FINAL REPORT

Crash Based Evaluation of the Watch for Me NC Program

NCDOT Research Project No. 2018-38

Taha Saleem

Phone: 919-962-3409; Email: saleem@hsrc.unc.edu

Bo Lan

Phone: 919-962-0465; Email: lan@hsrc.unc.edu

Raghavan Srinivasan

Phone: 919-962-7418; Email: srini@hsrc.unc.edu

Laura Sandt

Phone: 919-962-2358; Email: sandt@hsrc.unc.edu

Kristin Blank

Phone: 919-843-7007; Email: blank@hsrc.unc.edu

Sam Alden Blank

Phone: 919-962-2202; Email: blank@unc.edu

Performing Agency:

University of North Carolina at Chapel Hill

Highway Safety Research Center

Chapel Hill, NC

Submitted to North Carolina Department of Transportation

September 2018

Table of Contents

List of Tables

List of Figures

Executive Summary

This report describes the efforts to estimate the crash-based safety effectiveness of the Watch for Me NC program. Watch for Me NC program was launched in 2012 with four pilot communities. The program opened up to the entire state in 2014 and has been expanding each year since. In 2017, the program had grown to include a total of 32 communities (including 24 prior communities and 8 new communities). Over the course of six years (2012 – 2017), a total of 41 communities from 29 counties have participated in the program (with some communities participating only for a certain period of time). The objective of this project was to estimate the safety effectiveness of the Watch for Me NC program as measured by changes in pedestrian and/or bicyclist crash frequency.

Safety Evaluation Methodology

Empirical Bayes (EB) before-after study was used for this evaluation. This methodology is considered rigorous in that it accounts for the possible bias due to the regression to the mean (RTM) using a reference group of similar but untreated entities, safety performance functions (SPFs) to account for changes in exposure, time trends, and has been found to reduce the level of uncertainty in the estimates of the safety effect.

The treatment group included 29 counties that participated in the Watch for Me NC program, and reference group included 71 counties that did not participate in the Watch for Me NC program. The team's preference was to conduct either a site level or a corridor level analysis, as both of these options would have allowed a more detailed examination of the impacts of the enforcement component of the Watch for Me NC program. However, non-uniformity in enforcement data collection coupled with non-availability of exposure data at a site or corridor level led the team to proceed with a county level analysis, i.e., treating each county with a participating community as a treatment county.

Safety effects were derived for five types of pedestrian crashes (total, nighttime total, failed to yield – driver and pedestrian, walking along roadway, and permissive left turn) and four types of bicycle crashes (total, nighttime total, overtaking, and right hook). These target crash types were chosen in line with some of the key behaviors hypothesized to be impacted by the Watch for Me NC program activities.

Pedestrian and bicycle volume data were not available at the time of this research. Thus alternate exposure variables (traffic data: *vehicles miles travelled and vehicle distribution by size*; socio-economic data: *journey to work by mode, average household income, total urban and rural* *populations, and population distribution by age groups*) were carefully selected to serve as surrogates for pedestrian and bicycle exposure over the study time period.

Results

The results show a positive effect of the Watch for Me NC program on reducing county-wide pedestrian crashes. The total pedestrian crashes show a statistically significant reduction of 12.8% along with a 21.7% reduction in nighttime crashes and a 9.5% reduction in failed to yield crashes, both statistically significant.

The analysis indicated that the exposure variables that were used in the analysis were not able to accurately predict bicycle crashes. The team used three different evaluation options (using bicycle crash SPFs, using combined pedestrian and bicycle crash SPFs recalibrated using proportion of bicycle to total of pedestrian and bicycle crashes, and using pedestrian SPFs recalibrated using the ratio of bicycle to pedestrian crashes) as a part of sensitivity analysis. All the three options showed different results with respect to reduction or increase in the different bicycle crash types. Since all three scenarios show very different results and the analysis showed that we are not able to accurately predict bicycle crashes, the team cannot conclude whether the Watch for Me NC program has had a positive or a negative impact on bicycle crashes at this time.

Limitations and Recommendations

While this crash-based study provides some firm evidence of the program effects, it was not without its limitations. The team noted several baseline differences between the treatment and reference groups used in the analysis. Most obvious was that treated groups skewed more urban and higher population than the referent counties. The analysis method tried to account for this by including the before-period of the treatment group in developing SPFs. However, further sensitivity analysis could be performed in the future to see whether varying the reference group would affect the stability of the results.

Additionally, the lack of quality bicycle exposure measures to incorporate in the analysis impacted the validity of the bicycle crash evaluation. Cities should be encouraged to collect pedestrian and bicycle volumes at intersections and corridors. This would provide the best pedestrian and bicycle exposure to be used when developing SPFs and evaluating safety programs. Future studies could gather the data to adjust for the presence of bikeshare programs in the study areas or other key facilities that are opened during the study period and thought to influence bicycle ridership. This data collection could extend to pedestrian facilities as well and would allow for exploring the direct effects of specific components of the Watch for Me NC program as opposed to a collective effect of Watch for Me NC program and other treatments.

Further, we note that this study was based upon police-reported crash data. We are aware that police-reported crash data reflect only a portion of the total crashes and injuries experienced by pedestrians and bicyclists. It would be beneficial for future studies to also examine hospital-based data sources. For example, emergency department records of bicycle injuries could reveal important trends, and provide an additional source of data to explore specific injuries, such as the prevalence of traumatic brain injuries (TBI), that might be influenced by the Watch for Me NC program efforts.

Finally, the study was only able to evaluate effects at the county level, which might actually underestimate the true program impacts given that in many counties, efforts are concentrated in only a few cities or specific corridors and sites. Better data from participating communities on where enforcement and community engagement opportunities are taking place would allow for a finer-grain analysis of program effects. Police departments and partnering communities may need additional training, support, and incentives to provide such information to support robust program evaluation.

1. Introduction

According to the latest data available from the National Highway Traffic Safety Administration (NHTSA), in 2016, 5,987 pedestrians and 840 bicyclists were killed in motor vehicle crashes in the US *(1, 2)*. An additional 70,000 pedestrians and 45,000 bicyclists were estimated to have been injured (based on 2015 NHTSA data) *(3, 4)*. Pedestrian and bicycle safety is an important issue for the health, safety, and mobility of North Carolinians. In North Carolina, pedestrians and bicyclists represent approximately 12% of all motor vehicle crash fatalities, which is very similar to national proportions. Statewide, in 2016, approximately 2,200 pedestrians and 590 bicyclists were involved in crashes, with a large majority of these people sustaining injuries *(5)*.

NCDOT's commitment to a combined education, enforcement, and community capacity-building approach to improve pedestrian, bicyclist and driver behaviors has been in place for several years, beginning in 2010 with the initial development and evaluation of a comprehensive, evidence-based program. In August 2012, after a multi-year planning, data analysis, and coalition-building effort with partners, NCDOT launched the Watch for Me NC program in the Triangle area, which included comprehensive pedestrian and driver safety messaging for distribution in diverse media and via law enforcement. In 2013, the program expanded to include bicycle safety messaging and acquired new partners in the Triangle area to implement the program. From 2014-2017, the program continued to grow to include partners from all regions of the state. For many participating communities, the program scope also extended to support infrastructure/engineering changes to improve pedestrian safety at high-crash crossing locations in tandem with enforcement and public engagement strategies.

The following sections provide a brief background of the Watch for Me NC program (additional information is available on the program website: https://www.watchformenc.org/), a literature review focusing on studies evaluating pedestrian and bicycle safety, and a brief background of the program evaluation methods used in this crash-based study. For prior evaluations of the program on behavioral outcomes, see Sandt *et al. (6)*.

1.1. Watch for Me NC Program Background

The following sections provide information about the partner communities and how the program is delivered using various measures.

1.1.1. Program Participants

Watch for Me NC program was launched in 2012 with four pilot communities in the Triangle area. The program opened up a call to participation to the entire state in 2014 and has been expanding geographically each year since. In 2017, the program had grown to include a total of 32 communities (including 24 prior communities and 8 new communities). Over the course of six years (2012 – 2017), a total of 41 communities from 29 counties have participated in the program (with some communities participating only for a certain period of time). Table 1 lists the participant communities along with their years of participation in the program.

New participants are selected each year in the Spring after an application process. The application asks questions about:

- The motivation to participate, including prior history of pedestrian and bicycle crashes
- Prior community efforts and existing plans
- Staff capacity and how the program fits within existing roles and expectations
- A preliminary plan of action and evidence of support from key partners (including a required letter of support from local law enforcement).

Responses were considered by a steering committee that oversaw the selection of new communities, consisting of staff from NCDOT, Governor's Highway Safety Program (GHSP), North Carolina Department of Health and Human Services (DHHS), North Carolina State health Plan (SHP), and University of North Carolina's Highway Safety Research Center (UNC-HSRC). Prior crash history, staff capacity to participate, quality of pedestrian and bicycle safety plans and prior efforts, and continuity with the Watch for Me NC program, were all considerations driving acceptance of new applicants.

