REDUCING AGGRESSIVE DRIVING BEHAVIOR

Clearly Conveying Enforcement Wave Initiatives to Citizens Using Portable Changeable Message Signs

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Disclaimer

Abstract

The Federal Motor Carrier Safety Administration and the National Highway Safety Administration, as well as other local, state, and national organizations regularly conduct enforcement programs geared toward improving safety on the nation's roadways. Many of these programs are very successful; however, others indicate far less success. Previous research shows that a lack of success in these programs, in large part, may be due to the fact that the enforcement waves conducted under many of these programs may not be as well understood. Successful programs like Booze-It-and-Lose-It and Click-It-or-Ticket clearly convey what is being enforced when citizens drive through checkpoints; however, other programs are less likely to convey to drivers what is being enforced. Instead, citizens tend to believe speeding is the primary intent of patrols during an enforcement wave.

This research studies the effect of portable changeable message signs (PCMS) on aggressive driving behavior through a 6-mile enforcement zone. The PCMS is installed at the site over a four-month period, while enforcement is only conducted during a short one-week wave. Traffic was monitored at two interchanges just downstream of the sign, one and six miles away. The sign alone was not found to significantly affect traffic behavior through the 6-mile zone; however, supplementing the signage with enforcement did show positive effects, in addition some long-term impacts one month after enforcement for some measures. PCMS was shown to be a viable tool for enforcement agencies to convey the meaning of the enforcement waves. In addition, these findings indicate a positive correlation in the sustained effect after enforcement leaves the site.

Keywords: enforcement, sign, high visibility enforcement

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Introduction

The Federal Motor Carrier Safety Administration and the National Highway Safety Administration, as well as other local, state, and national organizations regularly conduct enforcement programs geared toward improving safety on the nation's roadways. Although there are many proven, long-standing enforcement programs, such as Click-It-or-Ticket *(1)* and Booze-It-and-Lose-It *(2)*, there are equally as many that do not have the sustained long-term impact. Often-times significant financial resources and time are put toward these programs through enforcement, media campaigns, and infrastructure, such as highly visible trucks or buses for impairment testing. However, not-withstanding that these efforts are expensive, the majority of these efforts are temporal or only applicable to the site being enforced, and arguably the most important effort, enforcement, is not properly conveying the intent of the program to the driving public. For instance, the success of the Booze-It-and-Lose-It program could be attributed to the fact that it is very clear to drivers what checkpoints are intended to enforce. However, in contrast, a program geared towards distracted driving (i.e. texting) or aggressing driving behaviors around trucks (i.e. FMCSA's "Ticketing Aggressive Cars and Trucks" program *(3)*) are the exact opposite in that enforcement on these target locations does not convey the intent of the program. The overwhelming majority of drivers that pass through an enforcement zone are more likely to believe that drivers are being pulled over for speeding.

Previous research on newer, less visible, enforcement waves help emphasize the point of the authors. These programs are conducted across the country using a combination of enforcement waves, radio and television ads, billboards, and posted road signs, among other efforts. FMCSA's "Ticketing Aggressive Cars and Trucks," or TACT, enforcement program focuses on aggressive driving behavior around heavy vehicles. A recently completed effort in North Carolina found that aggressive driving, primarily measured by studying the following behavior of all vehicle types, found that drivers did not change their following distances before, during, or after enforcement *(10)*. Instead, the research team saw that speed was the primary effected measure during enforcement. Although enforcement was positive, it did not show any improvement on the intended measure – following behavior of vehicles. When looking at speeding alone, even though speeds were effected during enforcement, the effect of enforcement on speeding was not sustained at that site. In fact, within hours of enforcement leaving, speeding returned to normal levels with no sustained impact. Since this study, NC State Highway Patrol has changed protocol to multiple enforcement waves over shorter periods of time to get maximum exposure. However, the subject of patrol wave intent is still not being relayed to citizens who clearly do not understand what is being enforced.

Another new and nationally recognized program, "High Visibility Enforcement," or HVE, has recently been studied in several states. In a two-wave HVE study on aggressive driving, Tarko et al. found reduction in aggressive driving was not sustained after enforcement was reduced to every-day levels despite increased awareness of the media campaign *(4)*. In contrast, a separate campaign evaluated by Chaudhary et al. studied HVE in the Syracuse, New York region as well as in Hartford, Connecticut *(5)*. A four-wave media and enforcement campaign was used to inform drivers of the ban on the use of handheld phones while driving. A survey of drivers concluded that there was increased awareness from the first wave to the fourth wave. This awareness translated to reduced cellphone usage of 57% in NY and 72% in CT as observed by researchers. Similar research in Delaware and California also saw reductions *(6)*. Interestingly, the latter study appears to have shown more success than the former which may give credence to providing waves of enforcement over a longer period of time to increase awareness. As noted with NC's TACT program, they have initiated shorter, more frequent waves to try to provide a more sustained effect.

The objective of this research effort was geared towards testing portable changeable message signs (PCMS) as a supplement to other less visible, but equally important, enforcement programs. PCMS is a cost-effective solution that provides information to the public on what is actually being enforced prior to entering an enforcement zone to provide citizens a clear understanding of the campaign being enforced. Although PCMS is primarily intended to be used during an actual enforcement wave, there are other possible advantages: 1) they can be easily installed prior to enforcement waves to assist in further saturating the public on the campaign being targeted, 2) they can be left out after enforcement waves to potentially extend the intended effect, and 3) they can be installed when no enforcement is taking place to bring additional awareness to the specific zone of interest. The first two additional advantages are considered in this research effort to provide additional insight to those agencies considering PCMS during enforcement waves. The latter is something that agencies should consider if conducting random enforcement waves to extend the impact of patrol initiatives throughout the year.

Methodology

This research focused on measuring the impact of a portable changeable message sign, or PCMS, used in conjunction with police enforcement to reduce aggressive driving behavior by and between vehicles of various types – specifically in instances of unsafe gaps by vehicles following too close, as well as in ensuring safe travel speeds of vehicles along the corridor. Video monitoring was used to measure and record gap sizes and speeds at four locations during three periods: before enforcement, during enforcement, and after enforcement. The PCMS was present during all three periods.

EVALUATION APPROACH

The evaluation framework rested on the assumption that continuous observations at a fixed, representative location could provide an effective sample of the traffic behavior of a facility. While monitoring over extended segments is preferable, range limitations of roadside or overhead monitoring technology make measurements over an extended distance infeasible. Therefore, detection took place at fixed positions along the roadway.

