FHWA-NJ-2009-008

Safety Comparison of Roadway Design Elements on Urban Collectors with Access

FINAL REPORT
April 2009

Submitted by

Kaan Ozbay, Ph. D.
Professor
Center for Advanced Infrastructure and Transportation (CAIT)
Civil and Env. Engineering
Rutgers University

Ozlem Yanmaz-Tuzel
Research Assistant
Center for Advanced Infrastructure and Transportation (CAIT)
Civil and Env. Engineering
Rutgers University

Satish Ukkusuri, Ph. D.
Assistant Professor
Civil and Env. Engineering
Rensselaer Polytechnic Institute

Bekir Bartin, Ph. D.
Research Associate
Center for Advanced Infrastructure and Transportation (CAIT)
Civil and Env. Engineering
Rutgers University

NJDOT Research Project Manager
Edward S. Kondrath

In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U.S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.
FHWA-NJ-2009-008

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
FINAL REPORT
Safety Comparison of Roadway Design Elements on Urban Collectors with Access

5. Report Date
April 2009

6. Performing Organization Code
CAIT/Rutgers University

7. Author(s)
Kaan Ozbay, Ozlem Yanmaz-Tuzel, Satish Ukkusuri and Bekir Bartin

8. Performing Organization Report No.
FHWA-NJ-2009-008

9. Performing Organization Name and Address
Rutgers University
100 Brett Road
Piscataway, NJ 08854

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
New Jersey Department of Transportation
PO 600
Trenton, NJ 08625

Federal Highway Administration
U.S. Department of Transportation
Washington, D.C.

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The main goal of this study identified by NJDOT can be defined as "the quantification of the effects of management treatments on roadway operations and safety on urban collectors with access".

Since, urban collector road runs through highly diversified areas, various factors have to be considered when before-and-after comparisons of improvements in terms of safety are conducted in this study. For 25-40 mph urban collectors with access, these are:

1. Increase in lane widths (10' or 11' to 12'),
2. Construction of 4,6,8, or 10 foot shoulders,
3. Removal of trees in median and border areas,
4. Installation of guide rails, and vertical & horizontal geometry changes to improve sight distances.

Before and after analysis for these countermeasures was conducted via several approaches, including naïve approach, analysis via control groups, analysis via Empirical Bayes approach, and analysis via Full Bayes approach. After conducting before-and-after analysis, Crash Reduction Factors (CRF) were estimated for each countermeasure. The individual CRF values and their relative order among different countermeasures are similar to the values in the literature. In particular, improvements in vertical and horizontal alignment results in highest reduction in the accident rate, followed by adding shoulders, median barrier installation, lane width increase, and guide rail installation.

17. Key Words
Road Safety, Before-and-After Analysis, Crash Reduction Factor.

18. Distribution Statement

19. Security Classif (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
114

22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENTS

The authors wish to thank various staff members without whom this rewrite would not have been possible. We thank Edward S. Kondrath, Evens Marcellus and Sansevalin Kumaresan of the New Jersey Department of Transportation (NJDOT) for their invaluable contributions to the success of this project from its inception to completion of the final report. At each step of the project, they provided the project team with timely advice that significantly enhanced the quality of the final product.

This project was funded by a grant from New Jersey Department of Transportation (NJDOT), and administered through the Center for Advanced Infrastructure and Transportation (CAIT).

Their support is both acknowledged and appreciated.

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EXECUTIVE SUMMARY

Ever increasing congestion of our roadway system has also caused a rapid increase in the number vehicular crashes increases. As a direct result of this alarming safety statistics, there has also been a welcomed increasing interest in enhancing roadway safety through safety research and safety conscious design, which are both mainly concerned "*with reducing the number of consequences of vehicle crashes*".

AASHTO which, in 1998, has approved its Strategic Highway Safety Plan, which was developed by the AASHTO Standing Committee on Highway Traffic Safety with the assistance of the Federal Highway Administration, the National Highway Traffic Safety Administration, and the Transportation Research Board Committee on Transportation Safety Management, has been the driving force in directing these safety related efforts in the US. In The AASHTO plan includes strategies in 22 key emphasis areas that affect highway safety. Each of the emphasis areas includes strategies and an outline of what is needed to implement each strategy.

According to recent NCHRP and AASHTO reports, however, the safety effectiveness of many of the strategies in the guides has not yet been rigorously evaluated. To address this need for more research, the Federal Highway Administration, in partnership with the state DOTs, has initiated a project to evaluate the safety effectiveness of the strategies in Volumes 1 through 6 of NCHRP Report 500. This specific project was charged with the evaluation of safety effectiveness evaluations of strategies from NCHRP Report 500, Volume 12: *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, A Guide for Reducing Collisions at Signalized Intersections.*

Thus, it is clear that more research is needed to evaluate the effectiveness of various safety treatments. Research is also needed to better understand "*the safety record or history of different types of geometric features that have been constructed to improve the safety of arterial roads in New Jersey*". The common way to evaluate the effectiveness of any safety improvement is to conduct before-and-after studies using the data collected before and after the safety treatments.

The main goal of this study is to quantify the effects of different safety treatments on roadway operations and safety on urban collectors with access.

Since, urban collector road runs through highly diversified areas, various factors have to be considered when before-and-after comparisons of improvements in terms of safety are conducted in this study. For 25-40 mph urban collectors with access, the safety treatments considered in this research are:

1. Increase in lane widths (10' or 11' to 12'),

2. Construction of 4,6,8, or 10 foot shoulders,
3. Removal of trees in median and border areas,
4. Installation of guide rails, and vertical & horizontal geometry changes to improve sight distances.

A number of sites along 25-40 mph urban collectors with access where the above safety improvements have been implemented were determined in close collaboration with NJDOT. The data sources include New Jersey Department of Transportation, Highway Safety Information System (HSIS), Ohio Department of Transportation, California Highway Patrol and Caltrans. From these sources, research team has identified seven different treatment sites from New Jersey, six different treatment sites from Ohio, and two different treatment sites from California.

Once the site selection process was completed, historical crash data for each of these sites were collected. NJDOT crash database was the main source of data for this comparative evaluation study. The impacts of improvements on safety were determined by an analysis of this NJDOT crash database for a period of three years before and three years after the implemented roadway treatment. In addition to the crash data, traffic and other relevant data were also collected because the selection of technique to be implemented is based on its impact of safety as well traffic performance. Thus, the final determination of the impacts of the potential techniques for future candidate sites was based on a combined assessment of their impacts on traffic performance and safety.

While conducting before and after analysis for the treatment sites four different methodologies were considered:

1. The simple (or naive) before-and-after study method
2. The before-and-after study with comparison group method
3. The before-and-after study with Empirical Bayes (EB) method
4. The before-and-after study with Full Bayes (FB) method

After conducting before-and-after analysis, Crash Reduction Factors (CRF) and Accident Modification Factors (AMF) were estimated for each countermeasure. The analysis results reveal that the individual CRF values and their relative order among different countermeasures are similar to the values in the literature. In particular, improvements in vertical and horizontal alignment are found to result in highest reductions in the accident rate, followed by adding shoulders, median barrier installation, lane width increase, and guide rail installation. However, impacts of guide rail installation were mixed because for some sites it did not show positive results.

It should be noted that the total benefit of implementing a countermeasure includes the costs saved resulting from the number of crashes or crash severity reductions; and the total cost of implementing a countermeasure includes construction and possibly maintenance costs. The determination of benefits from countermeasures depends on projected crash reductions, which is calculated as the expected number of crashes without the countermeasures multiplied by a CRF. Thus, CRF is simply a quantitative statement of the percentage of crashes that a countermeasure is expected to reduce.

Moreover, when considering individual CRF values, the transportation planner should keep in mind that the estimated values depend on the specific characteristics of the treatment site, reference groups considered in the estimation process, time period included in the analysis and the statistical tools used to calculate the CRF values.

INTRODUCTION

Ever increasing congestion of our roadway system has also caused a rapid increase in the number vehicular crashes increases. As a direct result of this alarming safety statistics, there has also been a welcomed increasing interest in enhancing roadway safety through safety research and safety conscious design, which are both mainly concerned "*with reducing the number of consequences of vehicle crashes*".

The main goal of this study identified by NJDOT can be defined as "the quantification of the effects of management treatments on roadway operations and safety on urban collectors with access".

Since, urban collector road runs through highly diversified areas, various factors have to be considered when before-and-after comparisons of improvements in terms of safety are conducted in this study. For 25-40 mph urban collectors with access, these are:

1. Increase in lane widths (10' or 11' to 12'),
2. Construction of 4,6,8, or 10 foot shoulders,
3. Removal of trees in median and border areas,
4. Installation of guide rails, and vertical & horizontal geometry changes to improve sight distances.

A number of sites along 25-40 mph urban collectors with access where safety improvements have been implemented were determined in close collaboration with NJDOT. Once the site selection process was completed, historical crash data for each of these sites were collected.

"The common way to evaluate the effectiveness of any safety improvement is to conduct "observational" before-and-after studies using the data collected before and after the implementation of specific countermeasures in a group of sites"*. In a before-and-after study, "the safety effect of a countermeasure is determined by calculating the difference in the number of crashes occurring before the improvement with those occurring after" (1).

The treatment sites required to conduct before-and-after analysis several different data sources were considered. The data sources include New Jersey Department of Transportation, Delaware Valley Regional Planning Commission, Highway Safety Information System (HSIS), Ohio Department of Transportation, California Highway Patrol and Caltrans. From these sources, research team has identified seven different treatment sites from New Jersey, six different treatment

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* The term "observational" means that no randomization or experimental design is involved in the selection of the treated sites – i.e., treated sites are not randomly selected.

sites from Ohio, and two different treatment sites from California. While conducting before and after analysis for the treatment sites four different methodologies were considered:

1. The simple (or naive) before-and-after study method
2. The before-and-after study with comparison group method
3. The before-and-after study with Empirical Bayes (EB) method
4. The before-and-after study with Full Bayes (FB) method

Next section reviews the existing before and after analysis methodologies. After describing data sources and the treatment sites, before and after analysis were conducted for each treatment site. After conducting before-and-after analysis, Crash Reduction Factors (CRF) and Accident Modification Factors (AMF) were estimated for each countermeasure. Then, recommendations regarding different safety treatments were provided followed by the conclusions and discussions.