In addition to an open call for applicants, specific high-crash communities (based on NCDOT's crash reports[1]) were also recruited directly each year and invited to participate. Once applicants were accepted, they would be automatically eligible to continue participation provided they submitted an annual renewal application to provide basic information.

Table 1. Watch for Me NC Partner Communities

Community	County	WFM Participation					
		2012	2013	2014	2015	2016	2017
Apex	Wake		✓			✓	✓
Asheville	Buncombe				✓	✓	✓
Boone	Watauga			✓	✓	✓	✓
Brevard	Transylvania					✓	✓
Burgaw	Pender						✓

[1] The latest pedestrian crash facts can be found online at: http://www.pedbikeinfo.org/pbcat_nc/pdf/summary_ped_facts11-15.pdf

Community	County	WFM Participation					
		2012	2013	2014	2015	2016	2017
Cape Fear	New Hanover						✓
Carrboro	Orange	✓	✓	✓	✓	✓	✓
Cary	Wake		✓	✓	✓	✓	✓
Chapel Hill	Orange	✓	✓	✓	✓	✓	✓
Charlotte	Mecklenburg				✓	✓	✓
Cornelius	Mecklenburg						✓
Corolla	Currituck				✓	✓	✓
Creedmoor/Oxford	Granville				✓	✓	✓
Davidson	Mecklenburg				✓	✓	
Durham	Durham	✓	✓	✓	✓	✓	✓
Edenton	Chowan			✓			
Elizabeth City	Pasquotank						✓
Elon	Alamance						✓
Fuquay-Varina	Wake		✓			✓	✓
Garner	Wake					✓	✓
Greensboro	Guilford			✓	✓	✓	✓
Greenville	Pitt			✓	✓	✓	✓
Jacksonville	Onslow				✓	✓	
Kannapolis	Cabarrus					✓	✓
Kill Devil Hills (OBX)	Dare			✓	✓	✓	✓
King	Stokes			✓			
Knightdale	Wake		✓				✓
Marion	McDowell				✓	✓	
Morganton	Burke					✓	✓
Morrisville	Wake		✓				✓
Murphy	Cherokee				✓	✓	✓
New Bern	Craven			✓		✓	
Newton	Catawba						✓
North Wilkesboro	Wilkes						✓
Oak Island	Brunswick						✓
Pine Knoll Shores	Carteret						✓
Raleigh	Wake	✓	✓	✓	✓	✓	✓
Surf City	Onslow				✓		
Sylva	Jackson			✓			
Wake Forest	Wake		✓				
Wilmington	New Hanover			✓		✓	✓

1.1.2. Program Delivery

The Watch for Me NC program is multi-pronged, with core elements involving capacity building (including training and technical assistance delivered to participant communities), and public engagement around pedestrian and bicycle safety issues (delivered through platforms including paid media, local outreach, social and earned media, and law enforcement operations). For a detailed background on how this program was developed and what the program entails, see Sandt *et al. (7)* or the Annual reports found at: https://www.watchformenc.org/about/.

1.1.2.1. Paid Media

Paid media is one element used in distributing pedestrian and bicycle safety messages to the general public, perhaps the most visual and easily identifiable component of the program. Purchased media includes sidewalk stencils, traditional and digital billboards, and external/internal bus ads placed in bus systems across the state. Media messages were designed by NCDOT communications staff, with input on messaging provided by UNC-HSRC based on an analysis of crash data and identification of key behaviors involved in crashes in several cities. Safety messages were adapted as needed over time, but in general focused on the following key issues:

- Conspicuity at night
- Attentiveness at intersections (e.g., messaging for drivers to look before turning, sidewalk stencils alerting pedestrians to look before crossing)
- Safe passing of bicyclists ("Make Room for Bikes")
- Driver yielding to pedestrians ("Yield to Pedestrians in Crosswalks")

1.1.2.2. Local Outreach and Earned Media

Participating communities perform extensive outreach, including distributing print material (including rack cards, posters, banners, and bumper stickers displaying the messages above) as well as safety gear for enhancing conspicuity (bike lights and reflective bracelets) and engaging with students, local businesses, community groups, and the general public through local events, public engagement, and operations events. Partner communities also engage with the media as a key strategy to help amplify the message to a broader audience and to support higher-visibility enforcement operations.

1.1.2.3. Law Enforcement Operations

Municipal police agencies and university police departments conduct operations targeting enforcement of pedestrian and/or bicycle-related laws. While the focus varies by community need, officers often focus on issuing warnings/citations to drivers that failed to yield to pedestrians in marked crosswalks and trying to engage neighborhood groups, local businesses, and others on pedestrian and bicycle safety issues and laws, to support a safety culture that respects multimodal travel and a shared responsibility to prevent crashes. Some communities also take a "good ticket" approach, partnering with local businesses to deliver "caught being good" tickets to pedestrians and bicyclists demonstrating safe behaviors (e.g., obeying signals, wearing helmets, etc.) that offer local business discounts or free food to serve as positive reinforcement of safe behaviors observed. These operations also provided ways to engage the broader community on pedestrian and bicycle safety issues in a positive way.

1.2. Review of Literature

Various researchers have conducted studies to evaluate pedestrian and bicycle crashes and suggest countermeasures to prevent these crashes. Much of the guidance available suggest that combined education and enforcement initiatives can significantly improve pedestrian and bicycle safety.

Blomberg *et al. (8, 9)* and Preusser *et al. (10)* looked at developing and testing public information and education messages as a way to reduce pedestrian injuries. Various other studies looked at the use of safety messages that were consistent with frequently occurring pedestrian bicycle crash types as a way to enhance pedestrian and bicycle safety. Examples of these include: low-light conditions – Zegeer *et al. (11);* pedestrian interactions with turning vehicles – Hunter *et al. (12)*; and driveways and parking lots – Agran *et al. (13)*, and Olson *et al. (14)*. Zegeer and Bushell *(15)* recommend conducting targeted public service announcements and informational campaigns to address specific pedestrian and bicycle safety concerns.

Various researchers also looked at how incorporating skills training in safety education campaigns can lead to enhanced pedestrian and bicycle safety. Barton *et al. (16, 17)* in their study concluded that children who practiced crossing a pretend road exhibited safer pedestrian behaviors compared to behaviors before practice. Constructive feedback from caregivers can enhance the safety effects of skills training – Albert *et al. (18)*, especially since children and older pedestrians often find it difficult to safely navigate complex traffic environments – Sarkar *et al. (19)*, Dunbar *et al. (20)*, and Barton *et al. (17)*.

Researchers have also looked at the effects of implementing targeted, high-visibility enforcements focused on protecting pedestrians and bicyclists. Van Houten and Malenfant *(21)* documented increased driver yielding to pedestrians up to a year following a two-week enforcement campaign in Miami Beach, FL. Moreover, Savolainen *et al. (22)* reported significant declines in pedestrian violations on the campus of Wayne State University in Detroit, MI both immediately and several weeks after the issuance of warnings to pedestrians ceased. Additionally, Van Houten *et al. (23)* documented significant increases in driver yielding to pedestrians in response to the implementation of high visibility enforcement operations in Gainesville, FL. The campaign involved: the issuance of warnings, tickets, and feedback from law enforcement; the distribution of informational flyers, parent outreach, earned media, paid radio advertisements; and in-street signs and innovative community feedback signs, which were placed on high traffic corridors and displayed the percentage of drivers yielding to pedestrians in crosswalks on any given week.

Most of the studies mentioned in this literature review look at how implementation of various different education, training, and enforcement programs lead to increased pedestrian and bicycle safety in terms of driver yielding behavior and safer pedestrian behavior. The study conducted by Zegeer *et al*. *(11)* evaluated the implementation of a comprehensive program to reduce pedestrian deaths and injuries among pedestrians in large urban environment, using Miami-Dade County in Florida as their study's focus. This study is of great relevance to what we are trying to achieve in this project, i.e. evaluating the crash-based effective of the Watch for Me NC program. Zegeer *et al. (11)* in their study targeted high crash locations for countermeasure implementation and analysis and on the basis of crash characteristics and pedestrian factors, 16 education, enforcement, and engineering treatments were implemented to reduce pedestrian crashes. They used a before-after time-series study with three control groups to evaluate the effects of the pedestrian safety program on pedestrian crashes. Their results showed that at the peak of the program effects, the pedestrian safety program reduced countywide pedestrian crash rates by anywhere from 8.5% to 13.3%, depending on which control group was used.

1.3. Background on Safety Evaluation Methods

The various safety evaluation methods fall under two broad categories: before-after and cross-sectional studies. Before-after studies include all techniques by which one may study the safety effect of some treatment that has been implemented on a group of sites. On the other hand, cross-sectional studies include those where one is comparing the safety of one group of sites having some common feature (treatment of interest) to the safety of a different group of sites not having that feature in order to assess the safety effect of the treatment *(24)*.

There is a general consensus in the safety community that well-designed before-after studies provide more reliable estimates of safety effects compared to cross-sectional studies. This is because before-after studies are less prone to confounding since we are dealing with the same roadway unit located in a particular place used by probably the same users in the before and after period *(25)*. Confounding, on the other hand, is a big issue in cross-sectional studies and can confuse the association between an exposure and an outcome.