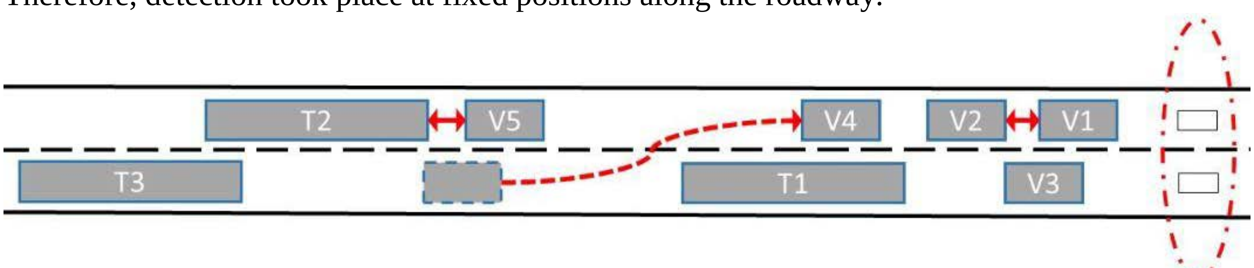


FIGURE 1: SCHEMATIC OF EVALUATION APPROACH

Figure 1 illustrates a snap shot in time of the relative position of various vehicles on a hypothetical two-lane freeway segment with a mix of passenger cars (V1-V5) and trucks (T1-T3). The elliptical shape denotes a hypothetical sensor location which, in this experiment, involves video detection loops. The relative position of trucks and passenger cars highlight several "aggressive" maneuvers, which were recorded as surrogate measures to describe the general level of safety in the traffic stream:

- Following-too-Close (FTC), an event where the time gap between two successive vehicles is too short to allow for appropriate driver reaction time, illustrated between cars V1 and V2 and vehicles T2 and V5.
- Truck-Following-too-Close (TFTC), a specific FTC event where the vehicle following too closely is a truck, illustrated between T2 and V5. This situation is of particular importance because heavy vehicles are incapable of decelerating as quickly as passenger cars.
- Aggressive Lane Changing (ALC), an event where a vehicle changes lanes in a manner that forces reactive deceleration or swerving by one or more other vehicles, illustrated by vehicle V4 moving in front of vehicle V5 in an attempt to overtake a slower-moving truck (T1).
- Speeding Vehicle (SV), an event where a vehicle travels more than 10mph over the posted speed limit (this event is not directly illustrated in Figure 1).

With the exception of ALC events, the remaining three measures can readily be observed at fixed observation locations. More importantly, all three measures are primarily based on speed and relative position data of one or more vehicles, which can be recorded using video detection. The automated collection of these performance measures is desirable because it has the potential to a) greatly decrease analysis time, b) increase sample size, c) improve reliability across multiple sites, and d) eliminate human observer bias. It is critical that the behaviors in question be *observable* and *quantifiable* and that a change in their frequency or rate can be shown to be associated with the presence of enforcement and/or signage. In addition, the automated video detection of such measures may prove beneficial in future efforts such as the use of Intelligent Transportation Systems (ITS) to provide real time feedback to drivers when aggressive driving maneuvers are taking place.

VIDEO-BASED EVALUATION

Several technologies were available to measure the driver behavior patterns of interest, including 1) in-road traffic sensors (magnetic inductance loops), 2) side-fire radar/microwave sensors, and 3) overhead video observations. In the research team's assessment, options 1 and 2 had significant potential for long-term instrumentation but are associated with the significant disadvantage that the results cannot be confirmed visually. Consequently, the team selected a video-based evaluation of the performance measures and deferred testing the feasibility of alternative instrumentation methods for future research. A video-based evaluation allowed the opportunity to perform both manual and automated observations. For manual observations, video could be played back (in slow motion if necessary) with a time-stamp overlay to record critical events, if necessary. Alternatively, automated video-image processing software is commercially available that can be used to deliver lane-by-lane volumes, speeds, and classification data, and can further be adopted to identify short gaps, i.e., FTC events. The research team selected the Autoscope software by Econolite©.

In the application of the video-based evaluation approach, overhead mounted traffic cameras were used to gather video data, which were recorded to a Digital Video Recorder (DVR). For automated processing with video-detection, cameras needed to be placed at an elevated vantage point; preferably on a bridge or overpass, but could also be mounted on nearby poles if necessary. The vantage point from an overpass is preferable as it minimized the potential for occlusion, for example a tall vehicle in one lane might block the view of a vehicle in an adjacent lane. The research team used cameras that were easily mountable and inconspicuous, and have small boxes that house the DVR, batteries, and excess cable.

Site Selection

There were several roadway characteristics that were required to ensure efficient data collection and similar traffic patterns each day. Originally, the research team had anticipated being able to collect adequate data in conjunction with the “Safe Drive on I-95” enforcement campaign. This campaign’s goal is to reduce traffic crashes and fatalities involving large trucks and buses by working to change driver behavior. It was scheduled to occur at sites within a reasonable distance from ITRE and during the timeframe of interest to the research team. Enforcement was scheduled to occur along I-95, I-77, I-85, and I-40, which are all major truck routes in the state of North Carolina. This included three-day periods in March, June, and August, with one more occurring in November.

While the “Safe Drive on I-95” campaign initially appeared to be ideal for this data collection effort, it was discovered that this campaign was only being carried out by FMCSA patrol officers and would not result in an increased enforcement presence, but simply a focus on identifying violations occurring in and around heavy vehicles. Therefore, in order to ensure an increased enforcement presence, as is required by high visibility enforcement standards, the research team contacted Troop C of the NCSHP and requested that there be an increase in the number of officers present in and around the study corridor during the research effort. This request was graciously granted by the NCSHP and there was a noticeable increase in law enforcement presence along this corridor during the week of first week of August. As a result, the research team was able to capture an adequate sample size of vehicles traveling through the enforcement corridor during this time period.

Moving on, the ideal site for testing would be limited to a width of three lanes based on previous experience with Autoscope’s video detection program. In previous studies, when using one camera to collect data on more than three lanes of traffic, instances of occlusion were common, particularly with trucks, resulting in invalid data for certain lanes. Another consideration made was for the freeway to be operating close to free flow speed during the study period each day. When roadways become congested, the timing of the detections for Autoscope can be thrown off, inducing false counts. These characteristics help create an ideal setup that allows for the efficient collection of accurate data.

Based on these criteria, a seven mile corridor along I-95 was selected for study implementation, with the PCMS being placed at the overpass of State Route 1154, and cameras being placed at the NC-42 and NC-581 overpasses. This selected corridor was under the enforcement of NCSHP's Troop C throughout each of the enforcement periods. Within this corridor, there are only two lanes in each direction which made it an optimal candidate for use with Autoscope as there would be little-to-no occlusion from vehicles in adjacent lanes. The AADT for this corridor was estimated at 27,000 vehicles (8). The relatively low AADT and proximity to other large freeways meant this corridor would likely not experience much congestion, if at all. Upon visiting the site, this assumption was confirmed as traffic was in constant free flow during field installations and was further confirmed in manual reviews of recorded video. Further, no interchanges are present between the NC-42 interchange and NC-581 overpass meaning that traffic is nearly identical in each direction at any given time, as a negligible number of vehicles enter I-95 southbound from NC-42 or exit onto NC-42 from I-95 northbound. This observation was confirmed by the vehicle and truck counts produced by the video detection software. Lastly, this site allowed for safe setup of recording devices as the overpass shoulders and medians at both locations were wide enough to stand comfortably without interrupting traffic. Satellite imagery of these sites is provided in Figure 2.