REVIEW OF BEFORE AND AFTER ANALYSIS METHODOLOGIES

Michaels (2) suggests following factors to be considered in the design of before-and-after studies:

1. Vehicle-miles for both the before and after periods should be calculated in order to equate crash exposure.
2. The traffic volumes for each of the two periods should be approximately the same.
3. The composition of the traffic on the study section should be unchanged during each of the two periods.
4. The crash total in the after period should be corrected for any existing trends.
5. If crash data for several years before modification are available, and show a variation of no more than 20 percent from year to year, they may be averaged.

In the traffic safety literature four different types of before-and-after methods exist:

1. The simple (or naive) before-and-after study method
2. The before-and-after study with comparison group method
3. The before-and-after study with Empirical Bayes (EB) method
4. The before-and-after study with Full Bayes (FB) method

Naïve Before-and-After Study Method

The concept of the simple before-and-after study assumes that if nothing has changed, the crash experience before improvement is a good estimate of what would have happened during the after period without any improvement. The basic formula for deriving a crash reduction factor (CRF) using this method is as follows:

$$CRF = \frac{(N_b - N_a)}{N_b} = 1 - \frac{N_a}{N_b} \tag{1}$$

where, N_b and N_a are, respectively, the number of crashes at a treated site before and after the countermeasure took place.

With this method, the safety effect of a countermeasure is determined by the difference between the crash rate before and the crash rate after the countermeasure is implemented. Lord et al. (3) provide an overview for the calculation of CRF and accident modification factors for various types of before-and-after studies and in highway design process. Table 1 summarizes the studies conducted using naïve before-and-after approach, along with the information regarding the study area including, characteristics of the treatment site, types of countermeasure, and other variables considered by each study. Moreover, an extensive literature review of studies that developed accident reduction factors using this methodology can be found in Agent et al. (4).

However, many researchers have already pointed out that this so called "naïve" method can lead to inaccurate and potentially misleading conclusions. When determining the effect of a treatment with equation (1), we assume that nothing has changed and that the difference in accident rates or counts is solely attributed to the treatment. Obviously, in road safety this type of assumption is usually false. Hauer (30) states that "We cannot assume that if the treatment had not been applied in a given site, safety in the 'after' period without treatment would have been the same as in the 'before' period". Some of the major problems that can be experienced by using "naïve" method are as follows:

1. Regression-to-the-mean (RTM) – "a statistical bias that occurs whenever a non-random sample is selected from a population" (7). RTM, also called regression toward the mean, is the statistical phenomenon stating that an "extreme event is likely to be followed by a less extreme event". In traffic safety, this concept refers to the fact that if a site is selected for implementing a safety treatment because it has an unusually high number of accidents in a given period, then the number of accidents in a subsequent period would probably be lower, even if no treatment were implemented. This problem has been widely recognized in the traffic safety literature (5, 7).
2. Crash migration (transfer of crashes from a treated site to surrounding locations as a result of a countermeasure (8))
3. Maturation (temporal changes in crash rates such as traffic flow, weather (7))
4. External causal factors (9, 10)

To correct the above problems associated with the naïve approach, alternative methods for before-after studies have been suggested in the safety literature.

These alternative techniques - discussed in the following sections - seek to correctly estimate the safety impacts of the entity in the after period if a given treatment had not been applied.

Table 1. Studies based on the naïve before-and-after method

Authors	Study Area	Countermeasure	Data Information	Variables
Persaud et al. (1984) (5)	Philadelphia	Intersections converted from 2 to all-way stop	222 treatment sites	Accident data
Yagar (1985)	Toronto, Ontario	Installation of pedestrian crosswalk markings	13 treatment sites	Accident data
Hauer et al. (1987) (11)	US	Installation of gates at rail crossings with flashers	934 treatment sites	Accident data
Hauer et al. (1987) (11)	US	Installation of gates at rail crossings with crossbucks	1037 treatment sites	Accident data
Klik et al. (1993) (12)	Omaha, NE	Installation of speed humps on residential streets	60 treatment sites	Accident data
Troutbeck (1993) (13)	Victoria, Australia	Intersections converted from conventional controls (traffic signals or stop signs) to modern roundabouts	73 treatment sites	Accident data
Schoon et al. (1994) (14)	Netherlands	Intersections converted from conventional controls (traffic signals or stop signs) to modern roundabouts	181 treatment sites	Accident data
Elvik et al. (1997) (15)	Norway	Intersections converted from yield to two-way stop and from traffic signal to roundabout	NA	Accident data
Persaud et al. (1997) (16)	Philadelphia	Intersections converted from signal to all-way stop	189 treatment sites	Accident data
Fleck et al. (1999) (17)	San Francisco	Installation of red light cameras at the intersections	4 treatment sites	Accident data
Griffith (1999) (18)	Illinois	Installation of continuous shoulder rumble strips	55 treatment sites (rural and urban freeways)	Accident data
McFadden et al. (1999)(19)	Florida	Installation of red light	4 treatment sites	Accident data

		cameras at the intersections		
Hughes et al. (2000)(20)	Los Angeles, CA (infrared and microwave), Phoenix, AZ (microwave), and Rochester, NY (microwave)	Automatic pedestrian detection for display of walk signal	4 treatment sites	Accident data, pedestrian volume, traffic volume
Knoblauch et al. (2000) (21)	Maryland, Virginia, and Arizona	Installation of pedestrian crosswalk markings	6 treatment sites	Accident data, pedestrian volume, traffic volume
Farradyne, Inc (2002) (22)	San Diego	Red light camera installation	19 intersections	Traffic data
Persaud et al. (2004) (23)	California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington	Centerline rumble strips had been installation on rural two-lane roads	98 treatment sites, average length of the treatment site was 2 miles	Traffic volume, traffic accident data
Persaud et al. (2005) (24) , Council et al. (2005) (7)	Seven jurisdictions across the US	Red-light camera installations to the intersections	132 treatment sites and 408 reference sites, comparison with EB method	Geometric design, traffic control, traffic volume and traffic accident data
Chen et al. (2006) (25)	Virginia	Centerline rumble strips installation	A total of 53, 248 miles of undivided highways, and local roads	Accident data
Shin et al. (2006) (26)	Arizona	Red-light camera installations to the intersections	24 treatment sites	Accident data, geometric design

Before-and-After Study Using Comparison Group Method

Before-and-after study with comparison group method has been developed to overcome the external causal factors and maturation problems. In this method, first a comparison group is defined as the group of control sites selected as being similar enough to the treatment sites in terms of traffic volume and geographic characteristics. Then, crash data at the comparison group are used to estimate the crashes that would have occurred at the treated site if the treatment had not been made. “As the similarity between the treated and the comparison site increases this method can potentially produce more accurate results” (27). The before-and-after with comparison group method has two fundamental assumptions: (30)

1. The factors that affected safety have changed in the same way from the before period to after the improvement on both treatment and comparison groups
2. The changes in the various factors influence the safety of treatment and comparison groups in the same manner.

Under these assumptions, the expected number of crashes in the after period for the treated sites without the improvement, N_{at}, can be predicted as the observed number of crashes in the before period for the treatment group, N_{bt}, multiplied by the ratio of after-to-before crashes at the comparison sites, R_c: (30)

$$N_{at} = N_{bt} \times R_c \tag{2}$$

After calculating N_{at}, CRF can be estimated using equation-1. Table 2 summarizes before-and-after studies that employ comparison group method, along with the information regarding the study area including, treatment site, types of countermeasure, and variables considered for each study described in Table 2. Although, this method solves one of the major problems associated with the naïve before-and-after method by considering natural time-related factors in both periods, its practical use is sometimes limited because of the difficulty in finding a sufficient number of similar sites that are left without treatment. Thus, the biggest challenge in using this method is in defining and collecting data for a truly comparable group.

Moreover, a major issue associated with this method is the RTM bias. As previously mentioned, treatments are commonly applied to sites with a relative high accident frequency and/or consequences - sites detected as hotspots or sites with promise (30, 57, 70). Thus, we could expect that in the treated sites, the frequency of collisions would drop normally from previous high levels in spite of the introduction of treatments – high accident frequencies may tend to the average over the long term. As a result, the application of the comparison group method may tend to over-estimate the treatment effect, since it fails to correct the RTM problem.

Table 2. Studies based on the before-and-after method with comparison group approach

Authors	Study Area	Countermeasure	Data Information	Variables
Freedman et al. (28)	US	Installation of improved lighting at pedestrian crosswalks	7 treatment sites, 7 control sites	Accident data
Polus et al. (1978) (29)	Israel	Floodlighting of crosswalks	99 treatment sites, 39 control sites	Accident data
Zaidel et al. (1987)	Israel	Installation of pedestrian signals and signal retiming	Total of 320 treatment and control sites	Accident data, geometric design, pedestrian volume
McGee et al. (1989) (31)	Saginaw, MI; Pueblo, CO; Rapid City, SD	Intersections converted from stop-control to yield control	Saginaw: 53 treatment sites, 42 control sites; Pueblo: 69 treatment sites, 15 control sites; Rapid City: 19 treatment sites, 8 control sites	Accident data gathered from Department of Transportation
Corban et al. (1990) (32)	Victoria, Austria	Intersections converted to roundabouts, converted from stop-control to signals, and signal retiming	82 treatment sites, 34 control sites	Traffic accident data
Benekohal et al. (1992) (33)	Illinois	Highway improvement	51 treatment sites with a total length of 349 miles	Accident data, geometry, traffic volume
Kulmala (1994) (34)	Finland	Road lighting, stop signs, signal control, and lowering of the speed limit value	325 three-leg and 298 four-leg treatment sites	Accident data
Gibby et al. (1994) (35)	California	Marked vs. unmarked crosswalks, unsignalized intersections	380 treatment sites, and similar control groups with unmarked crosswalks	Accident data
Griffith (1999) (18)	Illinois	Installation of continuous shoulder rumble strips	55 treatment sites (rural and urban freeways)	Accident data
Vinzant et al. (1999) (36)	Arizona	Red light camera installation	18 treatment sites, 6 control sites	Accident data
Zegeer et al. (2001) (38)	US	Marked vs. unmarked crosswalks	1000 treatment sites, 1000 control sites	Accident, volume, pedestrian exposure, number of lanes, speed limit, and geometric design
Huang et al. (2002) (37)	California, Washington	Lane reduction from four-lane to	30 treatment sites, 50	Traffic volume, accident

		three-lane	control sites	data
Retting et al. (2002a) (39)	Nassau County and Suffolk County, New York	Signal timing changes at four-leg intersections	40 treatment sites, 56 control sites	Traffic accident data gathered from Department of Transportation
Retting et al. (2002b) (40)	Oxnard, California	Red light camera installation	11 treatment sites, 114 comparison sites	Traffic accident data
Brabander et al. (2005) (41)	Flanders	Intersections converted to roundabouts	95 treatment sites, 110 reference groups	
Wong et al. (2006) (42)	Finland, France, US, Netherlands, Sweden, United Kingdom, Australia, New Zealand, Norway, Denmark, Iceland, Hungary, Spain, Poland, France	Road safety targets	Annual fatality accidents after the road safety, and before the road safety targets	Traffic accident data
Shin et al. (2006) (26)	Arizona	Red-light camera installations to the intersections	24 treatment sites, 13 control sites	Accident data, geometric design
Jagannathan et al. (2006) (43)	New Jersey	Elimination of left-turn phase on the major-road	44 jughandle intersections, 50 conventional intersections	Accident data
Garder et al. (2006) (44)	Maine	Installation of continuous shoulder rumble strips	472 miles of treated highway, and 99.1 miles of untreated highway	Accident data