1.3.1. Before-After Studies

Safety effects derived from before-after studies are based on the change in safety due to the implementation of a treatment. The most practically established approach for before-after evaluations is the empirical Bayesian method (EB). The EB approach associate a reference group which is similar to treated sites (treated group) and is introduced to offer referential information for before-after evaluations, as illustrated in Figure 1 *(26)*.

The five groups as identified in Figure 1 form a grid with the dimension of reference and treated groups crossed by dimension of before and after periods. The goal here is to seek a crash reduction rate (CRR) through a safety comparison between groups 4 and 5. The Bayesian calculation is to combine prior and current information to derive an estimate for the expected safety improvement of the treatment that is being evaluated *(26)*.

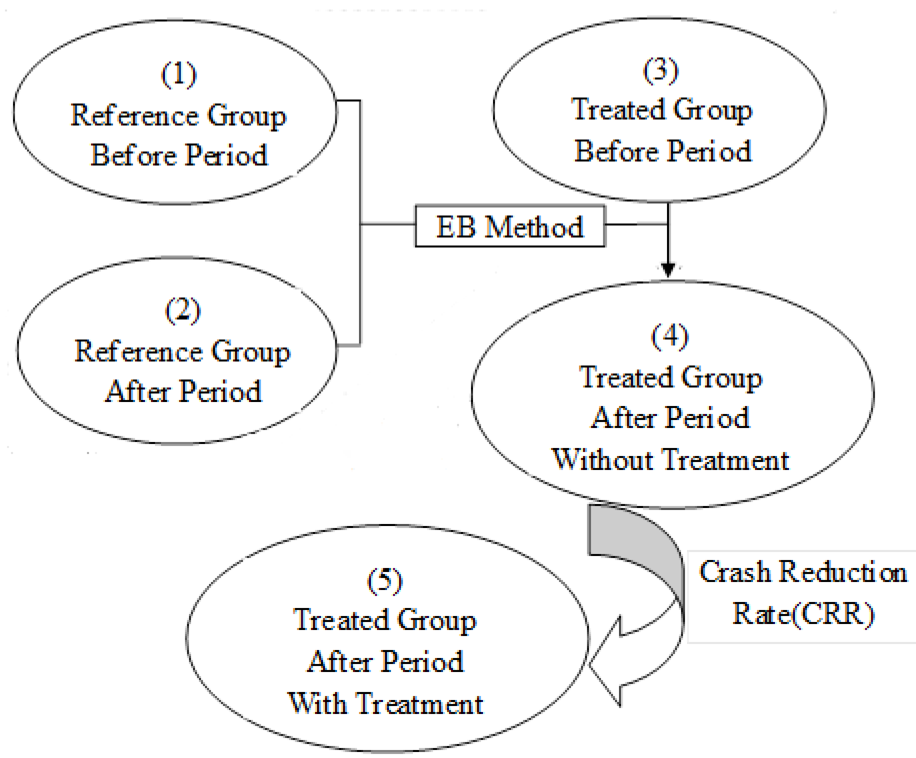

Figure 1. Logical Framework for Before-After Evaluations

The objective of the EB before-after study is to estimate the number of crashes that would have occurred at an individual treated site in the after period had the treatment not been implemented. The advantage of the EB approach is that it correctly accounts for changes in crash frequencies before and after a treatment that may be due to regression to the mean (RTM). Often, agencies select high crash locations for implementing treatments, and if the possible bias due to RTM is not properly accounted for, the safety effect of the treatment may be overestimated. In accounting for RTM, the number of crashes expected in the before period without the treatment is estimated as a weighted average of the number of crashes observed in the before period at treated sites and the number of crashes predicted at treated sites based on untreated reference sites with similar characteristics. The 1st edition of the Highway Safety Manual *(27)* considers that the EB approach has been effective approach for conducting before-after studies.

2. Study Objective

This study examined the safety effectiveness of the Watch for Me NC program, taking a crash-based approach to complement prior evaluations focusing on behavioral outcomes. The objective was to estimate the safety effectiveness of the Watch for Me NC program as measured by changes in pedestrian and/or bicyclist crash frequency. Ultimately, it is expected that the outcomes of this study will help NCDOT to assess the value of the program and support future decision-making related to program implementation and improvement.

In line with some of the key behaviors hypothesized to be impacted by the Watch for Me NC program activities, the following target crash types were considered:

- Pedestrian Crashes
  - Total pedestrian crashes.
  - Nighttime total pedestrian crashes.
  - Failed to yield crashes (combination of both driver and pedestrian failed to yield crashes).
  - Walking along roadway crashes.
  - Permissive left-turn crashes.

- Bicycle Crashes
  - Total bicycle crashes.
  - Nighttime total bicycle crashes.
  - Over taking crashes.
  - Right hook crashes.

3. Methodology

The EB methodology for before-after studies was used for this evaluation. As mentioned earlier, this methodology is considered rigorous in that it accounts for the possible bias due to the RTM using a reference group of similar but untreated sites, safety performance functions (SPFs) to account for changes in exposure, time trends, and has been found to reduce the level of uncertainty in the estimates of the safety effect.

The following steps are needed to conduct an EB before-after evaluation:

1. Identify a reference group of entities without the treatment, but similar to the treatment entities[2] in terms of the major factors that affect crash risk including traffic volume and other site characteristics.
2. Estimate SPFs using data from the reference entities relating crashes to the characteristics of the entity. If the entity is an intersection, the characteristics of an intersection will be the independent variables for the SPFs. If the entity is a county or city as in this project, then the characteristics of the county of city (e.g., vehicle miles travelled (VMT), population) could be the independent variables in a SPF. In some cases, if it is not possible to find a reference group similar to the treatment group, or when the treatment is implemented system-wide, the before data from the treatment entities is used along with reference or comparison entities to estimate the SPFs. In fact, in this evaluation, the before data from the treatment counties were combined with the reference counties for estimating SPFs.
3. In estimating SPFs, calibrate annual calibration factors (ACFs) to account for the temporal effects (e.g., variation in weather, demography, vehicle population, and crash reporting) on safety. The ACF for a particular year is the ratio of the observed crashes to the predicted crashes from the SPF.
4. Use the SPFs, ACFs, and data on county characteristics for each year in the before period for each treatment county to estimate the number of crashes that would be predicted for the before period in each site.

[2] Most of earlier applications of EB has been to examine the safety effects of individual locations (roadway segments or intersections) due to treatments. However, the same approach can be extended to more aggregate scenarios such as corridors, cities, and counties.

5. Calculate the EB estimate of the expected crashes in the before period at each treatment county as the weighted sum of the actual crashes in the before period and predicted crashes from step 4.
6. For each treatment county, estimate the product of the EB estimate of the expected crashes in the before period and the SPF predictions for the after period divided by the SPF predictions for the before period. This is the EB expected number of crashes in the after period that would have occurred had there been no treatment. The variance of this expected number of crashes is also estimated in this step. The expected number of crashes without the treatment along with the variance of this parameter and the number of reported crashes after the treatment is used to calculate the safety effect of the treatment (θ) along with the standard error, which is an estimate of the precision of the estimate of the safety effect.

Based on the safety effect (θ), the percent change in crashes is calculated as $100(1-\theta)$. Therefore a value of $\theta = 0.9$ with a standard of error of 0.05 indicates a 10% reduction in crashes with a standard error of 5%. Conversely, a value of $\theta = 1.2$ with a standard of error of 0.1 indicates a 20% increase in crashes with a standard error of 10%. Further details about the equations involved in estimating θ and its standard error are available in Appendix A.

4. Data Collection

4.1. Treatment Data

NCDOT provided a list of partner communities along with their years of participation. This data is summarized in Table 1. Enforcement data along with the location of enforcement was also provided. Based on the initial data availability, the evaluation could have been done at four levels:

- Site Level (treating each enforcement location as a treatment site).
- Corridor Level (treating each corridor consisting of an enforcement location as a treatment site).
- City Level (treating each participant community as a treatment site).
- County Level (treating each county with a participating community as a treatment site).

The team's preference was to conduct either a site-level or a corridor-level analysis, as both of these options would have allowed a more detailed examination of the impacts of the enforcement component of the Watch for Me NC program. However, due to the following reasons both of these options were deemed not feasible:

- Majority of enforcement location data was incomplete or missing.
- Some partner communities did not partake in enforcement activities and only relied on media and public outreach activities.

This left us with two options, conduct either a city level analysis or a county level analysis. At this point, the main factor in choosing amongst these was the availability of exposure data. Exposure data including vehicle miles travelled (VMT), journey to work by mode, household income, and population distribution were only available at a county level (more information on each of these variables is discussed in Section 4.4). Hence the team, in consultation with NCDOT, made the decision to proceed with a county level analysis, i.e. treating each county with a participating community as a treatment county. This led to a treatment group consisting of 29 counties, presented in Table 2.