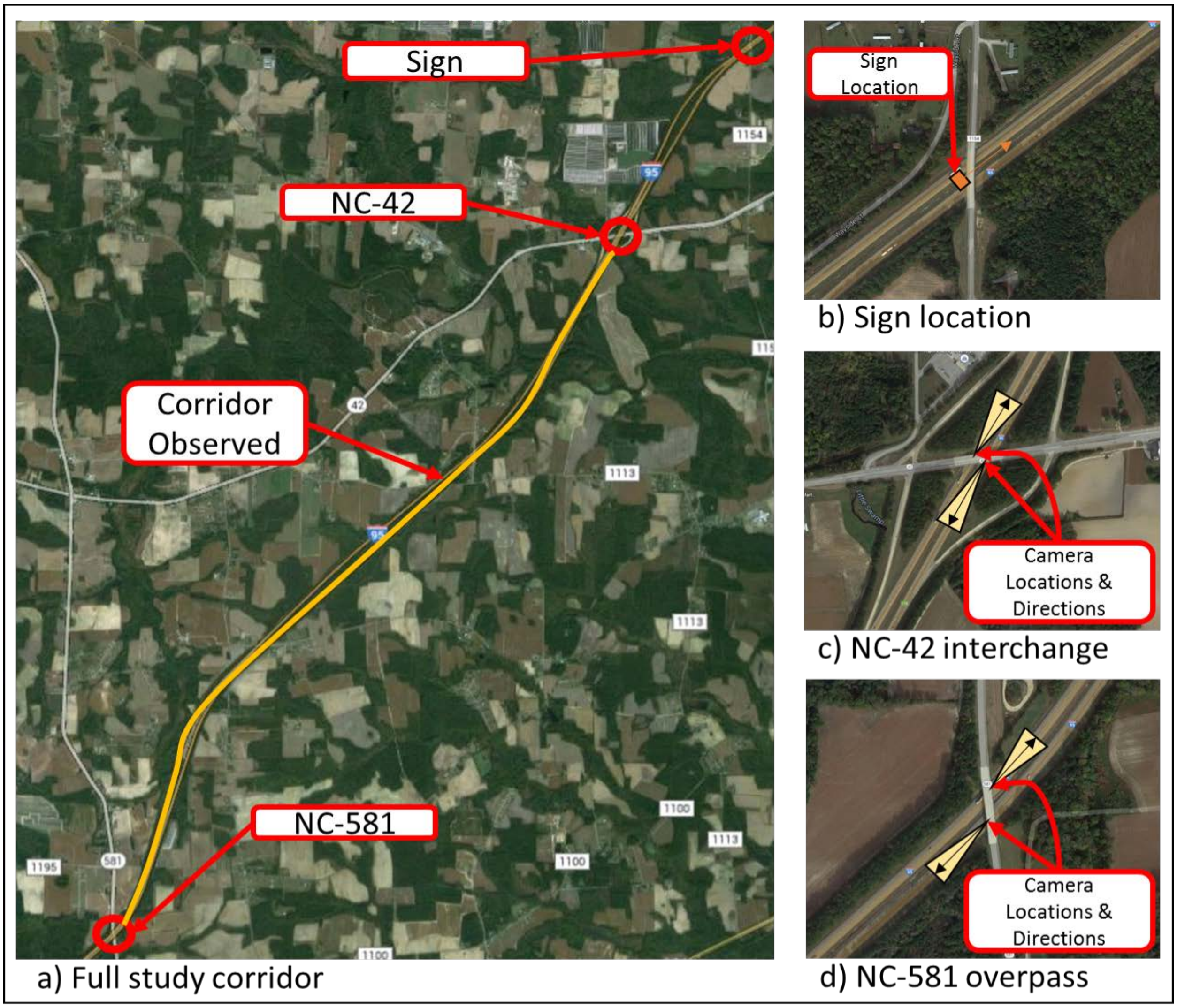


FIGURE 2: SITE SATELLITE IMAGERY

Field Data Collection Setup

As stated, the initial experiment design included four cameras mounted on the NC-42 and NC-581 overpasses facing upstream centered on the lane line dividing the two traffic lanes in each direction. Two cameras each were mounted to record northbound and southbound traffic. Although four locations were utilized, the camera capturing I-95 northbound traffic at NC-42 experienced a number of issues, i.e. it was stolen, and therefore did not record an adequate amount of video data and was not included in the analysis. Since this was one of two control sites, the 581 interchange site was utilized to control for externalities.

As shown in Figure 3, a PCMS sign was installed in the median immediately upstream of the State Route 1154 overpass. This overpass is approximately one and a half miles north of NC-42 and seven miles north of NC-581. The PCMS followed all applicable MUTCD guidance regarding the number of units of information, the duration of each phase, the transition period between phases, etc. found in Chapter 2L of the MUTCD (*9*). The two phases shown to drivers included “DO NOT TAILGATE” and “ENFORCED NEXT 10 MILES.” Although not a technical term, “tailgate” was used because it conformed to the character limitations – eight letters per word, no words broken between two lines, conservative use of contractions or abbreviations – and is understood and used by many motorists in everyday language.

The PCMS was visible only by southbound drivers, allowing for the northbound site to be used as a controlled comparison site. This allowed the research team to account for any changes in FTC that were related to factors not considered in this study (weather, unexpected media focus on driving behaviors, etc.). Enforcement of any kind was done outside the seven-mile camera boundary area whenever possible to reduce the effect of driver behavior through those detection zones (i.e. slowing down to go around a police officer).