Before-and-After Study with Empirical Bayes (EB) Method

Empirical Bayes (EB) method has been developed to adjust for the regression-to-the-mean problem, which is considered to be the most serious problem associated with the before-and-after studies. (30, 45, 46). The underlying theory of the EB method is that the crash rate at a specific site follows a probability distribution which can be estimated by collecting crash data from a number of similar entities. Using the Bayes' theorem, EB method combines information about this distribution (prior) with data collected from a treatment site (likelihood) to offset the impact of a temporary, random increase in crashes. In the before-after studies, the EB approach is usually implemented via the Negative Binomial model (also known as the Poisson/Gamma model) and the model parameters are estimated using a maximum likelihood technique or any other technique involving the use of the observed accident data from the similar sites (66).

The main idea behind EB method is to predict the number of crashes that would have been expected to occur during the after period had the treatment not been implemented.

In all methods developed to predict expected number of crashes, the following steps are considered: (30)

1. Establish the foundation for the prediction by estimating what the expected frequency of target crashes in the 'before' period was.
2. Based on this foundation, predict how the expected number of crashes would have changed from the 'before' to the 'after' period as a result of changes in traffic, weather, and other factors.

With these steps, the EB method uses data from the crash history of a treated site, as well as the information of what is known about the safety of reference sites with similar geometric characteristics, to estimate how many crashes would have occurred at the treated site had no improvements been made.

If $E(k)$ is the expected number of crashes at the reference sites and K is the actual crash count at the treatment sites, then $E(k \mid K)$ is the estimate of the expected number of crashes at the treatment sites given that the sites recorded K crashes. Accordingly,

$$E(k \mid K) = \alpha E(k) + (1-\alpha)K \tag{3}$$

where α is the weight factor, as shown in the following expression:

$$\alpha = \frac{1}{1 + \frac{VAR(k)}{E(k)}} \tag{4}$$

where $VAR(k)$ is the variance of the expected number of crashes at the reference sites. Detailed derivation of the EB methodology is provided in Appendix A.

In the EB evaluation the effect of a treatment is given by:

$$B - A \tag{5}$$

where B is the expected number of crashes that would have occurred in the "after" period without the treatment and A is the number of reported crashes in the after period.

B is estimated based on the accident prediction function (safety performance function) (SPF), where the number of crashes that would be expected in each year of the "before" period at locations with traffic volumes and other characteristics similar to the treatment site are estimated. The SPF function is estimated using the crash data obtained from "similar" sites, i.e. control groups. The sum of these annual SPF estimates (P) is then combined with the count of crashes (x) in the before period at the treatment site to obtain an estimate of the expected number of crashes (m) before the treatment. This estimate of m is:

$$m = w \sum_{\text{analysis period}} P + (1-w) \sum_{\text{analysis period}} x \tag{6}$$

where;

$$w = \frac{1}{1 + \sum_{\text{analysis period}} P \,/\, k}$$

The weight w depends on the dispersion parameter (k) of the assumed negative binomial distribution of the crash counts used in estimating the SPF.

A factor is then applied to m from Eq. (6) to account for the length of the after period as well as the differences in traffic volumes and general trends in crash risk due to factors such as weather, reporting practices and the other safety countermeasures between the before and after periods. This factor is:

$$f_i = \frac{P_i}{\sum_{\text{analysis period}} P} \tag{7}$$

The result, after applying this factor, is an estimate of B.

$$B_i = f_i * m \tag{8}$$

The estimate of B is then summed over all road sections in a treatment group of interest (to obtain B_{sum}) and compared with the count of crashes during the after period in that group (A_{sum}). The index of safety effectiveness (θ) is estimated as:

$$\theta = \frac{A_{sum} / B_{sum}}{1 + \left[Var\left(B_{sum}\right) / B_{sum}^2\right]} \tag{9}$$

The standard deviation of *θ* is given by:

$$S.D.(\theta) = \left[\frac{\theta^2 \left\{\left[Var\left(A_{sum}\right) / A_{sum}^2\right] + \left[Var\left(B_{sum}\right) / B_{sum}^2\right]\right\}}{\left[1 + Var\left(B_{sum}\right) / B_{sum}^2\right]^2}\right]^{0.5} \tag{10}$$

The percent change in crashes is in fact $100(1-\theta)$. Table 3 summarizes the before-and-after studies conducted using with EB method, along with information regarding the study area, treatment site, types of countermeasure, and variables considered during the analysis. Moreover, Persaud et al. (47) provide an overview of EB methodology and comparison of this methodology with naïve before-and-after study method on several study areas.

Table 3. Studies based on before-and-after method with EB approach

Authors	Study Area	Countermeasure	Data Information	Variables
Persaud et al. (1997) (49)	Philadelphia	Intersections converted from signal control to all-way stop control located in one-way streets in non-arterial streets	199 treatment sites and 71 control sites	Geometric design, traffic control, traffic volume and traffic accident data
Persaud et al. (2001) (50)	Colorado, Florida, Kansas, Maine, Maryland, Vermont	Intersections converted to roundabouts	19 were previously controlled by stop signs, and 4 were controlled by signals	Traffic volume, geometric design, accident type data
Harwood et al. (2002) (51)		Addition of right-turn and left turns to the intersections	199 sites where a left-turn lane was added, 108 sites where a right-turn line was added, 300 sites that were not improved	Geometric design, traffic control, traffic volume and traffic accident data
McGee et al. (2003) (52)	California, Florida, Maryland, Virginia, Wisconsin, Toronto	Intersections where stop signs were converted to signal controls	22 sites with three-leg treatment-118 control sites; 100 sites with four-leg treatment-295 control sites	Geometric design, traffic control, traffic volume and traffic accident data
Rimiller et al. (2003)	Connecticut	Addition of left turns to the intersections	16 treatment sites, and similar sites for control sites	Geometric design, number of lanes, traffic control, traffic volume and traffic accident data
Bauer et al. (2004) (53)	California	Urban freeway road sections improved from four to five lanes and from five to six lanes	79 sites with 36.4 miles, and 45 sites with 12.5 miles	Traffic volume, traffic accident data
Persaud et al. (2004) (23)	California,Colorado Delaware,Maryland Minnesota, Oregon, and Washington	Centerline rumble strips installation on rural two-lane roads	98 treatment sites, average length of the treatment site was 2 miles, control site data obtained from Highway safety information system (HSIS)	Traffic volume, traffic accident data
Hovey et al., (2005) (55)	Ohio	Add two-way left turn lane, Install median barriers, Remove/relocate fixed object, Flatten slope, remove guardrail, Flatten vertical curve, Provide interchange lighting, and Close median	All road types in rural and urban areas, separate models for each countermeasure	roadway width, shoulder width, median width, crash data, average daily traffic, average daily trucks, and section length

		opening		
Persaud et al. (2005) (24), Council et al. (2005) (56)	Seven jurisdictions across the US	Red-light camera installations to the intersections	132 treatment sites and 408 control sites	Geometric design, traffic control, traffic volume and accident data
Gan et al. (2005) (57)	Florida	103 different countermeasures	All road types, and intersections	Geometric design, traffic control, traffic volume and accident data
Miranda-Moreno et al. (2005) (58)	Canada	Highway-railway intersections, flashing light installation	Total of 5,094 treatment and control sites	Geographical location, type of warning service, geometric features, road and train volumes
Washington et al. (2005) (59)	Korea	speed humps, gate delay, crossing angle, crossing warning, road grade, sight distance to the crossing, gate interval, preemption, obstacle detection, pedestrian gate, lightning, in-vehicle warning system, a 4Q gate, constant warning time	Stated preference surveys, expert opinion	NA
Naik (2005) (60)	Lincoln, Nebraska	Addition of left-turn lanes at signalized intersections	3 treatment sites, 36 control sites	Geometric design, traffic control, traffic volume and traffic accident data
Aul et al. (2006) (61)	Twin Cities Metro District	Intersections converted from unsignalized to signalized	18 treated sites, 331 control sites	Crash, roadway, intersection, and traffic data from the HSIS
Pawlovich et al. (2006)(62)	Iowa	Lane reduction	15 treatment and 15 control sites	Traffic accident data
Shin et al. (2006) (26)	Arizona	Red-light camera installations to the intersections	24 treatment and 13 control sites	Accident data, geometric design
Miller et al. (2006) (63)	Virginia	Red-light camera installations to the intersections	13 treatment and 33 control sites	Accident data, geometric design, traffic volume data
Murphy et al. (2007) (64)	North Carolina	Installation of overhead flashing beacons to rural, four-leg intersections with no turn lanes and two-way stop control	34 treatment and 170 control sites	Accident data, traffic volume data
Patel et al. (2007) (65)	Minnesota	Centerline rumble strips installation on rural two-lane roads	183 miles treated and 47,602 miles control roadways	Accident data, traffic volume data
Hadayeghi et al. (2007) (67)	Ontario, Canada	Red-light camera installations to three- and four-leg intersections	Total of 447 treatment sites	Accident data, traffic volume data

Before-and-After Study with Full Bayes Method

As an alternative to the EB approach, there are several researchers who have very recently explored the use of a full Bayes (FB) approach (60, 61, 68). This approach allows better incorporation of the uncertainty in the analysis and is usually implemented via the hierarchical Bayesian models. These models have been extended to the multivariate case for modeling multiple crash responses (e.g., when working with accident data classified by different levels of severity with correlation problems) and space-time patterns - when working with accident data with spatial and/or temporal correlations (48, 68, 70).