4.2 Reference Group

The selection of reference group is done in such a way as to ensure that the eventual reference group would be as similar as possible to the treatment group. As described in the introduction, communities self-selected into the program during the application process, or were recruited based on high-crash histories. Due to the presence of self-selection bias in the process of selecting partner communities, a majority of the NC counties with high population and a high number of pedestrian and bicycle crashes were already a part of the treatment group. This led to the team selecting all of the remaining 71 counties as a part of the reference group. This process of selecting the rest of the state as the reference group is well documented and analyzed by Zegeer *et al.* *(11)* in their paper. The list of counties in the reference group are presented in Table 3.

Table 2. List of Counties in Treatment Group

29 Counties in Treatment Group		
Alamance	Currituck	Orange
Brunswick	Dare	Pasquotank
Buncombe	Durham	Pender
Burke	Granville	Pitt
Cabarrus	Guilford	Stokes
Carteret	Jackson	Transylvania
Catawba	McDowell	Wake
Cherokee	Mecklenburg	Watauga
Chowan	New Hanover	Wilkes
Craven	Onslow	

Table 3. List of Counties in Reference Group

71 Counties in Reference Group			
Alexander	Duplin	Lee	Rockingham
Alleghany	Edgecombe	Lenoir	Rowan
Anson	Forsyth	Lincoln	Rutherford
Ashe	Franklin	Macon	Sampson
Avery	Gaston	Madison	Scotland
Beaufort	Gates	Martin	Stanly
Bertie	Graham	Mitchell	Surry
Bladen	Greene	Montgomery	Swain
Caldwell	Halifax	Moore	Tyrrell
Camden	Harnett	Nash	Union
Caswell	Haywood	Northampton	Vance
Chatham	Henderson	Pamlico	Warren
Clay	Hertford	Perquimans	Washington
Cleveland	Hoke	Person	Wayne
Columbus	Hyde	Polk	Wilson
Cumberland	Iredell	Randolph	Yadkin
Davidson	Johnston	Richmond	Yancey
Davie	Jones	Robeson	

4.3. Crash Data

Crash data for the period of 2009 - 2017 were obtained from two sources and included many variables related to location, time, and characteristics of each crash:

- Pedestrian and Bicycle Crash Analysis Tool (PBCAT) data (2009 – 2015).
- Traffic Engineering Accident Analysis System (TEAAS) data (2016 – 2017).

TEAA data had to be used for 2016 and 2017 due to a lag in PBCAT data availability. Tables 4 – 7 provide summary statistics of pedestrian and bicycle crash data for the treatment and reference groups. Self-selection bias in the process of selecting partner communities leading to counties with a high number of pedestrian and bicycle crashes being a part of the treatment group is visible in these summaries. For e.g. there were an average of ~ 48 total pedestrian crashes per county-year in the treatment group compared to ~ 14 total pedestrian crashes per county-year in the reference group. Bicycle crashes also show a similar trend with an average of ~ 17 total bicycle crashes per county-year in treatment group compared to ~ 4 total bicycle crashes per county-year in the reference group.

Table 4. Pedestrian Crash Data Summary for Treatment Group

Pedestrian Crash Type	Minimum (/county/year)	Maximum (/county/year)	Average (/county/year)	Sum
Total	0	539	48.11	8227
Nighttime Total	0	252	24.41	4174
Failed to Yield Crashes	0	134	19.94	3409
Permissive Left Turn	0	52	3.18	543
Walking Along Roadway	0	43	5.4	924

Table 5. Pedestrian Crash Data Summary for Reference Group

Pedestrian Crash Type	Minimum (/county/year)	Maximum (/county/year)	Average (/county/year)	Sum
Total	0	151	14.21	9080
Nighttime Total	0	91	7.53	4812
Failed to Yield Crashes	0	50	5.36	3422
Permissive Left Turn	0	7	0.41	260
Walking Along Roadway	0	28	2.93	1875

Table 6. Bicycle Crash Data Summary for Treatment Group

Bicycle Crash Type	Minimum (/county/year)	Maximum (/county/year)	Average (/county/year)	Sum
Total	0	136	16.87	2884
Nighttime Total	0	49	5.02	859
Overtaking	0	18	3.1	530
Right Hook	0	21	1.47	251

Table 7. Bicycle Crash Data Summary for Reference Group

Bicycle Crash Type	Minimum (/county/year)	Maximum (/county/year)	Average (/county/year)	Sum
Total	0	35	4.13	2637
Nighttime Total	0	15	1.41	902
Overtaking	0	11	1.19	762
Right Hook	0	5	0.23	147

4.4. Exposure Data

Exposure data used in this evaluation is divided into two main categories: traffic data and socio-economic data. The following data elements from each of these categories were used in the analysis:

- Traffic Data
  - Annual and Daily Vehicle Miles Travelled (VMT).
  - Vehicle Distribution by Size.
- Socio-Economic Data
  - Journey to Work by Mode.
  - Average Household Income.
  - Total Population (Urban/Rural).
  - Population Distribution by Age Groups.

Pedestrian and bicycle volume data, at the site, corridor, city, or county level, were not available at the time of this research. Thus alternate exposure variables (see above) were carefully selected to serve as surrogates for pedestrian and bicycle exposure over the study time period. These variables served as independent variables in estimating the SPFs relating crash frequency with the characteristics of the county.

The VMT and vehicle distribution by size data was provided by NCDOT's Transportation Planning Division and Division of Motor Vehicles. The socioeconomic variables were extracted from the American Community Survey databases maintained by the U.S. Census Bureau. Summary statistics of these variables for the treatment and reference groups are provided in Tables 8 and 9.

Table 8. Summary Statistics for Treatment Group (29 Counties)

Data Element	Minimum	Maximum	Average	Standard Deviation
Annual VMT (1000)	117399	14544946	1969736	2847899.49
Daily VMT (1000)	322	39849	5397	7802.46
Number of Autos/Vans	6550	538883	86911	119270.85
Numbers of Trucks/Large Vehicles	5055	128562	30502	23912.30
Number of Motorcycles	167	12627	2847	2704.44
Percentage of Autos/Vans	51.78%	84.90%	64.47%	8.51%
Percentage of Trucks/Large Vehicles	13.38%	45.27%	32.89%	8.22%
Percentage of Motorcycles	1.33%	4.96%	2.64%	0.62%
Total Population	14556	1011774	170738	232149.36
Percentage of Urban Population	0%	98.93%	57.56%	27.57%
Percentage of Rural Population	1.07%	100.00%	42.44%	27.57%
NP with Ages <15	2452	209736	33250	49489.97
NP with Ages 15 -19	804	69187	11844	15790.37
NP with Ages 20-44	3511	390588	61651	89947.62
NP with Ages 45-64	4111	253348	43155	56187.78
NP with Ages 65+	2754	101483	20837	22045.63
PP with Ages <15	10.80%	22.85%	17.83%	2.49%
PP with Ages 15 -19	4.40%	12.62%	6.97%	1.54%
PP with Ages 20-44	23.30%	46.10%	32.74%	5.45%
PP with Ages 45-64	16.37%	32.89%	27.11%	3.50%
PP with Ages 65+	7.47%	27.94%	15.34%	4.63%
NP (Ages 16 plus) Working	5318	510506	80664	116166.45
NP (Ages 16 plus) Taking Public Transportation to Work	0	16606	1321	3122.77
NP (Ages 16 plus) Bicycling to Work	0	1695	277	403.79
NP (Ages 16 plus) Walking to Work	30	10135	1661	2186.27
PP (Ages 16 plus) Taking Public Transportation to Work	0%	7.54%	0.88%	1.50%
PP (Ages 16 plus) Bicycling to Work	0%	1.99%	0.35%	0.42%
PP (Ages 16 plus) Walking to Work	0.27%	7.72%	2.25%	1.54%
NH with Income Less than $50,000	3565	167865	32445	37608.64
NH with Income between $50,000 and $100,000	1286	116079	19951	27316.54
NH with Income $100,000 or more	532	125410	13962	25222.06
PH with Income Less than $50,000	35.30%	69.60%	54.25%	7.55%
PH with Income between $50,000 and $100,000	21.90%	42.00%	29.88%	3.25%
PH with Income $100,000 or more	5.60%	33.60%	15.87%	6.14%

* NP = Number of People; PP = Percentage of People; NH = Number of Households; PH = Percentage of Households

Table 9. Summary Statistics for Reference Group (71 Counties)