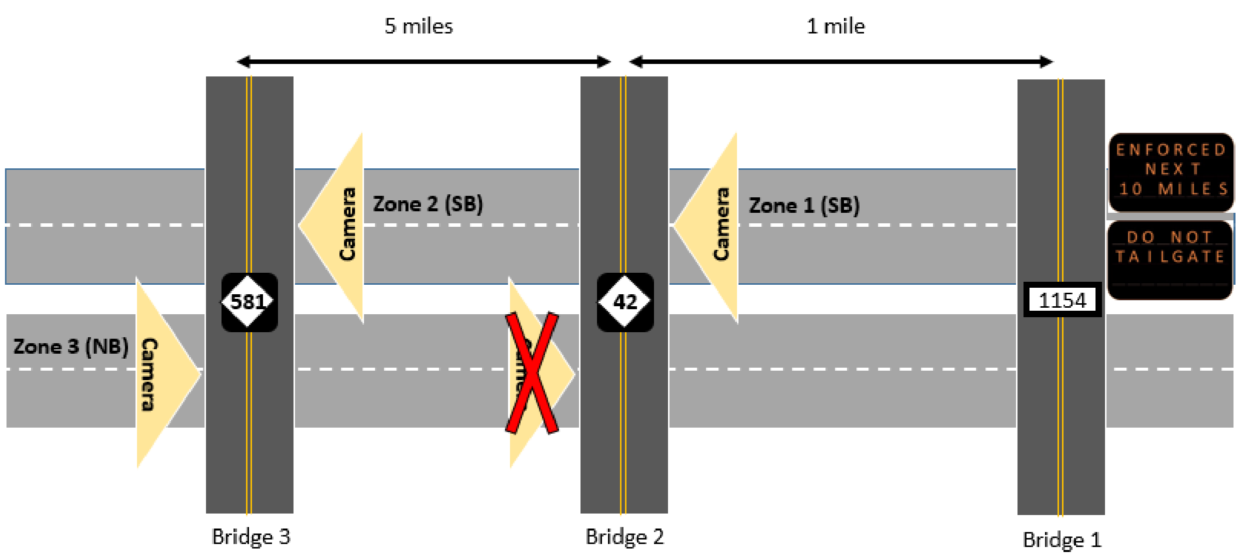


FIGURE 3: SIGN & CAMERA SETUP

Video-Based Algorithm & Detection

The recorded video was downloaded and played back through the Econolite's Autoscope Rackvision Terra system with virtual detectors overlaid on the video. Using a few dozen virtual detectors, the detection file was able to determine the presence of vehicles, trucks, and FTC events. This file included two count detectors, one in each lane, which were placed perpendicular to the travel direction. The virtual count detectors are capable of being paired in several various combinations and are capable of using functionality based on time delay or other notable features. The functionality present in Autoscope allowed the team to get traffic counts, FTC events, and speeds. For detection of FTCs, vehicles, and trucks, an arrangement of each of these detectors determined when these events occurred and how many of these events occurred over time. Figure 4 provides an image of the Autoscope detectors in place for one site. The virtual detection zones represented as count and speed detectors are placed on the roadway lanes. Functions tying the detectors together are shown as AND, OR, and NOR functions. When the functions meet the correct conditions, a count is provided as shown in the labels, V (volume), Truck (truck volume), FTC (FTC event), and TFTC (truck FTC event). These were provided for the left and right lanes separately. Speeds were shown in the individual lanes and were determined using speed detectors. All data were polled in 15-minute increments.

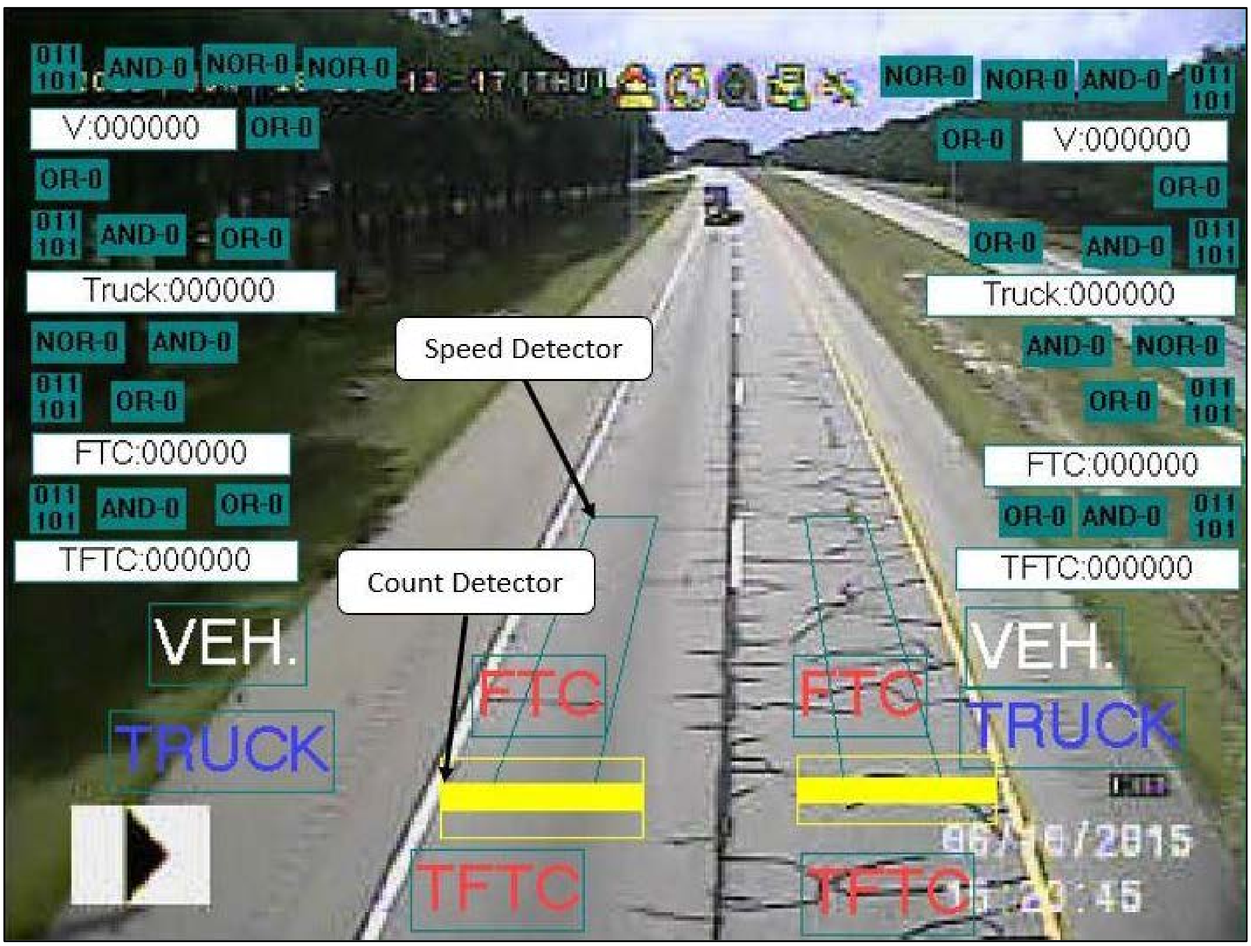


FIGURE 4: AUTOSCOPE ALGORITHM FOR NC-42 SOUTHBOUND

All of the logic for FTC detection ran through the count detector, while timing delays, extensions, and Boolean detectors helped in determining what type of vehicle was present. The setup across all sites was identical. Figure 5 demonstrates how each count was calculated through the sets of logic and timers.