The FB approach is also attractive because it may require less data by incorporating past experiences and practitioner's knowledge. Note that this issue is important since crash data collected for safety studies often have the unusual attributes of being characterized by low-accident frequency and small sample sizes, due to the prohibitive costs of collecting data (71, 66, 67). That is, accident data for before-after studies is sometimes collected from a small number of sites during short periods of time (e.g., 1 or 2 years). Previous studies have shown that under these conditions the model parameters can be misestimated when using the maximum likelihood (ML) technique – which affects the accuracy of the EB estimates (66). Another advantage of the FB approach is that safety performance functions are not required to be determined in advance since crash reduction factors (CRF) can be computed directly from the model's hierarchical structure – a CRF is estimated in one step. A disadvantage of the FB approach may be that it is more complex and may require more statistical training.

Safety Studies Conducted for Urban Collectors

The main focus of this current study is to analyze the effects of management treatment on roadway operations and safety on 25-40 mph urban collectors with access.

In Table 4 a summary of the studies which estimated crash rate functions and calculated crash reduction factor (CRF), on urban collectors is given. These studies either performed before-and-after study with comparison method, EB methodology, or generalized linear equations. The countermeasures considered in these studies include:

1. Changes in horizontal curves
2. Differential speed limit modifications between trucks and cars
3. Road side protection, access control, delineation
4. Increase in number of lanes
5. Installation of centerline rumble strips
6. Installation of median barriers
7. Removal or relocation of fixed objects
8. Slope flattening
9. Vertical curve flattening
10. Lane reduction
11. Installation of shoulder rumble strips

Table 4. Safety studies performed for urban collectors

Authors	Study Area	Variables	Countermeasure	SPF Function (Accident/year)	CRF
Griffith (1999) (18)	Illinois	Number of accidents	Installation of continuous shoulder rumble strips	NA	NA
Harwood et al. (2000)(74)	619 two-lane road segments in Minnesota, and 712 roadway segments in Washington	State: location L: length LW: lane width SW: shoulder width RHR: road side hazard rate WH: weight for horizontal curve DD: driveway density DEG: degree of curvature WV: weight for vertical curve V: crest vertical curve WG: weight straight grade GR: grade	Change in horizontal curves on two lane roadways	$\mu = \exp\left(\begin{matrix} 0.6409 + 0.1388\,State - 0.0846\,Lw \\ - 0.0591\,Sw + 0.0668\,Rhr + 0.0084\,D \end{matrix}\right.$ $\sum WH_i \exp(0.045\,DEG_i)(WV_i \exp(0.4652\,V_i))$ $(\sum WG_k \exp(0.1048\,GR_k))$	Accident Modification Factors: 1.05-1.5 for 9 ft road ways 1.02-1.03 for 10 ft road ways 1.01-1.05 for 11 ft. roadways
Huang et al. (2002) (37)	California, Washington	Number of accidents	Conversion of four undivided lanes to three divided lanes (Road diet)	NA	NA
Mayora et al. (2003)(76)	Valencia, Spain	TrV: Traffic volume AcD: Access density SpL: Average speed limit SiD: Average sight distance LGr: Average grade (%) NpP: no-passing zones	Road side protection, access control, delineation	$\mu = \exp\left(\begin{matrix} 86.571^* \ln TrV + 0.311^* AcD \\ -0.01139^* SpL - 0.0947^* SiD \\ -0.08434^* LGr + 0.59224^* Np \end{matrix}\right.$	NA
Sullivan (2003)(85)	65 road sections in California	presence or absence of median trees, posted speed, average daily traffic (ADT), number of lanes, median width, number of accidents	Removal of trees in the median and borders	$Model1: COLL_i = (e^{\beta_0 + \beta_1 ADT_i + \beta_2 L_i + \beta_3 MEDTREE_i + \beta_4 X_{i1}}$ *error term has negative binomial distribution* $Model2: COLL_i = L_i ADT_i (e^{\beta_0 + \beta_3 MEDTREE_i + \beta_4 X_{i1} \ldots})$ *error term has poisson distribution*	NA
Persaud et al. (2004)(23)	California, Colorado, Delaware, Maryland, Minnesota, Oregon, Washington	AADT: Average daily traffic Shldwid: Shoulder width (ft) Terrain: terrain type	Installation of center line rumble strips	$\mu = length^{\beta_1} AADT^{\beta_2}$ $\exp(\alpha + \beta_3 terrain + \beta_4 shldwid)$	Mean=0.12

Hovey et al., (2005)[55]	Ohio	Dy: Offset value for the duration of the time period ADT: Average daily traffic Trucks: Average daily trucks SW: Shoulder Width FC: Functional classification of the roadway (urban/rural) ACS: Highway access type SL: Section Length SYS_CL: System classification (road type)	Install median barriers	$\mu = \exp\left(-19.64 + Dy + 1.95 * \ln ADT\right)$	Mean=0.863 Std = 0.029
			Remove/relocate fixed object	$\mu = \exp\begin{pmatrix} 1.48 + Dy + 0.199 * \ln ADT + \\ 0.475 * \ln Trucks - 1.132 * \ln SW \\ + ACS + FC \end{pmatrix}$	Mean=0.382 Std = 0.103
			Flatten slope, remove guardrail,	$\mu = \exp\begin{pmatrix} -6.44 + Dy + 0.57 * \ln ADT + \\ 0.62 * \ln Trucks \end{pmatrix}$	Mean=0.424 Std = 0.575
			Flatten vertical curve	$\mu = \exp\begin{pmatrix} -2.94 + Dy + 0.547 * \ln ADT + \\ 0.62 * \ln SL + SYS\_CL \end{pmatrix}$	Mean=0.196 Std = 0.191
Garder et al. (2006)[44]	Maine	accident	Installation of continuous shoulder rumble strips	NA	NA
Garber et al. (2006)[79]	Virginia, Arkansas	ADT: Average daily traffic Length: road way length	Speed limit modification between cars and trucks	$\mu = 0.022 AADT^{0.548} * length^{0.622}$ $\mu = 0.0026 ADT^{0.714} * length$	Mean=0.31 Mean=0.25
Pawlovich et al. (2006)[62]	Iowa	Traffic accident counts	Lane reduction	Non-parametric regression	Mean = 0.188
Patel et al. (2007)[65]	Minnesota	ADT: Average daily traffic	Installation of shoulder rumble strips	$\mu = \exp(\alpha) AADT^{\beta} * yearly\_factors$	Mean=0.13 Std=0.08

NA: Not estimated

AVAILABLE DATA SOURCES

This section focuses on the data sources available for New Jersey and other states for the evaluation of various countermeasures described in the proposal and listed below:

Countermeasure 1.	Increase in lane widths (10’ or 11’ to 12’)
Countermeasure 2.	Construction of 4, 6, 8, or 10 foot shoulders
Countermeasure 3.	Removal of trees in median and border areas
Countermeasure 4.	Installation of guide rails, and vertical & horizontal geometry changes to improve sight distances.

The data sources considered in this study for both control and treatment sites are obtained from

1. New Jersey Department of Transportation
2. Delaware Valley Regional Planning Commission
3. Highway Safety Information System (HSIS)
4. California Highway Patrol and Caltrans

Following sections provide the details about these data sources.

New Jersey Based Data Sources

As part of this project, the research team has investigated data sources obtained from New Jersey Department of Transportation (NJDOT) (fiscal year reports, as-built database, and Bureau of Construction Engineering), NJDOT website (Professional Services Consultant Selections, and Awarded Projects (82)), Delaware Valley Regional Planning Commission (DVRPC) (fiscal year reports (81)), and North Jersey Transportation Planning Authority (NJTPA) (fiscal year reports). Research team also closely collaborated with the NJDOT project contacts to obtain relevant safety project information. The summary of these reports are provided in Table 5.

Table 5. Project reports provided by NJDOT

Year	Title	Publication Year
1993	NJDOT – NJ Transit Capital Program	
1994	NJDOT – NJ Transit Capital Program	July 1, 1993
1997-1998	Transportation New Jersey – Blue Print Actions	
2000	Transportation Capital Program	July 1, 1999
2001	Transportation Capital Program	November 30, 2000
2001-2003	NJDOT Statewide Transportation Improvement Program	September 1, 2000
2002	Transportation Capital Program	July 1, 2001
2002-2004	New Jersey Statewide Transportation Improvement Program	October 1, 2001
2003-2005	New Jersey Statewide Transportation Improvement Program	October 1, 2002
1986-2007	As-built Database	
2000-2005	NJDOT – Bureau of Construction Engineering – Completed Projects from 2000 to 2005	
2000-2007	NJTPA – Transportation Improvement Program Fiscal Year Reports	
2000-2007	DVRPC – Transportation Improvement Program Fiscal Year Reports	
1997-2008	NJDOT - Professional Services Consultant Selections	
1996-2008	NJDOT - Awarded Projects	

From these sources, the research team has identified eight safety projects that are suitable for this project. Most of the identified road sections are urban arterials satisfying the required speed limit criterion. The countermeasures along these road sections cover countermeasures 1, 2 and 4. The summary of these possible safety projects, including mile post, road type, speed limit, project/end start date, and the corresponding countermeasure are summarized in Table 6. All projects are completed between 1998 and 2004 accept the construction on NJ Route 21, which was partly completed in May 2006. The NJ Route 21 “Newark Needs Analysis” will study how to improve the safety and operation of Route 21 (McCarter Highway) from Murray Street (milepost 1.10) to Edison Place (milepost 2.15). Since the accident data available for NJ covers years between 1997 and 2006, currently there are no after accident data to conduct before-and-after comparison for this road section. In the next section, before-and-after analysis via naïve approach conducted for all these road sections is described.

Table 6. Identified safety projects

Road	Mile Post	County	Road Type	Speed Limit	Start Date	Completion Date	Countermeasure
RT 166	0-1.866	Beachwood, Ocean	Urban Minor Arterial	25-35	5/16/1998	6/8/2001	Skid Resistance Improvements to reduce accidents (*Countermeasure 4*)
RT 4	1.82-2.7	Paramus, Bergen	Urban Principal Arterial	40	12/27/2000	7/25/2003	safety widening, median barrier, capacity improvement (*Countermeasure 4*)
RT 35	46-47.3	Middlesex	Urban Principal Arterial	40	10/21/1999	8/2/2001	Guide rail installation (*Countermeasure 4*)
RT 71	10-11.7	Monmouth	Urban Minor Arterial	35	10/21/1999	8/2/2001	Guide rail installation (*Countermeasure 4*)
RT 517	12.42-12.707	Sussex	Urban Collector	40	5/1/2000	12/15/2000	Realignment (*Countermeasure 4*)
RT 322	4.097-4.986	Gloucester	Urban Arterial	45	8/23/1999	5/3/2000	Realignment (*Countermeasure 4*)
RT 30	50.73-52.503	Atlantic	Urban Arterial	40	2/19/2001	5/5/2004	Road widening (*Countermeasure 1*)

Apart from these reports, NJDOT has provided several safety projects to the research team.