Data Element	Minimum	Maximum	Average	Standard Deviation
Annual VMT (1000)	51632	4736643	720892	748909.93
Daily VMT (1000)	141	12977	1975	2051.81
Number of Autos/Vans	1504	203228	33783	34422.67
Numbers of Trucks/Large Vehicles	1444	60020	18734	14618.06
Number of Motorcycles	43	7527	1465	1474.14
Percentage of Autos/Vans	45.21%	75.85%	59.37%	5.39%
Percentage of Trucks/Large Vehicles	21.96%	53.47%	38.08%	5.43%
Percentage of Motorcycles	1.00%	4.64%	2.55%	0.58%
Total Population	4128	364691	65840	66872.84
Percentage of Urban Population	0%	92.65%	31.13%	24.40%
Percentage of Rural Population	7.35%	100.00%	68.87%	24.40%
NP with Ages <15	437	72344	13031	14384.46
NP with Ages 15 -19	179	25558	4406	4765.64
NP with Ages 20-44	1228	124952	20637	23025.16
NP with Ages 45-64	1211	97090	17891	17014.11
NP with Ages 65+	667	52428	9875	8474.96
PP with Ages <15	9.98%	26.20%	18.50%	2.49%
PP with Ages 15 -19	4.34%	9.06%	6.46%	0.79%
PP with Ages 20-44	22.10%	39.12%	29.85%	3.06%
PP with Ages 45-64	21.42%	35.44%	28.29%	2.03%
PP with Ages 65+	7.12%	28.07%	16.90%	3.87%
NP (Ages 16 plus) Working	1315	161825	27423	29843.99
NP (Ages 16 plus) Taking Public Transportation to Work	0	2107	109	251.47
NP (Ages 16 plus) Bicycling to Work	0	265	31	44.95
NP (Ages 16 plus) Walking to Work	0	5759	411	653.67
PP (Ages 16 plus) Taking Public Transportation to Work	0%	1.76%	0.29%	0.28%
PP (Ages 16 plus) Bicycling to Work	0%	5.30%	0.17%	0.46%
PP (Ages 16 plus) Walking to Work	0%	9.99%	1.67%	1.14%
NH with Income Less than $50,000	978	77045	14446	13535.41
NH with Income between $50,000 and $100,000	333	41441	7330	7748.95
NH with Income $100,000 or more	73	26661	3375	4510.75
PH with Income Less than $50,000	36.50%	77.90%	60.39%	7.23%
PH with Income between $50,000 and $100,000	17.90%	38.90%	28.10%	3.64%
PH with Income $100,000 or more	4.20%	31.10%	11.52%	4.43%

* NP = Number of People; PP = Percentage of People; NH = Number of Households; PH = Percentage of Households

5. Results and Discussion

As discussed in the methodology in Section 3, the first step in the evaluation is to estimate a safety performance function (SPF). Generalized linear modeling was used to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. SPFs were estimated for each pedestrian and bicycle target crash types identified in Section 2 as well for combined total pedestrian and bicycle crashes. These SPFs and the annual calibration factors (ACFs) are documented in Appendices B and C, respectively.

5.1. Estimated Pedestrian Crash Safety Effects

The estimated safety effects of the Watch for Me NC program on pedestrian crashes are shown in Table 10. Changes in crashes that are statistically significant from 1.0 at the 0.05 significance level are shown in bold. For each crash type, the EB expected crashes in the after period had the program not been implemented are shown along with the actual number of crashes observed in the after period, the safety effect, and the standard error of the safety effect.

Table 10. Estimated Pedestrian Crash Safety Effects

Crash Type	EB Expected Crashes in the After Period	Number of Crashes Observed in the After Period	Safety Effect	Standard Error of Safety Effect	Percentage Change in Crashes
Total	7500.57	6541	**0.872**	**0.016**	**-12.8%**
Nighttime Total	3988.56	3123	**0.783**	**0.021**	**-21.7%**
Failed to Yield	3044.34	2757	**0.905**	**0.028**	**-9.5%**
Walking Along Roadway	713.76	693	0.969	0.052	-3.1%
Permissive Left Turn	576.32	591	1.023	0.069	+2.3%

*CMFs in bold are statistically different from 1.0 at 0.05 significance level

The results indicate that the introduction of the Watch for Me NC program has had a positive impact on county-wide pedestrian crash reduction. The total pedestrian crashes show a statistically significant reduction of 12.8% along with a 21.7% reduction in nighttime crashes and a 9.5% reduction in failed to yield crashes, both statistically significant. The analysis also show a 3.1% reduction in walking along roadway crashes and a 2.3% increase in the permissive left turn crashes, though both of these were not statistically significant.

5.2. Estimated Bicycle Crash Safety Effects

The estimated safety effects of the Watch for Me NC program on bicycle crashes are shown in Table 11. Changes in crashes that are statistically significant from 1.0 at the 0.05 significance level are shown in bold. For each crash type, the EB expected crashes in the after period had the program not been implemented are shown along with the actual number of crashes observed in the after period, the safety effect, and the standard error of the safety effect.

Table 11. Estimated Bicycle Crash Safety Effects

Crash Type	EB Expected Crashes in the After Period	Number of Crashes Observed in the After Period	Safety Effect	Standard Error of Safety Effect	Percentage Change in Crashes
Total	1896.08	2338	**1.232**	**0.038**	**+23.2%**
Nighttime Total	518.12	647	**1.246**	**0.074**	**+24.6%**
Overtaking	355.92	393	1.101	0.079	+10.1%
Right Hook	440.31	291	**0.659**	**0.051**	**-34.1%**

*CMFs in bold are statistically different from 1.0 at 0.05 significance level

The results above would indicate that the introduction of the Watch for Me NC program has not been as effective for bicyclists as it has been for pedestrians. The total bicycle crashes show an increase of 23.2% along with a 24.6% increase in nighttime crashes, and a 34.1% reduction in right hook crashes, all statistically significant. The analysis also show that overtaking crashes had a non-statistically significant increase of 10.1%.

The research team further investigated as to why the data would reflect a negative impact on bicycle crashes, while having a positive impact on pedestrian crashes.

Assuming the model results were valid, one hypothesis was that the Watch for Me NC program is by-design more oriented to focus on pedestrian safety issues than bicycle safety issues. For example, the initial pilot program in 2012 focused exclusively on pedestrian safety, and bicycle messages were added a year later, so there was an extra year of "treatment" for pedestrian crashes than for bike crashes. Relatedly, the law enforcement operations, and training and support materials, focus heavily on driver yielding operations at crosswalks, which would not theoretically have an impact on bicycle crashes. However, there was no clear rationale for why the program would result in an increase in crashes involving bicyclists, as indicated in Table 11.

Thus, the team also considered the possibility that the model results were not valid. The ACFs provide a valuable insight on this issue. The ACFs, which are the ratio between observed and predicted crashes for each year, should be close to 1. In this case, it was clear that the bicycle crash ACFs showed that the SPFs were either under- or over-predicting bicycle crashes by up to 30% for the years 2012, 2014, and 2016. This is a clear indication that the exposure variables that were available in the analysis cannot accurately predict bicycle crash frequency.

Many factors affect bicycle travel rates (or exposure) that may not influence pedestrian travel rates in the same way. For example, introduction of bikeshare systems and new bike facilities (such as protected bike lanes), can heavily influence changes in bike ridership in short amounts of time. While the Watch for Me NC program was not designed to systematically capture or measure infrastructure changes happening as a result of, or at the same time as, the program, the project team is aware of several major bicycle projects that were implemented in treatment cities. These may have influenced bicycling trends in ways that could not be captured by the Journey to Work data used in the model, as much new bike exposure may be unrelated to work trips.

To further examine this issue, the project team decided to conduct sensitivity analysis using two more options to recalibrate the SPFs used in the EB methodology for evaluating bicycle crashes:

- Option A: Develop SPFs for combined pedestrian and bicycle crashes and use the product of the proportion of bicycle crashes (i.e., ratio of number of bicycle crashes to the total of pedestrian and bicycle crashes) with the predictions from the SPF, to estimate the predicted number of bicycle crashes.

- Option B: Use the SPF for total Pedestrian crashes and estimate the predicted number of bicycle crashes as the product of the ratio of bicycle crashes to pedestrian crashes with the predictions from the SPF.

The project team has conducted such sensitivity analysis for other studies as a way of assessing the reliability of counterintuitive results. The resulting safety effects from both of the above mentioned options are shown in Tables 12 and 13.

Table 12. Bicycle Crash Safety Effects (Option A)

Crash Type	EB Expected Crashes in the After Period	Number of Crashes Observed in the After Period	Safety Effect	Standard Error of Safety Effect	Percentage Change in Crashes
Total	2178.69	2324	1.066	0.034	+6.6%
Nighttime Total	647.04	647	0.998	0.056	-0.2%
Overtaking	380.81	393	1.059	0.073	+5.9%
Right Hook	182.25	291	**1.591**	**0.132**	**+59.1%**

*CMFs in bold are statistically different from 1.0 at 0.05 significance level

Table 13. Bicycle Crash Safety Effects (Option B)

Crash Type	EB Expected Crashes in the After Period	Number of Crashes Observed in the After Period	Safety Effect	Standard Error of Safety Effect	Percentage Change in Crashes
Total	2606.77	2338	**0.896**	**0.028**	**-10.4%**
Nighttime Total	759.17	647	**0.851**	**0.049**	**-14.9%**
Overtaking	424.73	393	0.923	0.067	+7.7%
Right Hook	215.23	291	**1.347**	**0.114**	**+34.7%**

*CMFs in bold are statistically different from 1.0 at 0.05 significance level

It can be seen that Option A still shows a negative impact on all crash types. An interesting thing to note here is that the right hook crashes now show a statistically significant increase of 59.1% (compared to a statistically significant decrease of 34.1% seen in Table 10). Option B shows improved results, where total and nighttime show statistically significant decreases of 10.4% and 14.9%, respectively. However, even in this case, the right hook crashes are showing a statistically significant increase of 34.7%.