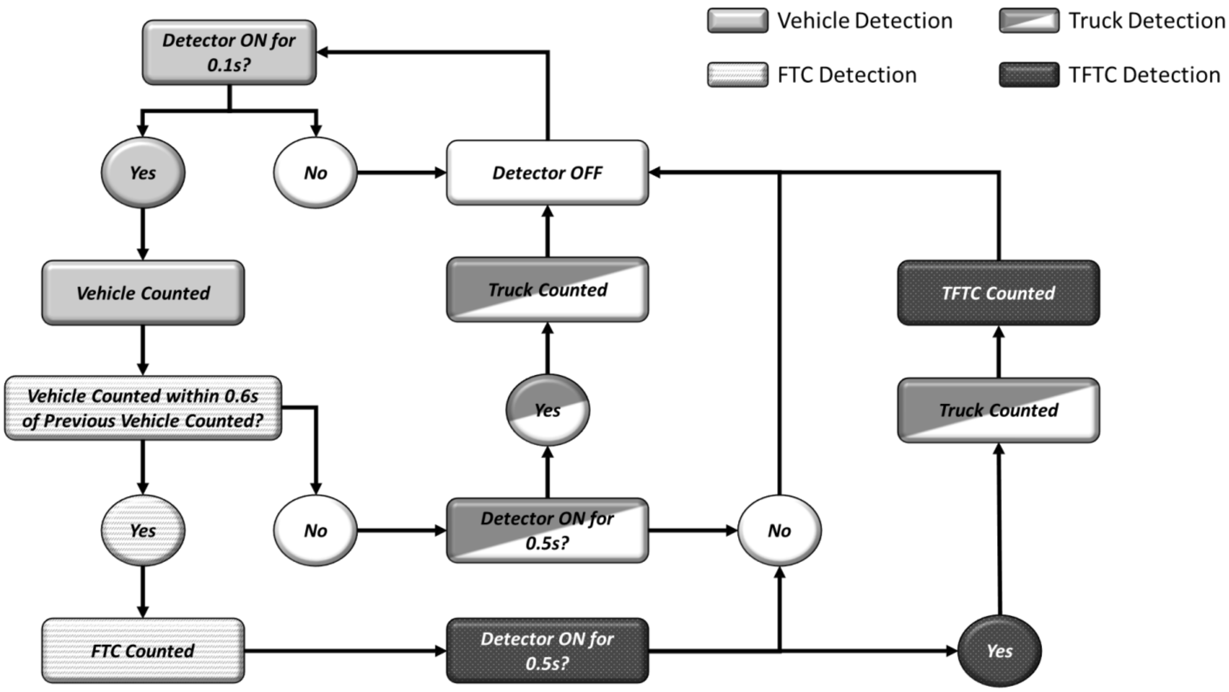


FIGURE 5: AUTOSCOPE DETECTION FLOW CHART FOR COUNT AND FTC EVENTS

VEHICLE COUNTS

A vehicle was counted if the count detector was actuated for a time of 0.1 seconds. This prevented any small change in the background image from being identified as a vehicle (such as a shadow from a cloud or nearby tree). Ideally, this time could have been set to slightly less time so that vehicles traveling at a high rate of speed (over 90mph) would be detected, but Autoscope's times could only be set in increments of tenths of a second with a minimum time of 0.1 seconds. The solid gray boxes in Figure 5 represent requirements for the algorithm to count a vehicle.

TRUCK COUNTS

Once a vehicle was detected, the algorithm was setup so that the length of time the count detector was on could help determine what type of vehicle was present. Generally, the longer the detector was on, the longer the vehicle was. To account for faster trucks and potentially shorter heavy vehicles (dump trucks or buses), the threshold for detecting a truck was set at a 0.5 seconds. In other words, the count detector needed to be activated for 0.5 seconds for the vehicle to be counted as a truck. Notably, this 0.5 second delay is in no way related to the 0.5 threshold for an FTC event. The truck count algorithm is represented by gray and white diagonal boxes in Figure

5. As seen in the figure, there are two places in the cycle where trucks can be counted: after a vehicle or after an FTC. This did not result in double counting, but rather resulted in two different methods for truck detection.

FOLLOWING TOO CLOSE (FTC) COUNTS

In previous research (*10*), a 0.5-second gap had been selected as the maximum gap to classify a FTC event. The Highway Capacity Manual predicts a theoretical freeway capacity of 2,400 passenger-cars per hour per lane, which corresponds to an average headway of 1.5 seconds over an hour, or an approximate gap time of 1.3 seconds at 70 miles per hour. The selected FTC threshold for this analysis was significantly below the 1.3 second capacity threshold, but corresponded well when accounting for reaction time, and therefore represented a sub-section of following times that clearly fell into the aggressive driving range. Therefore, the same threshold of a 0.5-second gap time between vehicles was used for this analysis. Simply put, the front bumper of one vehicle needed to be detected within a 0.5 seconds of the rear bumper of the previous vehicle in order to be considered a FTC event.

However, Autoscope required additional detectors in order to determine that there was a gap between the cars, i.e., that the detector turned off at some point. In order for there to be a perceived gap, a NOR detector was linked to an AND detector with a delay time of 0.1 seconds. This meant that there could not be a vehicle detected for at least 0.1 seconds. Additionally, this delay helped avoid an FTC count when a tractor trailer passed over the detector, which could cause the count detector to turn off and on very quickly. This formulation translated to a second vehicle being counted between 0.1 and 0.6 seconds after a first. The 0.6 seconds was used because of the additional 0.1 seconds that was required to count a vehicle. Realistically, there should have been very few vehicles, if any, with a following time of 0.1 seconds as this is extremely unsafe, equating to only a 10’ gap while going 70mph.

This part of the formulation is represented by gray striped boxes in Figure 5 and stems from the vehicle counting algorithm. Note that if a vehicle was counted and a truck was not, this vehicle was considered a passenger vehicle.

TRUCK FOLLOWING TOO CLOSE (TFTC)

The goal in capturing this specific FTC event was to identify when the vehicle that is tailgating is a truck or heavy vehicle. A truck following another vehicle would be considered much more dangerous, as its larger size and momentum would obviously make it much more difficult for the truck to slow down if the vehicle in front were to rapidly brake. A collision involving a truck would also have a more catastrophic effect on the operation of the freeway. To recognize this hazardous situation, the program needed to observe a truck as the second vehicle passing through the detector after it had already recognized an FTC. TFTC event calculation is represented in dark gray in Figure 5 and follows only after an FTC is counted.

SPEED DETECTION

Throughout this segment of interstate, the posted speed limit was 70 miles per hour. It was decided that an 80 mile per hour threshold would be used to determine speeding vehicles, or anything exceeding 9 miles per hour over the speed limit. This was chosen because roadways are designed for drivers to travel at five miles per hour over the posted speed limit; therefore, a threshold of ten miles per hour in excess of the posted speed limit was considered to be aggressive. Due to the lack of congestion along this corridor, speeds detected below 50 miles per hour were considered outliers or errors in detection and therefore were not included in the analysis. Note that it was difficult to calibrate the speed of vehicles as consistent across all sites due to camera angles and roadway geometry. However, this did not affect the analysis results, as the analysis consisted of a before-after comparison within each site, not a site-to-site comparison.