The first safety project provided by NJDOT includes the road section around the intersection between US-9 and CR-563. Even though the location of the improvement satisfies the properties for the road sections and improvement type required for the project, according to the South Jersey fiscal year report published in 2006(66), the project has not begun until 2006. The accident data for New Jersey are available between 1997 and 2006. In order for the researchers to perform before-and after analysis, at least 3 years of before and after data are necessary. Thus only the safety projects that were completed between years 2000 and 2003 can be used for this type of before and after analysis.

Other projects are conducted as a part of Division of Local Aid and Economic Developments program (Closed out Projects for Local Safety). The summary of these projects are provided in Table 7.

Table 7. Division of local aid and economic developments - closed out projects for local safety

Year	Project Name	MPO	County	Amount	Start Date	End Date
2004	Upgrade School Crossing & Pedestrian Crossing Signs on Unsignalized Intersection	NJTPA	Ocean	$82,000	5/1/2005	3/1/2006
2004	Raised Pavement Markers in Centerline of county roads	NJTPA	Passaic	$157,400	5/6/2006	12/11/2006
2004	Safety program to install raised pavement markers	DVRPC	Gloucester	$157,000	Jan-05	Jun-06
2004	CR 553 Corridor Safety Improvements	SJTPO	Cumberland	$125,891	Jan-05	Oct-06
2004	Ninth street & West Avenue traffic signal upgrade & replacement	SJTPO	Cape May	$183,509	5/5/2005	Jun-06
2005	Safety Improvements to JFK Blvd.	NJTPA	Hudson	$140,000	6/29/2006	7/17/2006
2005	South Orange Avenue / CR 510	NJTPA	Essex	$2,446,545	5/9/2006	3/21/2007
2005	Flashing Signal Construction at CR 607 and CR 538	DVRPC	Gloucester	$58,000	5/8/2006	10/6/2006

As indicated by NJDOT Local Aid Department, CR 553 corridor safety improvements project consists of:

1. CR 553 S. Woodruff Road & CR 654 Lebanon Road – Traffic Flashing Beacon: Install 4-Way Traffic Flashing Beacon to improve the safety and visibility of the intersection.
2. CR 553 S. Woodruff Road & CR 552 Irving Avenue – Traffic Signal: Replace 4-Way Traffic Flashing Beacon by Semi-actuated Traffic Signal to improve safety and reduce severity of accidents at the intersection.

Similarly, the safety improvements to JFK Blvd. cover the area from 67th Street to 91st Street. The project consists of removing existing stripping and replacing with a highly reflective performed tape of centerline, stop lines and pedestrian crosswalks.

Unfortunately, none of these safety improvements are part of the four countermeasures requested by NJDOT. Moreover, all the projects provided by local aid were completed in year 2006. Thus, there are no after accident data in order for research team to conduct before-and-after comparison.

Table 8 summarizes the possible safety projects along with the corresponding countermeasure

Table 8. Safety projects from NJ based sources

Countermeasure	Road Section	Year of Change
1	Route 30, Route 21	2002-2006
2	-	-
3	-	-
4	Route 4, Route 35, Route 71, Route 517, Route 322, Route 166	2001,2000

Data Obtained from Other States

Apart from New Jersey accident data sources, the research team has obtained accident, road, and vehicle information from several different states. These data sources are obtained from three different sources, namely Highway Safety Information System (HSIS) (84), Ohio Department of Transportation (ODOT) (55) and California Highway Patrol (CHP) (85). Table 9 summarizes the detailed data sources available from safety projects conducted in other states.

Table 9. Data sources from other states

State	Period	Countermeasure	Data type
Illinois	1990-2003	Installation of continuous shoulder rumble strips	Accident, road, occupant and vehicle data from HSIS
Ohio	1997-2004 (HSIS)	install median barriers, flatten slope, remove guardrail, flatten vertical curve, and close median opening	Accident, road, occupant and vehicle data from HSIS
California	1993-2001	Installation of center line rumble strips, Lane increase for Urban freeways	Accident, road, occupant and vehicle data from HSIS
Ohio	1995-2002	Shoulder width increase	Accident, road, occupant and vehicle data from ODOT
California	1996-2001	Existence of trees in the median and borders	Accident data from California Highway Patrol

The following sections describe the details regarding these databases, and identified possible safety projects from these sources.

HSIS Database

The data obtained from HSIS include accident, road, occupancy and vehicle information for each accident that occurred in Illinois, Ohio, and California. For the datasets obtained from HSIS, information regarding the location, year or type of the countermeasures implemented on different road sections is not available. Instead, the database provides the road characteristics of each section for different years. Thus, in order to determine safety projects, the database obtained from HSIS is carefully investigated and the road characteristics of all road sections are compared to determine the changes in these sections over different years. Since the focus of this project is only urban collectors with access, and speed limit between 25-40 mph, the road sections satisfying these criteria are analyzed. Due to geographical considerations, only Ohio is selected to identify the possible treatment sites.

While identifying the possible safety projects the following process is followed:

1. Road subset for each year is extracted from the database
2. For each year, the changes road characteristics such as, lane width, shoulder width, median type, and degree of curvature (when data are available) are compared.

Based on the comparison results possible safety projects for the Countermeasures 1, and 2 are identified. After identifying the possible safety projects, the construction dates are justified based on the accident data for these road sections. In particular, for these road sections there were no accident record during the construction period. Based on this identification process five possible treatment sites are determined. The information regarding these road sections including type of countermeasure and year of change are provided in Table 10. Similarly, the before and after periods for these road sections are presented in Table 11. The summary of the characteristics of each road section is provided in Table 12.

Table 10. Possible safety projects from Ohio HSIS database

State	Road Section	Year of Change	Type of Change
Ohio	FAI793R1	2000	Lane width increase from 10’ to 14’ (*Countermeasure 1*)
Ohio	HOC664R1	2001	Shoulder width increase from 0’ to 4’ (*Countermeasure 2*)
Ohio	CLI134R1	2002	Shoulder width increase from 0’ to 4’ (*Countermeasure 2*)
Ohio	COL344R1	2002	Shoulder width increase from 0’ to 6’ (*Countermeasure 2*)
Ohio	UNI038R1	2002	Shoulder width increase from 0’ to 8’ (*Countermeasure 2*)

Table 11. Before-and-after periods for the possible safety projects

Road Section	Before Period	After Period
FAI 793	1997-1999	2001-2004
HOC 664	1998-2000	2002-2004
CLI 134	1999-2001	2003-2004
COL 344	1998-2001	2003-2004
UNI 038	1998-2001	2003-2004

Table 12. Road information summary

Road Name	Mile Post	No of Lanes	Lane Width	Sh. Width	Median Width	Speed Limit
FAI793R1	3.91-4.62	2	from 10' to 14'	from 4' to 0’	0	35
HOC664R1	15.93-16.33	2	12	from 0' to 4'	0	35
CLI134R2	14.24-14.85	2	15	from 0' to 4'	0	25
COL344R1	0.29-1.1	2	14	from 0' to 6'	0	35
UNI038R1	8.88-9.79	2	20	from 0' to 8'	0	25

ODOT Database

Apart from HSIS database, the research team has identified several countermeasures and possible safety projects from ODOT database (55). The countermeasures included in the ODOT database are:

- Add two-way left turn lane,
- Install median barriers,
- Remove/relocate fixed object,
- Flatten slope, remove guardrail,
- Flatten vertical curve,
- Provide interchange lighting,
- Close median opening.

However, only flatten vertical curve (Countermeasure 4) countermeasure is conducted on an urban collector. For this countermeasure, the research team has obtained the control and treatment sites along with corresponding accident and road characteristics data. The information regarding this treatment site is provided in Table 13. Similarly, in Table 14, the before-and-after period, and the exact construction date are provided.

Table 13. Safety project from ODOT database

State	Road Section	Year of Change	Type of Change	Lane	Speed Limit	Mile Post
Ohio	WAS676R1	1998	Flatten Vertical Curve (*Countermeasure 4*)	2	35	18.3-18.8

Table 14. Before-and-after periods for the safety project

Road Section	Before Period	After Period	Construction Period
WAS676R1	1995-1997	1999-2002	7/14/1998 – 7/30/1998

CHP Database

The database obtained from CHP contains information related to the accident and road characteristics of urban highways regarding the existence of trees in the median and borders (Countermeasure 2) (85). Table 27 summarizes the safety projects conducted in California, along with the road section information and the particular countermeasure.

Table 15. Summary of the safety projects from CHP (85)

Project Title and Section	Road Information	Study
California		
Buena Park, SR 39 - D12	Speed limit:35-40 mph No of lanes: 3-4 lanes	Existence/nonexistence of median trees, California
Huntington Beach, SR 1 - D12	Speed limit:45 mph No of lanes: 2-3 lanes	Existence/nonexistence of median trees, California

Table 16 summarizes the safety projects obtained from the crash databases of other states.

Table 16. Summary of safety projects obtained from other states

Countermeasure	State and Road Section	Year of Change
1	Ohio (Route 793)	2000
2	Ohio (Route 664, 344, 174, 38)	2001-2002
3	California (SR 39, SR 1)	-
4	Ohio (Route 676)	1998

In the following section naïve before-and-after analysis is conducted for the safety projects summarized in Table 17.

Table 17. Summary of all safety projects

Countermeasure	State and Road Section
1	Route 793 (Ohio)
2	Route 30 (NJ), Route 664-344-174-38 (Ohio)
3	SR 39-1 (California)
4	Route 4-35-71-517-322 (NJ), Route 676 (Ohio)
other	Route 166 (NJ)

NAIVE BEFORE-AND-AFTER STUDY FOR DIFFERENT COUNTERMEASURES

This section focuses on the "naïve before-and-after analysis" of the countermeasures determined by NJDOT.