Due to the fact that all three scenarios show very different results and the initial analysis showing that we are not able to accurately predict bicycle crashes, the team cannot conclude whether the Watch for Me NC program has had a positive or a negative impact on bicycle crashes at this time. We provide some recommendations for next steps in the conclusions section.

6. Conclusions

The objective of this study was to estimate the crash-based safety effectiveness of the Watch for Me NC program. EB before-after methodology was employed to evaluate the safety effectiveness of the program. This robust study design, takes into account changes in exposure as well as other variables that could affect crash rates, provides a sound research foundation that complements other evaluations of the program. The treatment and reference groups used in the evaluation consisted of 29 counties and 71 counties, respectively. As a part of EB methodology, SPFs were estimated using data from the reference group and the before-period of the treatment group. Safety effects were derived for five types of pedestrian crashes (total, nighttime total, failed to yield – driver and pedestrian, walking along roadway, and permissive left turn) and four types of bicycle crashes (total, nighttime total, overtaking, and right hook).

The results show a positive effect of the Watch for Me NC program on reducing county-wide pedestrian crashes with total, nighttime total, and failed to yield crashes showing statistically significant reductions.

The analysis show that the exposure variables that were used in the analysis were not able to accurately predict bicycle volume changes. The team used three different evaluation options (using bicycle crash SPFs, using combined pedestrian and bicycle crash SPFs recalibrated using proportion of bicycle to total of pedestrian and bicycle crashes, and using pedestrian SPFs recalibrated using the ratio of bicycle to pedestrian crashes) as a part of sensitivity analysis. All the three options showed different results with respect to reduction or increase in the different bicycle crash types. Without accounting for changes in bicycle exposure, the evaluation cannot provide conclusive results with respect to the effects of the Watch for Me NC program on bicycle crashes.

While this crash-based study provides some firm evidence of the program effects, it was not without its limitations.

For example, the team noted several baseline differences between the treatment and reference groups used in the analysis. Most obvious was that treated groups skewed more urban and higher population than the referent counties. It is not understood what impact these differences may have on the estimated safety effects. A sensitivity analysis could be performed in the future to see whether varying the referent group would affect the stability of the results.

Additionally, as noted in section 5.2, lack of quality bicycle exposure measures to incorporate in the analysis impacted the validity of the bicycle crash evaluation. Cities should be encouraged to collect pedestrian and bicycle volumes at intersections and corridors. This would provide the best pedestrian and bicycle exposure to be used when developing SPFs and evaluating safety programs. Future studies could gather the data to adjust for the presence of bikeshare programs in the study areas or other key facilities that are opened during the study period and thought to influence bicycle ridership. This data collection could extend to pedestrian facilities as well and would allow for exploring the direct effects of specific components of the Watch for Me NC program as opposed to a collective effect of Watch for Me NC program and other treatments.

Further, we note that this study was based upon police-reported crash data. We are aware that police-reported crash data reflect only a portion of the total crashes and injuries experienced by pedestrians and bicyclists. It would be beneficial for future studies to also examine hospital-based data sources. For example, emergency department records of bicycle injuries could reveal important trends, and provide an additional source of data to explore specific injuries, such as the prevalence of traumatic brain injuries (TBI), that might be influenced by the Watch for Me NC program efforts.

Finally, the study was only able to evaluate effects at the county level, which might actually underestimate the true program impacts given that in many counties, efforts are concentrated in only a few cities or specific corridors and sites. Better data from participating communities on where enforcement and community engagement opportunities are taking place would allow for a finer-grain analysis of program effects. Police departments and partnering communities may need additional training, support, and incentives to provide such information to support robust program evaluation.

References

1. National Highway Traffic Safety Administration. (2018). *Traffic Safety Facts 2016 Data, Pedestrians* (Publication No. DOT HS 812493). National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, DC, 2018. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812493.
2. National Highway Traffic Safety Administration. (2018a). *Traffic Safety Facts 2016 Data, Bicyclists and Other Cyclists* (Publication No. DOT HS 812507). National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, DC, 2017. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812507.
3. National Highway Traffic Safety Administration. (2017a). *Traffic Safety Facts 2015 Data, Pedestrians* (Publication No. DOT HS 812375). National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, DC, 2017. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812375.
4. National Highway Traffic Safety Administration. (2017b). *Traffic Safety Facts 2015 Data, Bicycles and Other Cyclists* (Publication No. DOT HS 812382). National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, DC, 2017. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812382.
5. Highway Safety Research Center at University of North Carolina at Chapel Hill. (n.d.). *North Carolina Crash Data Query Web Site.* Retrieved from http://nccrashdata.hsrc.unc.edu/index.cfm.
6. Sandt, L.S., Marshall, S.W., Rodriguez, D.A., Evenson, K.R., Ennett, S.T., & Robinson, W.R. (2016). Effect of a Community-based Pedestrian Injury Prevention program on Driver Yielding Behavior at Marked Crosswalks. *Accident Analysis & Prevention, 93*, 169-178.
7. Sandt, L.S., Marshall, S.W., & Ennett, S.T. (2015). Community-Based Pedestrian and Bicycle Safety Program – Developmental Framework and Process Evaluation. *Transportation Research Record 2519*, 51-60.
8. Blomberg, R.D., Preusser, D.F., Hale, A., & Leaf, W.A. (1983). *Experimental Field Test of Proposed Pedestrian Safety Messages*. Final report DOT HS 806 522. U.S. Department of Transportation.
9. Blomberg, R.D., Cleven, A.M., & Edwards, J.M. (1993). *Development of Safety Information Materials and Media Plans for Elderly Pedestrians.* Final report DOT HS 808 132. U.S. Department of Transportation.

10. Preusser, D.F., & Lund, A.K. (1988). And Keep on Looking: A Film to reduce pedestrian Crashes among 9 to 12 Year Olds. *Journal of Safety Research*, 19, 177-185.
11. Zegeer, C. V., et al. (2008). Evaluation of Miami–Dade Pedestrian Safety demonstration Project. *Transportation Research Record 2073*, 1-10.
12. Hunter, W. H., Stutts, J. C., Pein, W. E., & Cox, C. L. (1996). *Pedestrian and Bicycle Crash Types of the Early 1990's*. Publication No. FHWA-RD-95-163. Washington, DC: Federal Highway Administration.
13. Agran, P. F., Winn, D. G., & Anderson, C. L. (1994). Differences in Child Pedestrian Injury Events by Location. *Pediatrics, 93*, 84-288.
14. Olson, L. M., Sklar, D. P., Cobb, L., Sapien, R., & Zumwalt, R. (1993). Analysis of Childhood Pedestrian Deaths in New Mexico, 1986-1990. *Annals of Emergency Medicine*, *22*, 512-516.
15. Zegeer, C.V., & Bushell, M. (2012). Pedestrian Crash Trends and Potential Countermeasures from Around the World. *Accident Analysis & Prevention, 44,* 3-11.
16. Barton, B. K., Schwebel, D. C., & Morrongiello, B. A. (2007). Brief report: Increasing Children's Safe Pedestrian behaviors through Simple Skills Training. *Journal of Pediatric Psychology*, *32*, 475-80S.
17. Barton, B. K. & Morrogienello, B. A. (2012). Examining the Impact of Traffic Environment and Executive Functioning on Children's Pedestrian Behaviors. *Journal of Developmental Psychology, 47,* 182-191.
18. Albert, R. R, & Dolgin, K. G. (2010). Lasting Effects of Short-Term training on Preschoolers' Street-crossing Behavior. *Accident Analysis & Prevention*, *42*, 500-508.
19. Sarkar, S., Kaschade, C., and de Faria, F. (2003). How Well Can Child Pedestrians Estimate Potential Traffic Hazards? *Transportation Research Record: Journal of the Transportation Research Board*, *1828,* 38-46.
20. Dunbar G., Holland C., & Maylor E. (2004, June*). Road Safety Research Report No. 37 Older Pedestrians: A Critical Review of the Literature.* London: Department of Transport.
21. Van Houten, R., & Malenfant, J.E.L. (2004). Effects of a Driver Enforcement Program on Yielding to Pedestrians. *Journal of Applied Behavior Analysis, 37,* 351-363.
22. Savolainen, P. T., Gates, T. J., & Datta, T. K. (2011). Implementation of Targeted Pedestrian Traffic Enforcement Programs in an Urban Environment. *Transportation Research Record: Journal of the Transportation Research Board, 2265,* 137-145.
23. Van Houten, R., & Malenfant, J.E.L., Blomberg, R.D., Huitema, B.E., Casella, S. (2013, August). *High-visibility Enforcement on Driver Compliance with Pedestrian Right-of-Way Laws.* National Highway Traffic Safety Administration. Report No: DOT HS 811 786.