SHADOW DETECTION

The consistency of this entire algorithm relied entirely upon the count detector turning on and off properly. If the detector was able to detect the presence of a vehicle accurately, the program was able to sort through the logic properly. However, problems with vehicle detection tended to occur during periods where vehicles or other objects cast shadows across the freeway. If not accounted for, shadows can result in the activation of the count detector in an empty lane simply because a vehicle is in the adjacent lane. In an effort to avoid this issue, lighting settings were changed so that Autoscope would assume the same lighting orientation throughout the recorded period. AM and PM templates were created for the desired shadow direction, allowing the algorithm to account for shadows based on the time of day of the video being processed.

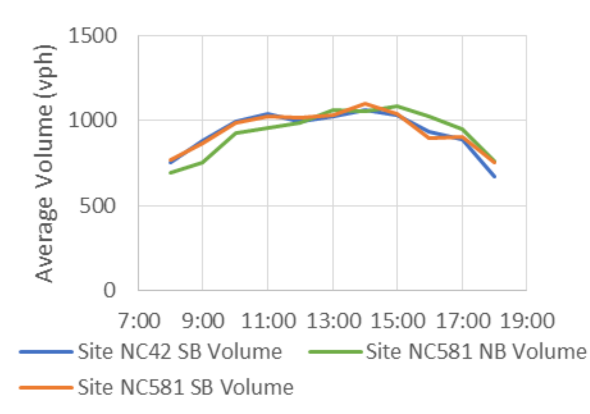
POLLED DATA COLLECTION

Once all of the detection algorithms were calibrated to each site, polling could begin. Polling for any single day required a change between the AM and PM detection algorithm (due to shadow detections). This change occurred at 2 PM of each recorded video due to a lack of significant shadows at this time and, through manual review of videos, seemed to be the approximate time at which shadows began to change direction on the observed video. These polls recorded the precise time at which detectors turned on and off and when counts were made for each of our detectable aggressive driving measures.

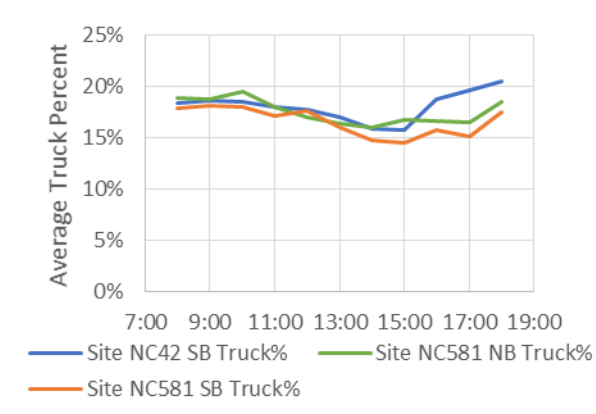
Results

GENERAL OBSERVATIONS

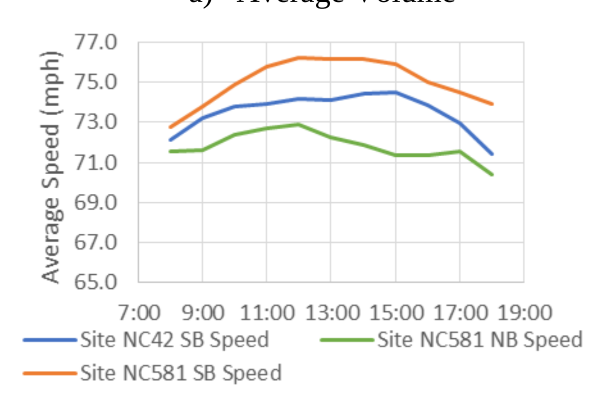
Figure 6 shows summary charts of volume, truck percent, speed, and following too close percentage by time of day for each of the three locations across all study days. Both northbound and southbound directions have a similar peaking pattern with no AM/PM peak period but a shallow midday peak period. The percentage of trucks is fairly consistent between sites, hovering between 15-20%. The trends of truck percentage were opposite of the volume trends with lower percentage during the higher volume period in midday. The average speed was detected as different for each site, which was determined to be an error in calibrating the detection, so subsequent analysis based on speed will consider each site separately. It is also interesting to note that the speed increased during the midday peak volume period, which is counterintuitive under the fundamental speed flow relationship from the HCM, which shows constant speeds at low volumes and decreasing speeds as volume increases.