One of the main issues while investigating the impacts of countermeasures on the safety of a road section is the consideration of the combined effects of several countermeasures simultaneously implemented on the same treatment site. In 2001, NCHRP (90) performed a study in order to determine if there is a difference in the crash performance of resurfacing projects with and without improvements. According to the literature reviewed and the results of the data analysis, the effect of resurfacing a roadway is found to be differing within and among the states because of the difference in individual site characteristics, and a consistent trend could not be found to explain this difference. Moreover, the analysis of the data did not reveal strong relationship between crash occurrence after resurfacing and pre-resurfacing pavement conditions, geometric conditions, or aspects of the resurfacing project (90). The researchers recommend that with greater control over the site conditions and treatment selection, it might be possible to determine more definite relationships. For all the treatment sites so far used in this current study, only one countermeasure has been implemented in order to improve safety and to reduce accidents. If necessary, the research team may investigate resurfacing only projects in order to observe the difference in the crash performance of resurfacing projects without improvements.

Next sections provide detailed results of the before-and-after analysis via naïve approach. Moreover, Appendix C explains how to conduct this approach on a real treatment site using an example.

Countermeasure 1 – Increase Lane Width

NJ based Road Sections

The first countermeasure is “increase lane width”. From NJ based sources, research team identified one possible safety project located along NJ Route 30. Road characteristics of this road section are shown in Table 18.

Table 18. Road characteristics, countermeasure 1

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width	Start Date	End Date
Route 30	Urban Principal Arterial	50.73-52.503	40-45	2-3	From 12’ to 18’	8	From 8’ to 0’	2/19/2001	5/5/2004

Similarly, Figure 1 shows the photos of NJ Route 30 taken by the research team from site visits.

Figure 1. Photos of NJ route 30

Table 19 shows the summary of the before-and-after analysis for the impacts of lane width increase. The results show that the number of accidents has reduced by around 41% after the construction of shoulders. The number of injuries has been reduced as well, while total number of fatalities has not been reduced after the implementation of the countermeasure.

Table 19. Naïve before-and-after analysis, NJ route 30

Period		**Before**				**After**	
Year		**1997**	**1998**	**1999**	**2000**	**2005**	**2006**
Total accidents	**Total**	131	128	167	130	88	76
	Average	139 (78 acc/mile)				82 (46 acc/mile)	
	% Change	***-41.01%***					
Injuries	**Total**	74	70	96	88	60	52
	Average	82 (46 inj/mile)				56 (32 inj/mile)	
	% Change	***-31.71%***					
Fatalities	**Total**	0	1	2	0	0	2
	Average	0.75				1	
	% Change	***33.33%***					

Analysis Results from Other States

Research team has identified another safety project in this category from other states listed above. This study is located on Route 793 in Ohio. Table 20 summarizes the characteristics of the road section, while the results of the naïve before-and-after analysis are provided in

Table 21. The analysis results show an increase after the lane increase.

Table 20. Road characteristics, FAI793

Route	**Road Type**	**Mile Post**	**Speed Limit**	**No Lanes**	**Lane Width**	**Med. Width**	**Shoulder Width**	**Year of Change**
FAI793	Urban Collector	3.91-4.62	35	2	from 10' to 14'	0	from 4' to 0'	2000

Table 21. Naïve before-and-after analysis, FAI793

Period		Before			After			
Year		**1997**	**1998**	**1999**	**2001**	**2002**	**2003**	**2004**
Total accidents	**Total**	13	9	15	20	15	23	26
	Average	14 (20 acc/mile)				21 (30 acc/mile)		
	% Change	***49.70***						
Injuries	**Total**	7	1	1	8	7	13	9
	Average	4 (6 acc/mile)				10 (14 acc/mile)		
	% Change	***127.45***						
Fatalities	**Total**	0	0	0	0	0	1	0
	Average	0				0		
	% Change	0						

Countermeasure 2 – Add Shoulders

Analysis Results Based on the Data Obtained from Other States

From HSIS data, the research team has identified four possible safety project sites. The summary of the road characteristics of these projects is provided in Table 22.

Table 22. Road information for safety projects in Ohio, countermeasure 2

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width	Year of Change
HOC664R1	Urban Collector	15.93-16.33	35	2	12	0	from 0' to 4'	2001
CLI134R2	Urban Collector	14.24-14.85	25	2	15	0	from 0' to 4'	2002
COL344R1	Urban Collector	0.29-1.1	35	2	14	0	from 0' to 6'	2002
UNI038R1	Urban Collector	8.88-9.79	25	2	20	0	from 0' to 8'	2002

Table 23, Table 24, Table 25 and Table 26 summarize the naïve before-and after analysis results for the road sections HOC664, CLI134, COL344 and UNI038, respectively. For each road section, after the increase in the shoulder width, the total number of accidents has been reduced slightly, whereas, major improvements were observed in the severity of the accidents.

Table 23. Naïve before-and-after analysis, HOC664R1

Period		Before			After		
Year		1998	1999	2000	2002	2003	2004
Total accidents	**Total**	25	29	32	34	21	28
	Average	29 (73 acc/mile)			28 (70 acc/mile)		
	% Change	***-3.49%***					
Injuries	**Total**	7	15	9	9	3	11
	Average	10 (25 inj/mile)			8 (20 inj/mile)		
	% Change	***-25.81%***					
Fatalities	**Total**	0	0	1	0	0	0
	Average	0			0		
	% Change	***-100%***					

Table 24. Naïve before-and-after Analysis, CLI134R2

Period		Before			After	
Year		1999	2000	2001	2003	2004
Total accidents	**Total**	25	37	42	31	21
	Average	35 (58 acc/mile)			26(43 acc/mile)	
	% Change	***-25.00%***				
Injuries	**Total**	7	20	9	5	11
	Average	12 (20 inj/mile)			8 (13 inj/mile)	
	% Change	***-33.33%***				
Fatalities	**Total**	0	0	0	0	0
	Average	0			0	
	% Change	***0.00%***				

Table 25. Naïve before-and-after analysis, COL344R1

Period		Before			After	
Year		1999	2000	2001	2003	2004
Total accidents	**Total**	-	14	13	12	5
	Average	14 (18 acc/mile)			9 (11 acc/mile)	
	% Change	***-37.04%***				
Injuries	**Total**	-	1	7	0	2
	Average	4 (5 inj/mile)			1 (1 inj/mile)	
	% Change	***-75.00%***				
Fatalities	**Total**	-	0	0	0	0
	Average	0			0	
	% Change	***0%***				

Table 26. Naïve before-and-after Analysis, UNI038

Period		Before			After	
Year		1999	2000	2001	2003	2004
Total accidents	**Total**	-	19	31	26	19
	Average	25 (28 acc/mile)			23 (25 acc/mile)	
	% Change	***-10.00%***				
Injuries	**Total**	-	11	8	5	1
	Average	10 (11 inj/mile)			3 (3 inj/mile)	
	% Change	***-68.42%***				
Fatalities	**Total**	-	0	0	0	0
	Average	0			0	
	% Change	***0%***				

Countermeasure 3 - Removal of Trees in Median and Border Areas

<u>Analysis Results Based on the Data Obtained from Other States</u>

Removal of trees in the median and border areas of road sections is another countermeasure that may be implemented in order to improve safety and reduce accidents on urban collectors (Countermeasure 3). Even though, treatment sites for this countermeasure could not have been identified in New Jersey, the research team has found a recent study performed in California (85). The collision, road characteristics and traffic volume data are available for all study sections for the six-year period from January 1996 through December 2001. The final dataset includes 24 road sections with trees in the median/border, and 12 road sections with no trees in the median/border areas. Among these road sections, the ones near Buena Park and Huntington Beach are available for before and after analysis, i.e. for these road sections some portion of the roads has trees in the median and border areas while other portions do not have trees.

Table 27 and Table 28 summarize the safety projects conducted in California, along with the road section information and the particular countermeasure. Table 29 shows the before-and-after analysis summary for the impacts of existence/nonexistence of trees in the median and borders. The results show that for two road sections considered the number of accidents have reduced by around 20-30% after the removal of median trees. This result is consistent with the conclusions obtained by Cal Poly (85) stating that existence of median trees on urban conventional highways is associated with an increased number of total collisions and fatal and injury collisions, when collisions are limited to those that involve the left and middle lanes, the median shoulder, the median, or beyond (No-Right-Side collisions).

Table 27. Summary of safety projects from California

Project Title and Section	Road Information	Study
Buena Park, SR 39 - D12	Speed limit:35-40 mph No of lanes: 3-4 lanes	Existence/nonexistence of median trees, California
Huntington Beach, SR 1 - D12	Speed limit:45 mph No of lanes: 2-3 lanes	Existence/nonexistence of median trees, California

Table 28. Location of safety projects from California

Route	Mile Post
Buena Park, SR 39 - D12	With trees: 14:38-15.82 Without trees: 12.96-14.36
Huntington Beach, SR 1 - D12	With trees: 0.00-1.65 Without trees: 25.00-25.89

Table 29. Summary of accidents before-and-after countermeasure 3

Accident Type	Period	Buena Park	Huntington Beach
total accidents (acc/mile)	**before**	325	117
	after	235	95
	change	***27.7%***	***18.8%***
total number of injuries (acc/mile)	**before**	165	50
	after	120	34
	change	***27.3%***	***32%***
total number of fatalities (acc/mile)	**before**	0	1
	after	0	0
	change	*0%*	***100.0%***

Countermeasure 4 - Installation of Guide Rails, and Vertical & Horizontal Geometry Changes to Improve Sight Distances

NJ Based Road Sections

The final countermeasure is “the installation of guide rails and vertical and horizontal geometry changes”. From NJ based sources, research team identified 6 different safety project sites. Road characteristics of these road sections are shown in Table 30. Among these road sections, NJ Route 4, NJ Route 35 and NJ Route 71 are improved via guide rail installations, while vertical and horizontal alignments are implemented on NJ Route 517, NJ Route 322, NJ Route 166 to improve sight distance and reduce accidents (NJDOT Bureau of Construction Engineering Reports and Falcon Database).

Table 30. Road characteristics, countermeasure 4

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width	Start Date	End Date
NJ Route 4	Urban Arterial	1.82-2.7	40	2-4	11	6	5	12/27/2000	7/25/2003
NJ Route 35	Urban Arterial	46-47.3	40	2	12	0	6	10/21/1999	8/2/2001
NJ Route 71	Urban Arterial	10-11.7	35	2	12	16	6	10/21/1999	8/2/2001
NJ Route 517	Urban Collector	12.42-12.71	40	2	12	0	3	5/1/2000	12/15/2000
NJ Route 322	Urban Arterial	4.097-4.986	45	2	12	20	5-12	8/23/1999	5/3/2000
NJ Route 166	Urban Arterial	0-1.866	25-35	2	12	0	5-6	5/16/98	12/21/1999

Figure 2, Figure 3, and Figure 4 presents the photos of the road sections obtained from site visits by the Rutgers team, for NJ Route 4, NJ Route 35 and NJ Route 71, respectively. Similarly, Figure 5 and Figure 6 show the road pictures for NJ Route 517, NJ Route 322, respectively.