24. Carter, D., Srinivasan, R., Gross, F., and Council, F. (2012), *Recommending Protocols for Developing Crash Modification Factors.* NCHRP 20-7(314) Final Report, 2012.
25. Elvik, R. (2011), Assessing Causality in Multivariate Accident Models, *Accident Analysis and Prevention*, Vol. 43, pp. 253-264.
26. Chen, Y. (2013). *Integrating Information from Prior Research into a Before-after Road Safety Evaluation.* PhD Thesis, Ryerson University, 2013.
27. AASTHO (2010). *Highway Safety Manual*, 1st Edition, AASTHO, Washington, DC.

Appendix A. Empirical Bayes (EB) Methodology

In the EB approach, the estimated change in safety for a given crash type at a site is given by the equation in Figure 2

$$\Delta Safety = \lambda - \pi$$

Figure 2. Equation. Estimated Change in Safety

Where:

λ = Expected number of crashes that would have occurred in the after without the treatment.

π = Number of reported crashes in the after period.

In estimating λ, the effects of regression to the mean and changes in exposure were explicitly accounted for using SPFs. In this effort, the SPFs were estimated using crash data and characteristics of the sites in the reference group and the before-period of the treatment group. The SPFs were estimated using negative binomial regression. The SPFs were also used to estimate ACFs for each year. The ACFs are defined as the ratio of the total observed crash frequency to the total predicted crash frequency from the SPF, and are calculated for each year. The ACFs are estimated to account for time trends.

The sum of the annual SPF estimates for the before period (P) was then combined with the count of crashes (x) in the before period at a treatment site to obtain an estimate of the expected number of crashes (m) before the treatment was applied.

$$m = w(P) + (1 - w)(x)$$

Figure 3. Equation. Empirical Bayes Estimates of Expected Crashes in the Before Period

Where the EB weight, w, was estimated from the mean and variance of the SPF estimate using the equation in Figure 4.

$$w = \frac{1}{1 + kP}$$

Figure 4. Equation, Empirical Bayes Weight

Where:

k = Overdispersion parameter of the negative binomial distribution.

The expected number of crashes in the after period, λ, was calculated by applying a factor to m as seen in the equation in Figure 5. This factor was the sum of the annual SPF estimates for the after period (A) divided by P.

$$\lambda = m \times \left(\frac{A}{P}\right)$$

Figure 5. Equation. Empirical Bayes Estimates of Expected Crashes in the After Period

The estimate of λ and variance of λ, were then summed over all sites to obtain λ_{sum} and $Var(\lambda_{sum})$. λ_{sum} was then compared with the sum of count of crashes observed during the after period over all sites (π_{sum}) to obtain the safety effect (θ). The safety effect θ was calculated using the equation in Figure 6 and the standard error of θ was calculated using the equation in Figure 7.

$$\theta = \frac{\pi_{sum}/\lambda_{sum}}{1 + \left(\frac{Var(\lambda_{sum})}{\lambda_{sum}{}^2}\right)}$$

Figure 6. Equation. Safety Effect

$$Standard\ Error\ of\ \theta = \sqrt{\frac{\theta^2 \left(\frac{Var(\pi_{sum})}{\pi_{sum}{}^2} + \frac{Var(\lambda_{sum})}{\lambda_{sum}{}^2}\right)}{\left(1 + \frac{Var(\lambda_{sum})}{\lambda_{sum}{}^2}\right)^2}}$$

Figure 7. Equation, Standard Error of Safety Effect

The percent change in crashes is calculated as $100(1 - \theta)$. Therefore a value of $\theta = 0.9$ with a standard of error of 0.05 indicates a 10% reduction in crashes with a standard error of 5%. Conversely, a value of $\theta = 1.2$ with a standard of error of 0.1 indicates a 20% increase in crashes with a standard error of 10%.

Appendix B. Safety Performance Functions

SPFs were estimated for each of the five target pedestrian crash types and four target bicycle crash types. An SPF was also developed for combined total of pedestrian and bicycle crashes. The relationship between the crash frequency and the independent variables can be seen in Figure 8.

$$Crashes = \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \_\_\_ + \beta_n X_n)$$

Figure 8. Equation. Sample Safety Performance Function

Where:
α = intercept,
X = independent (exposure) variables, and
β = coefficient estimates.

The exposure variables used in the SPFs are defined in Table 14 and the SPFs are presented in Tables 15 - 17.

Table 14. Exposure Variables used in Safety Performance Functions

Variable	Description
AVMT1000	Annual VMT (1000)
DVMT1000	Daily VMT (1000)
Num1000_Auto_Van	Number of Autos/Vans (1000)
Num1000_Truck_LGV	Numbers of Trucks/Large Vehicles (1000)
Num1000_MC	Number of Motorcycles (1000)
Pct_Auto_Van	Percentage of Autos/Vans
Pct_Truck_LGV	Percentage of Trucks/Large Vehicles
Pct_MC	Percentage of Motorcycles
Population	Total Population
Pct_Upop	Percentage of Urban Population
Pct_Rpop	Percentage of Rural Population
Num1000_age_lt15	Number of People with Ages <15 (1000)
Num1000_age15_19	Number of People with Ages 15 -19 (1000)
Num1000_age20_44	Number of People with Ages 20-44 (1000)
Num1000_age45_64	Number of People with Ages 45-64 (1000)
Num1000_age_gt64	Number of People with Ages 65+ (1000)
Pct_age_lt15	Percentage of People with Ages <15
Pct_age15_19	Percentage of People with Ages 15 -19
Pct_age20_44	Percentage of People with Ages 20-44
Pct_age45_64	Percentage of People with Ages 45-64
Pct_age_gt64	Percentage of People with Ages 65+
Num1000_wrk_age16p	Number of People (Ages 16 plus) Working (1000)
Num1000_wrk_bus_age16p	Number of People (Ages 16 plus) Taking Public Transportation to Work (1000)
Num1000_wrk_bk_age16p	Number of People (Ages 16 plus) Bicycling to Work (1000)
Num1000_wrk_wk_age16p	Number of People (Ages 16 plus) Walking to Work (1000)
Pct_wrk_bus_age16p	Percentage of People (Ages 16 plus) Taking Public Transportation to Work
Pct_wrk_bk_age16p	Percentage of People (Ages 16 plus) Bicycling to Work
Pct_wrk_wk_age16p	Percentage of People (Ages 16 plus) Walking to Work
Num1000_HHI_lt50k	Number of Households with Income Less than $50,000 (1000)
Num1000_HHI50k_100k	Number of Households with Income between $50,000 and $100,000 (1000)
Num1000_HHI_gt100k	Number of Households with Income $100,000 or more (1000)
Pct_HHI_lt50k	Percentage of Households with Income Less than $50,000
Pct_HHI50k_100k	Percentage of Households with Income between $50,000 and $100,000
Pct_HHI_gt100k	Percentage of Households with Income $100,000 or more

Table 15. SPFs for Pedestrian Crashes

Parameter	Total		Nighttime		Driver Failed to Yield		Pedestrian Failed to Yield		Walking along Roadway		Permissive Left Turn	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Intercept	-6.5914	0.7652	-21.0631	3.6346	-0.7311	0.55	-24.8412	5.3309	-27.4053	5.5846	-4.7539	0.4055
year_acc 2010	-0.0346	0.0569	-0.0104	0.0601	-0.0867	0.0877	0.1958	0.0846	-0.0111	0.0956	0.1611	0.183
year_acc 2011	-0.1305	0.0576	-0.0941	0.0608	-0.1102	0.0883	0.0818	0.0861	-0.0704	0.0958	0.0986	0.1819
year_acc 2012	0.1486	0.0563	0.175	0.06	0.1402	0.0864	0.2875	0.0859	0.2401	0.0932	0.2658	0.1885
year_acc 2013	0.0707	0.0577	0.1246	0.0625	0.006	0.0899	0.0059	0.0933	0.2055	0.0971	0.0891	0.2012
year_acc 2014	0.1645	0.0613	0.1606	0.0684	0.155	0.0952	-0.0335	0.102	0.2647	0.1044	0.3097	0.2101
year_acc 2015	0.1663	0.0643	0.2881	0.0691	-0.0111	0.1007	0.1512	0.1055	0.3567	0.1071	0.7	0.2096
year_acc 2016	-0.0438	0.071	-0.0639	0.0799	-0.1972	0.1115	-0.2094	0.1217	0.3411	0.1143	-0.0765	0.2548
year_acc 2017	-0.053	0.0747	0.0396	0.0829	-0.4913	0.1264	0.3664	0.1119	0.5894	0.1156	-0.478	0.305
year_acc 2009	0	0	0	0	0	0	0	0	0	0	0	0
DVMT1000	0.0001	0			0.0001	0	-0.0001	0				
N1000_Auto_Van	-0.0061	0.0026	-0.0064	0.0019	-0.0083	0.003						
N1000_Truck_LGV	0.0234	0.0053	0.0224	0.0044	0.0284	0.0074			0.0134	0.0065		
Pct_Auto_Van	5.1922	0.6679	16.04	3.8439			23.7354	5.3968	18.0575	5.6914		
Pct_Truck_LGV			10.227	4.054	-4.8683	1.0907	20.5985	5.7773	12.5422	6.0615		
pop1000	0.0242	0.0042	0.063	0.0055	0.0065	0.0032	0.0305	0.0038	0.1017	0.0089		
pop_U1000	-0.0163	0.0017	-0.0151	0.0017	-0.0158	0.0024	-0.016	0.0016	-0.0175	0.0026		
Pct_Upopavg	2.2303	0.166	1.8742	0.1925	2.4322	0.2918	2.8718	0.2488	1.7326	0.2752	3.1276	0.3082
N1000_age_lt15			-0.0828	0.0124					-0.1065	0.0185	-0.0775	0.0135
N1000_age15_19	-0.1034	0.0249	-0.1043	0.0214			-0.0951	0.0213	-0.2338	0.0361		
N1000_age20_44							0.0291	0.0051			0.063	0.014
N1000_age45_64	-0.0532	0.0103	-0.0836	0.0125	-0.0373	0.0099			-0.1271	0.0189	0.0688	0.0132
Pct_age_lt15	3.1147	1.0701	9.3571	1.6794					15.2546	2.597		
Pct_age15_19	13.5063	3.0261	13.1262	3.4343					25.1749	5.2509	25.1431	4.7839
Pct_age20_44			2.5417	1.0561					4.1612	1.6855		
Pct_age45_64	5.1641	1.5151	10.6245	2.2198					18.5388	3.3633		