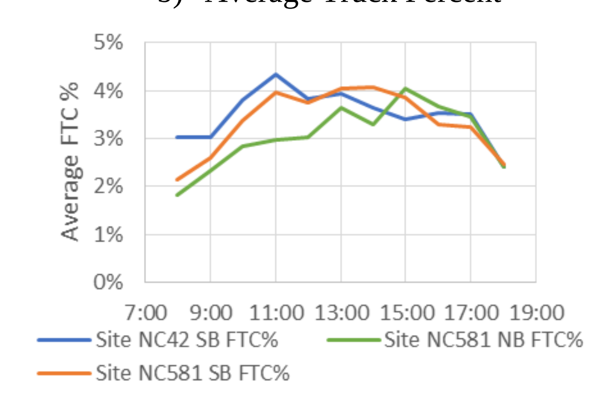
a) Average Volume



b) Average Truck Percent



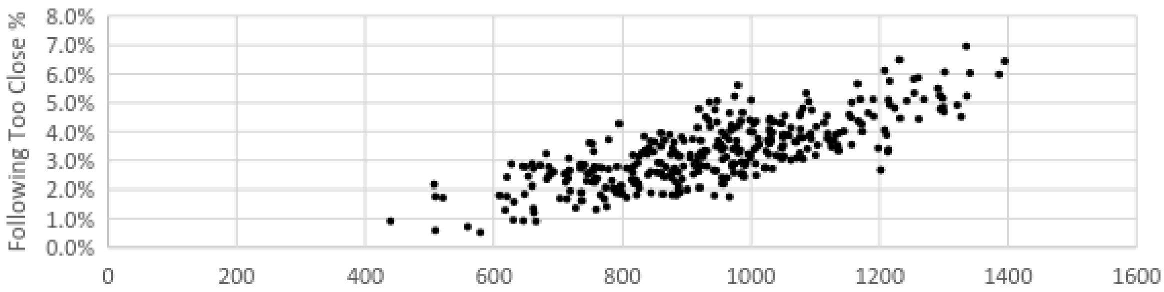
c) Average Speed



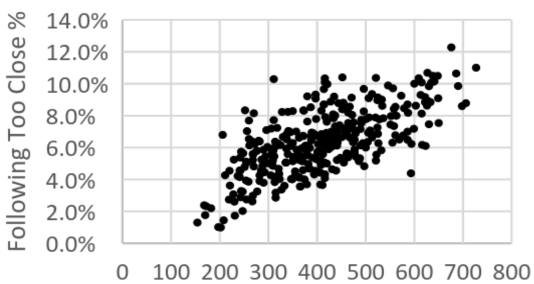
d) Average Following Too Close Percent

FIGURE 6 SUMMARY CHARTS OF TIME OF DAY PERFORMANCE

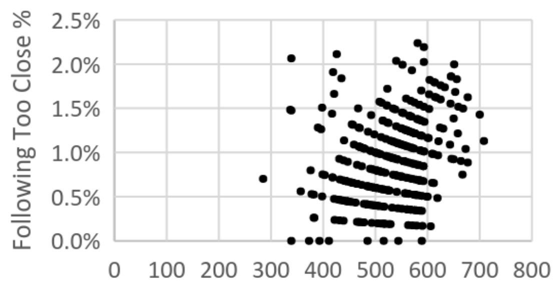
Following too close (FTC) or “tailgating” should be correlated to volume, as the average gap time between vehicles will decrease as volume increases. Figure 6d shows that the percentage of vehicles FTC does indeed follow a somewhat similar trend with the volume, indicating that it is important to look at the effects on FTC with consideration of the percentage you would expect for a given volume. Therefore, further examination was performed, with the individual hourly observations of volume and FTC percent graphed for the total traffic flow as well as for the left and right lanes individually. Figure 7 shows the resulting graphs, where there is a clear positive linear relationship between FTC percent and volume for the total traffic stream and the left lane, while the right lane is not as clear. The spread in data seen in the right lane data can be attributed to the very low FTC percent, as the readings represented between zero and thirteen events per hour, which creates the stratified observations seen in Figure 7c. This is likely explained by a much higher likelihood that aggressive drivers tend to drive more in the left-most lane.



a) FTC% as a function of Total Volume Both Lanes



b) FTC% as a function of Left Lane Volume



c) FTC% as a function of Right Lane Volume

FIGURE 7 FOLLOWING TOO CLOSE AS A FUNCTION OF VOLUME

Based on the positive relationship shown in Figure 7 and the similar peaking patterns of volume and speed, linear regression was performed to estimate FTC and speeding percent as a function of volume. Regression was then repeated for the left and right lane-specific observations as well. Table 1 shows the linear models developed to estimate FTC and speeding percentage, as a function of total or lane-specific volume in hundreds of vehicles per hour. Each model shows a clear positive relationship, meaning that the FTC % and Speeding % increase with increased volume.

TABLE 1 VOLUME-BASED FTC AND SPEEDTABLE 1 VOLUME-BASED FTC AND SPEEDING % LINEAR MODELS

	FTC %		Speeding %	
Model	Intercept	Volume (hundreds)	Intercept	Volume (hundreds)
Total	**-1.928%**	**0.545%**	**-6.865%**	**1.667%**
	-5.23	*14.34*	*-2.34*	*5.53*
Left Lane	**1.031%**	**1.263%**	**0.335%**	**2.472%**
	1.95	*10.4*	*0.13*	*4.25*
Right Lane	**-0.616%**	**0.271%**	**-14.207%**	**4.103%**
	-1.81	*4.29*	*-3.57*	*5.55*

T TESTS: VOLUME-ADJUSTED FTC AND SPEEDING

In order to determine the effects of the signage and enforcement on FTC and speeding, the models developed in Table 1 were used to control for the effects of volume on the two performance measures. Residuals were calculated by subtracting the estimated FTC percent or speeding percent from the observed percentage, and t tests were performed on these residuals to determine significant effects. Cochran t values were used to identify significance as the two samples were of different sample sizes and had different variance in each test. Table 2 shows the results of the t tests performed, with a positive difference indicating an improvement. Note that the direction indicated for each site (southbound or northbound) refers to the direction of travel along I-95, and the sign being tested for is the PCMS. Below is a short description of each test:

1. *Effect of Sign only* compares the period with no sign or enforcement to the period with the sign present before enforcement begins.
2. *Effect of Enforcement (with sign)* compares the period with the sign present before enforcement begins to the period with the sign and enforcement present.
3. *Effect of Enforcement (no sign)* is used as a control (NC581NB) and compares the period before enforcement to the period with enforcement present.
4. *Before and After (with enforcement and sign)* compares the period with the sign and enforcement present to the period with no sign or enforcement.
5. *Before and After (with sign)* compares the period with the sign present before enforcement begins to the period with the sign present after enforcement ends.
6. *Before and After (no sign)* is also used as a control (NC581NB) and compares the period before enforcement to the period after the enforcement.

Overall, very few changes in FTC percent were found to be significant with the best improvement found at the NC42 SB site, when comparing the before period (with no sign present) to the enforcement period with the sign present. The other two significant changes in FTC percent involved a latent improvement after the enforcement period at the NB site and a significant increase in FTC percent after enforcement at the NC581 SB site.

The percentage of speeding vehicles had more statistically significant results, with both significant improvements identified at the NC42 SB site, which was closer to the PCMS. The first improvement was during the period before enforcement when the sign was in place, and an even greater improvement was found during the enforcement period with the sign in place. However, speeding increased significantly at the NC581 SB site during and after the enforcement period.

TABLE 2 T TESTS FOR ENFORCEMENT EFFECTS: VOLUME-WEIGHTED FTC AND SPEEDING PERCENT

Control vs. Treatment	Test for:	Site	Lane	FTC % Diff.	FTC % t	Speeding % Diff.	Speeding % t
T	Effect of Sign only	NC42 SB	Total	0.21%	1.36	2.73%**	2.90
		NC42 SB	Left	0.33%	0.93	3.28%*	1.97
		NC42 SB	Right	-0.07%	-0.73	2.75%**	4.90
		NC581 SB	Total	0.18%	1.22	0.11%	0.08
		NC581 SB	Left	0.35%	1.01	0.92%	0.60
		NC581 SB	Right	-0.06%	-0.78	-0.98%	-0.80
	Effect of Enforcement (with sign)	NC42 SB	Total	0.02%	0.12	0.43%	0.43
		NC42 SB	Left	0.21%	0.55	0.40%	0.24
		NC42 SB	Right	0.00%	-0.03	0.22%	0.33
		NC581 SB	Total	-0.14%	-0.64	-3.61%*	-2.07
		NC581 SB	Left	-0.18%	-0.37	-3.98%*	-1.79
		NC581 SB	Right	-0.13%	-0.95	-3.16%*	-1.85
C	Effect of enforcement only	NC581 NB	Total	-0.07%	-0.46	-0.98%	-1.25
		NC581 NB	Left	-0.06%	-0.17	-0.89%	-0.99
		NC581 NB	Right	0.03%	0.29	-0.93%	-1.25
T	Before and After (with enforcement and sign)	NC42 SB	Total	0.34%*	1.88	3.22%**	3.19
		NC42 SB	Left	0.63%	1.63	3.96%**	2.24
		NC42 SB	Right	-0.02%	-0.22	2.93%**	4.30
		NC581 SB	Total	0.08%	0.32	-1.48%	-0.86
		NC581 SB	Left	0.15%	0.28	-0.87%	-0.38
		NC581 SB	Right	-0.12%	-0.88	-2.01%	-1.21
	Before and After (with sign)	NC42 SB	Total	-0.22%	-1.24	-0.12%	-0.09
		NC42 SB	Left	-0.20%	-0.54	-0.55%	-0.27
		NC42 SB	Right	-0.10%	-0.88	0.08%	0.10
		NC581 SB	Total	-0.10%	-0.64	-5.20%**	-2.62
		NC581 SB	Left	-0.86%	0.13	-5.63%**	-2.56
		NC581 SB	Right	-0.18%*	-1.78	-5.46%**	-2.92
C	Before and After (no sign)	NC581 NB	Total	0.28%*	1.70	-0.58%	-0.62
		NC581 NB	Left	0.44%	1.40	-0.87%	-0.78
		NC581 NB	Right	0.10%	1.37	-0.46%	-0.56