Figure 2. Photos of NJ route 4

Figure 3. Photos of NJ route 35

Figure 4. Photos of NJ route 71

Figure 5. Photos of NJ route 517

Figure 6. Photos of NJ route 322

Table 31, Table 32 and Table 33 summarize the results of naïve before-and-after analysis for road sections NJ Route 4, NJ Route 35 and NJ Route 71, respectively.

Table 31. Naïve before-and-after analysis for NJ route 4

Period		**Before**			**After**		
Year		**1997**	**1998**	**1999**	**2004**	**2005**	**2006**
Total accidents (acc/section)	**Total**	124	139	132	142	113	125
	Average	132 (150 acc/mile)			127 (144 acc/mile)		
	% Change	*-3.80%*					
Injuries (acc/section)	**Total**	69	52	40	52	53	46
	Average	54 (61 inj/mile)			50 (57 inj/mile)		
	% Change	*-6.21%*					
Fatalities (acc/section)	**Total**	1	1	0	1	0	0
	Average	1			0		
	% Change	*-50.00%*					

Table 32. Naïve before-and-after analysis for NJ route 35

Period		**Before**		**After**		
Year		**1997**	**1998**	**2003**	**2004**	**2005**
Total accidents	**Total**	62	51	49	45	44
	Average	57 (44 acc/mile)		46 (35 acc/mile)		
	% Change	***-18.14%***				
Injuries	**Total**	27	14	24	31	23
	Average	21 (16 inj/mile)		26 (20 inj/mile)		
	% Change	*23.81%*				
Fatalities	**Total**	0	0	0	1	0
	Average	0		0		
	% Change	*0.00%*				

Table 33. Naïve before-and-after analysis for NJ route 71

Period		**Before**		**After**		
Year		**1997**	**1998**	**2002**	**2003**	**2004**
Total accidents	**Total**	27	24	39	43	34
	Average	26 (15 acc/mile)		38 (22 acc/mile)		
	% Change	*46.15%*				
Injuries	**Total**	14	10	9	18	17
	Average	12 (7 inj/mile)		14 (8 inj/mile)		
	% Change	*16.67%*				
Fatalities	**Total**	0	0	0	0	0
	Average	0		0		
	% Change	*0.00%*				

The highest number of accidents is observed on NJ Route 4, followed by NJ Route 35 and NJ Route 71. Similarly, the highest reduction in accidents is observed for NJ Route 35, followed by NJ Route 4. On the other hand, it is observed that annual number of accidents has been increased along NJ Route 71, after the installation of guide rails. However, the total number of accidents along this road section is quite low and this increase can be solely due to the normal stochastic fluctuations in the system.

Table 34 summarizes the results of the naïve before-and-after analysis for road alignment improvements along NJ Route 517. The analysis results show that the total number of accidents have been reduced by around 39% after the safety improvements. Moreover, the severity of the observed accident has been decreased due to these improvements.

Table 34. Naïve before-and-after analysis for NJ route 517

Period		**Before**			**After**		
Year		**1997**	**1998**	**1999**	**2001**	**2002**	**2003**
Total accidents (acc/section)	**Total**	20	19	15	10	14	11
	Average	18 (62 acc/mile)			11 (38 acc/mile)		
	% Change	***-38.89%***					
Injuries (acc/section)	**Total**	13	5	1	6	3	2
	Average	6 (21 inj/mile)			4 (14 acc/mile)		
	% Change	***-33.33%***					
Fatalities (acc/section)	**Total**	0	1	0	0	0	0
	Average	0.33 (1 fat/mile)			0		
	% Change	***-100.00%***					

Table 35 summarizes the changes in safety along NJ Route 322 after the improvements in terms of road alignment. The results of the analysis show that total number of accidents has been reduced after the treatment, and significant improvements were observed in terms of the severity of these accidents.

Table 35. Naïve before-and-after analysis for NJ route 322

Period		Before		After		
Year		1997	1998	2001	2002	2003
Total Accidents	**Total**	21	23	4	14	9
	Average	22 (24 acc/mile)		9 (10 acc/mile)		
	% Change	***-59.09%***				
Injuries	**Total**	18	19	3	5	3
	Average	19 (21 inj/mile)		4 (5 inj/mile)		
	% Change	***-80.18%***				
Fatalities	**Total**	0	0	0	0	0
	Average	0		0		
	% Change	***0.00%***				

Table 36 summarizes the changes in the safety along NJ Route 166 after the improvements in skid resistance. The analysis results show that total number of accidents has been slightly increased after the treatment, and no improvements were observed in terms of the severity of these accidents. However, it should be noted that the before data are available only for one year, whereas after data are available for three years. Moreover, the before data were collected in 1997. Along these years accident data are not very accurate, affecting the credibility of the analysis results.

Table 36. Naïve before-and-after analysis for NJ route 166

Period		**Before**	**After**		
Year		**1997**	**2000**	**2001**	**2002**
Total accidents	**Total**	94	97	108	100
	Average	94 (50 acc/mile)	102 (54 acc/mile)		
	% Change	*8.16%*			
Injuries	**Total**	25	37	59	33
	Average	25 (13 inj/mile)	43 (23 inj/mile)		
	% Change	*72.00%*			
Fatalities	**Total**	1	1	0	0
	Average	1 (1 fat/mile)	0		
	% Change	***-66.67%***			

Analysis Results Based on the Data Obtained from Other States

In the literature, Hovey et al. (55) have performed before-and-after analysis via EB methodology in order to investigate the impacts of median closure, and improvement of vertical geometry. The authors state that after these countermeasures the total number of accidents have been reduced and the safety of the road sections have been improved.

From ODOT database, the research team has identified one possible safety project namely flattening of slope to reduce the accidents. Table 37 summarizes the characteristics of the road section WAS676R1. Similarly, Table 38 summarizes the naïve before-and-after analysis results for this specific road section. It is found that, after flattening the slope of the road section, total number of accidents has been reduced by around 58%.

Table 37. Road characteristics for WAS676R1

Road Name	**Mile Post**	**No of Lanes**	**Lane Width**	**Sh. Width**	**Median Width**	**Speed Limit**
WAS676R1	18.3-18.8	2	13’	4’	0	35

Table 38. Naïve before-and-after analysis, WAS676R1

Period	Before		After		
Accident	7/1/1995-6/30/1996	7/1/1996-6/30/1997	7/1/1999-6/30/2000	7/1/2000-6/30/2001	7/1/2001-6/30/2002
Acc/year	16	10	4	3	9
Acc/year/mile	32	20	8	6	18
Average acc/year/mile	26			11	
% Change	***-57.69***				

BEFORE-AND-AFTER ANALYSIS WITH CONTROL GROUP

Road improvements are generally made in reaction to perceived problems at specific sites with high number of crashes. The site could be unusually dangerous, or it could have just randomly experienced an unusual number of crashes. If the high crash rate were part of the natural distribution of crashes, the rate should go down without any improvement, a phenomenon known as regression to the mean. Because of the way sites are selected for improvement, it is impossible to discern whether a drop in observed crash rates is due to the improvement or due to regression to the mean without relating the results to comparison sites that have not undergone the improvement.

NCHRP (90) suggests that the desired control group sample size should be twice the size of the treatment group. Apart from the size, the characteristics of the control group are also important. The control group should exhibit properties similar to the treatment sites in terms of volume, road and accident characteristics. Despite general geometric similarities such as number of lanes and the presence of an intersection, there are still many factors that can vary between similar roadway sites. Average daily traffic (ADT) will have a big impact on the number of crashes and varies considerably between sites. Additional factors such as shoulder width and the type of development will also affect the number of crashes. These factors must be taken into account when comparing control and treatment sites.

While determining the control sites for the urban collectors in New Jersey, as the first step several road sections for which the specific countermeasures have been implemented need to be selected. Then, for each treatment site, control sites of traffic, road, and accident characteristics that have not been subject to any safety treatment will be selected. Variables required for both control and treatment sites can be listed as follows:

1. Functional Class (Urban collector)
2. Roadway Width

3. Shoulder Width
4. Median Width
5. Number of lanes
6. Crash Data
7. Average Daily Traffic
8. Section Length
9. Access Control
10. Speed limit
11. Median barrier type

This section focuses on the “before-and-after analysis with control group” for the countermeasures determined by NJDOT. Road characteristics and the accident information of the control sites are provided in Appendix B. Moreover, Appendix C illustrates the before-and-after analysis via control-group method on an example.

The control sites for each treatment type, required to perform before-and-after analysis, are obtained from straight line diagrams (SLD) available at New Jersey Department of Transportation (NJDOT) (http://www.state.nj.us/transportation /refdata/sldiag/) and from individual site visits. Straight line diagrams were investigated for each treatment site except the “guide rail installation” treatment. Since there was no information regarding the guide rail availability for the NJ roadways in SLD, research team made three site visits to identify the control sites for the “guide rail installation” treatment. Table 39 summarizes the number of control sites found for each treatment site in NJ.

Table 39. Control sites from NJ based sources

Road	NJ RT 4	NJ RT 35	NJ RT 71	NJ RT 517	NJ RT 322	NJ RT 30
Treatment	Median barrier installation	Guide rail installation		Vertical/ horizontal improvement		Road widening
No of Control Sites	30	32		47		31

Similarly, the control sites for the treatment sites in Ohio were obtained from HSIS database. While identifying the control sites, the research team investigated the HSIS database throughout the whole analysis period, and made sure that the road characteristics of each control site satisfy the before conditions of the treatment sites. Table 42 summarizes the number of control sites found for each treatment site in Ohio.

Table 40. Control sites from HSIS database

Road	HOC664	CLI134	COL344	UNI038
Treatment	Add Shoulder			
No of Control Sites	20	21	18	31

Countermeasure 1 – Increase Lane Width

NJ based Road Sections

The first countermeasure is increase in lane width. From NJ based sources, research team identified one possible safety project located along NJ Route 30. In order to conduct before-and-after analysis via control groups, research team has identified 31 different road sections.