Parameter	Total		Nighttime		Driver Failed to Yield		Pedestrian Failed to Yield		Walking along Roadway		Permissive Left Turn	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
N1000_wrk_age16p							-0.021	0.009	-0.0199	0.0077	-0.0415	0.0145
N1000_wrk_bk_age16p	0.4085	0.133					0.5256	0.1502				
Pct_wrk_bus_age16p									-9.9419	4.8634		
N1000_HHI_lt50k	0.0466	0.0103			0.059	0.0112						
N1000_HHI50k_100k									-0.0505	0.0258		
N1000_HHI_gt100k	0.0443	0.0177			0.0923	0.0187	-0.0477	0.0098				
Pct_HHI_lt50k	1.6813	0.3118	2.0161	0.2897	2.4239	0.5022	2.1738	0.5214				
Dispersion	0.0631	0.0078	0.0408	0.0083	0.0705	0.0168	0.0288	0.0135	0.0679	0.0173	0.1345	0.0572

Table 16. SPFs for Bicycle Crashes

Parameter	Total		Nighttime		Overtaking		Right Hook	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Intercept	-33.1096	5.7678	-40.2303	11.2446	-5.2328	1.2237	-14.284	2.9964
year_acc 2010					0.0699	0.1149	0.242	0.1891
year_acc 2011					-0.0902	0.1163	0.4116	0.1829
year_acc 2012					0.0754	0.1164	0.1312	0.2142
year_acc 2013					-0.0941	0.1225	0.248	0.2192
year_acc 2014					-0.2497	0.1369	-0.084	0.2751
year_acc 2015					-0.0442	0.1412	0.2949	0.292
year_acc 2016					-0.3794	0.1621	0.6322	0.2684
year_acc 2017					-0.3976	0.1717	1.1069	0.2473
year_acc 2009					0	0	0	0
DVMT1000							0.0001	0
N1000_Truck_LGV			-0.0599	0.0137				
N1000_MC			0.2578	0.1186				
Pct_Auto_Van	30.0395	5.8325	30.8368	11.317	4.1925	1.3171		
Pct_Truck_LGV	25.7727	6.1382	32.0396	12.2424				
pop1000	0.0399	0.0074	0.0302	0.0071	0.101	0.0133		
pop_U1000	-0.0225	0.0019	-0.0348	0.0037	-0.024	0.0023	-0.0126	0.0032
Pct_Upopavg	3.7367	0.2136	3.9985	0.3707	2.0444	0.2659	4.6027	0.3953
N1000_age_lt15					-0.1069	0.0192		
N1000_age15_19	-0.1373	0.0433			-0.0817	0.0292		
N1000_age45_64	-0.0573	0.0145	-0.0422	0.0197	-0.1118	0.0214		
Pct_age_lt15			6.4329	2.514				
Pct_age15_19	11.4041	4.7437					21.144	7.2441
Pct_age20_44			8.0745	2.183			9.2933	4.3694
Pct_age45_64	8.623	2.3792	14.255	3.8064	7.5171	3.0521	19.6834	5.84
Pct_age_gt64					-5.9599	1.7381		
N1000_wrk_age16p	0.0301	0.0102			-0.0564	0.0134		
N1000_wrk_bus_age16p			-0.1464	0.0362				
N1000_wrk_bk_age16p			0.5902	0.2553				
Pct_wrk_wk_age16p	6.5814	2.9868						
Pct_wrk_bus_age16p					-10.2205	5.0865		
Pct_wrk_bk_age16p					38.2486	9.2392	1.1167	0.2891
N1000_HHI_lt50k	0.0301	0.007	0.0684	0.0192				
N1000_HHI50k_100k	-0.1153	0.0362					0.0851	0.0228
N1000_HHI_gt100k	3.9287	1.2795	0.079	0.0312	0.0679	0.0167		
Dispersion	0.1847	0.0215	0.1113	0.0288	0.0583	0.0274	0.0154	0.0408

Table 17. SPF for Total Pedestrian and Bicycle Crashes

Parameter	Total Pedestrian + Bicycle	
	Estimate	S.E.
Intercept	-28.0696	4.2555
year_acc 2010	-0.0258	0.0556
year_acc 2011	-0.1424	0.0561
year_acc 2012	0.1058	0.0553
year_acc 2013	-0.0006	0.0577
year_acc 2014	0.0414	0.0621
year_acc 2015	0.0961	0.0634
year_acc 2016	-0.1336	0.0691
year_acc 2017	-0.0949	0.0718
year_acc 2009	0	0
N1000_MC	0.1283	0.0392
Pct_Auto_Van	22.8794	4.2196
Pct_Truck_LGV	20.6302	4.3488
pop1000	0.0906	0.0168
pop_U1000	-0.0218	0.0012
Pct_Upopavg	2.8361	0.1325
N1000_age_lt15	-0.0426	0.0189
N1000_age15_19	-0.2071	0.0277
N1000_age20_44	-0.0405	0.0146
N1000_age45_64	-0.1614	0.0311
Pct_age_lt15	4.7896	1.492
Pct_age15_19	18.426	3.0211
Pct_age20_44	4.422	1.2596
Pct_age45_64	13.303	2.5147
N1000_wrk_bk_age16p	0.5272	0.1779
N1000_wrk_wk_age16p	-0.0987	0.0419
N1000_HHI_lt50k	0.0627	0.0125
N1000_HHI50k_100k	-0.0683	0.0162
N1000_HHI_gt100k	0.0684	0.0191
Dispersion	0.0709	0.0074

Appendix C. Annual Calibration Factors

The SPFs presented in Appendix B were used to estimate annual calibration factors (ACFs). The ACFs are defined as the ratio of the total observed crash frequency to the total predicted crash frequency from the SPF, and are calculated for each year. The ACFs are estimated to account for time trends. The ACFs are presented in Tables 18 – 20.

Table 18. ACFs for Pedestrian Crashes

Crash Type	Total	Nighttime	Drive Failed to Yield	Pedestrian Failed to Yield	Walking Along Roadway	Permissive Left Turn
ACF 2009	0.960	0.975	0.988	0.985	0.984	1.092
ACF 2010	0.988	0.992	0.995	1.027	1.007	1.062
ACF 2011	1.075	1.059	1.016	1.015	1.037	0.846
ACF 2012	1.016	1.025	1.026	0.989	1.000	0.969
ACF 2013	0.961	0.953	0.980	0.971	0.961	1.054
ACF 2014	0.894	0.923	0.911	0.996	0.951	1.036
ACF 2015	0.989	1.011	0.991	1.005	1.008	0.833
ACF 2016	0.999	0.992	1.002	1.008	0.999	1.089
ACF 2017	0.982	0.983	1.023	1.003	0.971	1.041

Table 19. ACFs for Bicycle Crashes

Crash Type	Total	Nighttime	Overtaking	Right Hook
ACF 2009	0.970	0.912	1.066	0.603
ACF 2010	0.996	1.011	0.904	1.063
ACF 2011	0.963	1.071	1.077	0.953
ACF 2012	1.161	1.328	1.131	0.927
ACF 2013	0.953	1.068	0.992	0.784
ACF 2014	0.855	0.793	1.064	1.426
ACF 2015	0.998	1.069	0.985	1.070
ACF 2016	0.776	0.793	0.910	1.087
ACF 2017	0.927	0.921	0.999	0.996

Table 20. ACFs for Total Pedestrian and Bicycle Crashes

Crash Type	ACF 2009	ACF 2010	ACF 2011	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017
Total Pedestrian + Bicycle	0.944	1.010	1.078	0.995	0.935	0.926	0.962	1.017	1.007