* Significant at α=0.10 ** Significant at α=0.05

REGRESSION RESULTS: FTC AND SPEEDING

Based on the mixed results of the t tests, linear regression models were developed for each of the lanes individually as well as the total traffic stream. For these models, the observed FTC percent or speeding percent was modeled using the following variables: Volume, Truck Percent, Sign Present, Enforcement Present, Sign and Enforcement Present, After Enforcement, After Enforcement and Sign Present, NB Site, SB Near Sign Site, Percent Vehicles in Left Lane. The significant variables were selected by first modeling using all variables and then removing the least significant variable until all remaining variables were significant at α=0.10.

Table 3 shows the results of the FTC percent models, which show additional significant effects compared to the t tests. Overall, FTC events occur more frequently at the SB sites with the site closest to the PCMS showing the highest FTC percent. In the total and left lane models, the sign decreases FTC events, however this effect is decreased after the enforcement in the SB sites, calculated by *Sign Present* + *After Enforcement* + *After Enforcement & Sign Present* = -0.22% compared to -0.31%. This indicates that the sign's effects on FTC are reduced over time and are most impactful nearer to the sign. FTC events are rare in the right lane, as there was a minor decrease in FTC percent as truck percentage increases, but in the left lane model, the truck percentage increased FTC event frequency.

TABLE 3 REGRESSION: PERCENT VEHICLES FOLLOWING TOO CLOSE

Model	Variable	Parameter Estimate	Standard Error	F Value	Pr > F
Total	Intercept	-3.2620%	0.3840%	72.02	<.0001
	Total Volume (hundreds)	0.2872%	0.0388%	54.8	<.0001
	Sign Present	-0.3070%	0.1120%	7.48	0.0066
	After Enforcement	-0.3420%	0.1540%	4.92	0.0272
	After Enf. & Sign Present	0.4290%	0.1880%	5.24	0.0227
	NB Site	-0.5970%	0.1220%	23.99	<.0001
	SB Near Sign Site	0.1930%	0.0891%	4.69	0.0311
	% Veh in Left Lane	9.7090%	1.5300%	40.27	<.0001
Left Lane	Intercept	1.5190%	0.3860%	15.49	0.0001
	Left Lane Volume (hundreds)	1.2739%	0.0710%	321.6	<.0001
	Left Lane Truck Pct	6.0960%	3.0260%	4.06	0.0447
	Sign Present	-0.5780%	0.2360%	6.01	0.0147
	NB Site	-1.3100%	0.2410%	29.62	<.0001
Right Lane	Intercept	0.3060%	0.2840%	1.17	0.2809
	Right Lane Volume (hundreds)	0.1476%	0.0339%	18.91	<.0001
	Right Lane Truck Pct	-1.1010%	0.5990%	3.37	0.0672
	NB Site	-0.1300%	0.0545%	5.66	0.0179
	SB Near Sign Site	0.4080%	0.0549%	55.32	<.0001

Table 4 shows the regression models for the percentage of vehicles speeding. It is important to remember the site speed differences are most likely due to calibration errors rather than real effects. Interestingly, speeding increased with volume when it is expected to remain steady during low volumes and decrease with an increase in volume as the road approaches capacity. For the overall model and right lane model, the percentage of trucks significantly lowered speeding percent as would be expected since truck free flow speeds are lower than passenger cars. The sign reduced speeding for the first two weeks of placement, but its effect was reversed after the enforcement with higher speeding percentage compared to the before period. Again, it is likely that the enforcement period temporarily delayed the decrease in effectiveness.

TABLE 4 REGRESSION: PERCENT VEHICLES SPEEDING

Model	Variable	Parameter Estimate	Standard Error	F Value	Pr > F
Total	Intercept	10.7700%	3.1820%	11.46	0.0008
	Total Volume (hundreds)	0.9880%	0.1862%	28.17	<.0001
	Total Truck Pct	-20.5980%	10.2070%	4.07	0.0444
	Sign Present	-1.5230%	0.8440%	3.26	0.0719
	After Enf. & Sign Present	2.2710%	0.7960%	8.15	0.0046
	NB Site	-10.6360%	0.8240%	166.44	<.0001
	SB Near Sign Site	-4.8880%	0.6720%	52.9	<.0001
Left Lane	Intercept	8.6780%	1.3380%	42.07	<.0001
	Left Lane Volume (hundreds)	2.1745%	0.3243%	44.95	<.0001
	Sign Present	-2.3270%	1.0960%	4.51	0.0345
	After Enf. & Sign Present	2.5090%	1.0920%	5.28	0.0222
	NB Site	-11.0210%	1.0940%	101.56	<.0001
Right Lane	Intercept	5.8480%	3.2300%	3.28	0.0711
	Right Lane Volume (hundreds)	1.0975%	0.4080%	7.23	0.0075
	Right Lane Truck Pct	-13.6390%	6.0360%	5.11	0.0245
	After Enf. & Sign Present	1.7930%	0.6340%	7.99	0.005
	NB Site	-10.5450%	0.5850%	324.74	<.0001
	SB Near Sign Site	-9.1720%	0.5370%	292.1	<.0001
	% Veh in Left Lane	17.0900%	6.4280%	7.07	0.0082

Summary

In summary, the presence of the sign was shown to have significant impacts on both measures of aggressive driving at the location nearest to the sign with less impact at the farther downstream location. Additionally, the effect of the sign's presence decreases over time, with FTC percent still lower than originally observed but with speeding percent increasing slightly. Enforcement did not have a statistically significant impact during the enforcement period except to extend the duration of the impact of the sign on FTC percent. It is possible that the enforcement period in the southbound direction was less effective due to returning drivers' experience of no enforcement presence during the first two weeks, but in the northbound direction there was a decrease in FTC percent *after* the enforcement period, which supports the idea that there is a short term lingering impact of enforcement. Speeding followed similar trends of following too close; however, it was actually higher in the after enforcement period than in the before period.

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