con Modified All Crashes

- Qry Con Morehead/Queens/Providence Crashes
  - Qry Con All Crashes
- Qry Con Fairview/Tyvola Crashes
  - Qry Con All Crashes
- Qry Con All other Crashes
  - Qry Con All Crashes
    - Qry Con Segment Crashes
      - *tAccAllData*
      - *ControlLinkTable*
    - Qry Con Intersection Crashes
      - Qry Con Nodes
        - Qry Con Nodes (Intermediate)
          - Qry Con Street1 Nodes
            - *ControlLinkTable*
            - *ControlNodeTable*
          - Qry Con Street2 Nodes
            - *ControlLinkTable*
            - *ControlNodeTable*
          - Qry Con Street3 Nodes
            - *ControlLinkTable*
            - *ControlNodeTable*
      - *tAccAllData*

Note: Red (italicized) tables and queries were base data provided by Charlotte