After identifying the control sites and accident information on these sites, following the estimation process provided in Section 3 – eq. (2), before-and-after analysis results via control groups is conducted. Table 41 presents the analyses results. The analysis results are consistent with Naïve approach results, confirming that after the lane width increase the crash rate has been reduced by 56%, while the injury rate has been reduced by 37%.

Table 41. Before-and-after analysis results, NJ route 30

Accident	**Naïve Approach**			**Comparison Method**			
	Before	**After**	**Change (%)**	**Before**	**Rate**	**After**	**Change (%)**
Total	79	46	**-41.77**	79	1.33	105	**-56.22**
Injury	46	32	**-30.43**	46	1.103	51	**-36.93**

Countermeasure 2 – Add Shoulders

Analysis Results based on the Data Obtained from Other States

From HSIS data, the research team has identified four possible safety projects. For each of these treatment sites, control sites have been identified from HSIS database.

Table 42 summarizes the results of the before-and-after analysis via control group. The analysis results are found to be consistent with Naïve approach results, confirming that after adding shoulder to the road sides, the accident rates have been reduced. However, the rate of decrease in the injury rate was overestimated in Naïve approach.

Table 42. Before-and-after analysis results, countermeasure 2

Route	Accident	Naïve Approach			Comparison Method			
		Before	After	Change (%)	Before	Rate	After	Change (%)
HOC664	**Total**	73	70	-4.11	73	1.31	96	**-26.80**
	Injury	23	20	-13.04	23	0.98	23	**-11.27**
CLI134	**Total**	58	43	-25.86	58	1.00	58	**-25.86**
	Injury	20	13	-35.00	20	1.34	27	**-51.49**
COL344	**Total**	18	11	-38.89	18	0.93	17	**-34.29**
	Injury	5	1	-80.00	5	1.264	6	**-84.18**
UNI38	**Total**	28	25	-10.71	28	1.46	41	**-38.85**
	Injury	11	3	-72.73	11	0.83	9	**-67.14**

Countermeasure 3 - Removal of Trees in Median and Border Areas

Analysis Results Based on the Data Obtained from Other States

Research team has identified two road sections in California, regarding the tree removal in the median and border areas of the road sections. Unfortunately, for these road sections we do not have before-and-after accident data. Instead, we have identical road sections for which some part of the road section has trees in the median, while the other part does not. And the accident database covers only year 2001. Thus, it is not possible to conduct before-and-after analysis for this specific countermeasure.

Countermeasure 4 - Installation of Guide Rails, and Vertical & Horizontal Geometry Changes to Improve Sight Distances

NJ Based Road Sections

The final countermeasure is “the installation of guide rails and vertical and horizontal geometry changes”. From NJ related sources, research team identified 6 different possible safety projects. Among these road sections, NJ Route 4, NJ Route 35 and NJ Route 71 are improved via guide rail installations, while vertical and horizontal alignments are implemented on NJ Route 517 and NJ Route 322 to improve sight distance and reduce accidents.

Table 43 summarizes the results of the before-and-after analysis via control group. The analysis results are consistent with Naïve approach results, except for guide rail installation. The overall results confirm that median barrier installation, and vertical & horizontal geometry changes may have a positive impact on reducing the crash rates on these road sections.

Table 43. Before-and-after analysis results, countermeasure 4

Route	Accident	Naïve Approach			Comparison Method			
		Before	After	Change (%)	Before	Rate	After	Change (%)
NJ 4	**Total**	150	144	-4.00	150	1.68	252	**-42.86**
	Injury	62	57	-8.06	62	1.51	94	**-39.12**
NJ 35	**Total**	44	35	-20.45	44	0.98	43	**-18.83**
	Injury	16	20	25.00	16	0.99	16	**26.26**
NJ 71	**Total**	15	22	46.67	15	0.87	13	**68.58**
	Injury	7	8	14.29	7	1.025	7	**11.50**
NJ 517	**Total**	62	38	-38.71	62	1.49	92	**-58.87**
	Injury	21	14	-33.33	21	1.11	23	**-39.94**
NJ 322	**Total**	24	10	-58.33	24	1.28	79	**-87.40**
	Injury	21	5	-76.19	21	1.45	30	**-83.58**

Analysis Results Based on the Data Obtained from Other States

From ODOT database, the research team has identified one possible safety project namely flattening of slope to reduce the accidents. The control sites for this treatment site are determined from ODOT accident database (55). Table 44 summarizes the results of the before-and-after analysis via control group for Ohio Route 676. Since the accident database do not provide any information regarding the injury rates, control group analysis is conducted only for total crash rates. Overall, the analysis results show that Naïve approach slightly overestimates the crash reductions after the countermeasure.

Table 44. Before-and-after analysis results, Ohio route 676

Accident	Naïve Approach			Comparison Method			
	Before	After	Change (%)	Before	Rate	After	Change (%)
Total	26	11	-57.69	26	0.97	25	**-56.38**

The overall before-and-after analysis via control groups shows that the analysis results are consistent with the naïve approach results. Specifically, increase in lane width, adding shoulders, installation of median barriers, and improvements in the horizontal & vertical alignment result in reduction of accident rates; while installation of guide rails has no impact on accident rate reduction. Moreover, for most of the treatment sites, naïve approach underestimates the relative rate of reduction in the accidents. Next section develops safety performance functions based on EB methodology.

BEFORE-AND-AFTER ANALYSIS VIA EB METHODOLOGY

The before-and-after analysis with Empirical Bayes (EB) methodology has been developed to adjust for the regression-to-the-mean problem, which is considered to be the most serious problem associated with before-and-after studies (*30, 45, 46*). It is based on the recognition that crash counts are not the only clue to the safety of an entity. Another clue is in what is known about the safety of similar entities (*46*). The underlying theory of the EB method is that the crash rate at a specific site follows a probability distribution which can be estimated by collecting crash data from a number of similar entities. EB method combines information about the prior distribution with data collected from a treatment site (likelihood) to offset the impact of a temporary, random increase in crashes. In transportation safety field, many studies have conducted before-and-after analysis based on EB methodology (*30, 45, 46, 49, 50, 55*). Unfortunately, none of these studies were applied to urban collectors/ arterials; rather they focus on the safety performance of intersections or freeways.

While performing before-and-after analysis via EB methodology, *B*, in eqn-5 is estimated from the SPF, and SPF function is estimated via crash data obtained from “similar” sites, i.e. control groups. As the number of data points available for the treatment site increases, the within-site variance (year to year variability in crashes for the treatment site) component decreases, and as a consequence, *w*, in eqn-6 increases. When there is much information available for the treatment site, the estimator of its expected number of crashes is based mostly on the data available for that treatment site. Thus, as more data for the treatment site of interest becomes available, we rely less and less on information about "similar" sites (89).

This sections focus on estimation of safety performance functions using control sites and before-and-after analysis based on EB methodology. Moreover, Appendix C explains how to conduct this approach on a real treatment site using an example.

Safety Performance Functions

In the before-and-after studies, the usual application of EB approach is to understand the relationship between geometric and traffic factors and the accident occurrence. Poisson or Negative Binomial (NB) (also known as the Poisson/Gamma model) models are the two most common models used in the traffic safety literature (*45, 46, 49, 50, 55, 53, 79*). In EB approach, the model parameters are estimated using a maximum likelihood technique, or any other technique involving the use of the observed accident data from the similar sites (*67*).

The NB regression models have more desirable properties compared with the Poisson model to describe the interaction between road characteristics and the accident occurrence behavior. Unfortunately, even though NB models can deal with between-site variations, these models suffer from the limitations that time variations are not well considered (92, 93). Consequently, the estimates of the standard error in the regression coefficients may be underestimated and the t-ratios may be inflated. Since, geometric and traffic variables are likely to have location-specific effects, and spatial effects exist in the data, random effects negative binomial (RENB) models can be developed to overcome the problems faced by NB models (*92, 93, 94*).

The general form of the safety performance function represented as a negative binomial regression model is as follows:

$$P(y_{it}|\gamma_{it},\delta_i) = \frac{e^{-\gamma_{it}}{\gamma_{it}}^{y_{it}}}{\gamma_{it}!} \tag{11}$$

$$\gamma_{it} = \mu_{it}\delta_i \tag{12}$$

$$log(\mu_{it}) = \boldsymbol{X}_{it}\boldsymbol{\beta} \rightarrow \mu_{it} = e^{\boldsymbol{X}_{it}\boldsymbol{\beta}} \tag{13}$$

where;

y_{it}: Number of observed crashes at site *i* in year *t*

$\boldsymbol{X}_{it}$: Vector of explanatory variables including traffic volume and geometric characteristics

$\boldsymbol{\beta}$: Regression parameter vector

δ_i: Dispersion parameter

In the above formulation, eqn-11, eqn-12 and eqn-13 contain the functional form required for the NB model.

The RENB model, on the other hand, allows the dispersion parameter to vary randomly with the following equation:

$$\frac{1}{1+\delta_i} \sim Beta(p, q) \quad (14)$$

where;
p, q: Parameters of the beta distribution

Next section summarizes the estimation of safety performance functions via NB and RENB models based on EB methodology.

Estimation Results

Control data for each of the six treatment sites are used to estimate the safety performance functions based on NB and RENB models. For each treatment site the explanatory variables include “average annual daily traffic volume (AADT)”, “section length”, “shoulder width”, “speed limit”, “number of lanes” and “lane width” information. The crash records for each treatment and control site are obtained from the NJDOT raw crash records (95). Crash data are available for each crash that occurred, providing detailed information on the crash, the vehicles involved, and the driver and vehicle occupants, as well as any pedestrians concerned. Similarly, road characteristics required for the estimation of the safety performance functions are obtained from New Jersey specific straight line diagrams (96). The relevant time period for this analysis is three years before and after the implementation of the specific treatment. The relevant fields for this study were:

- Number of vehicles involved,
- Crash location (milepost),
- Severity,
- Road divided by (concrete isle, concrete bar, grass median, or none),
- Road character (lane width, speed limit, shoulder width, median width, number of lanes).

Apart from crash records and road characteristics information, traffic volume data are needed to calculate crash rates at each treatment site. NJDOT (97) provides traffic volume and roadway information for each road section in New Jersey between years 2001 and 2006. To estimate the unavailable past traffic volume data, an annual change of 1.25% is applied.

Table **45** and Table 46 summarize the estimation results for NB and RENB models based on EB methodology. The values in the parentheses are the standard deviation of each model parameter. All models based on EB methodology are estimated in Stata Software [98]. The log-likelihood values show that RENB models perform better than NB models for the EB methodology. In particular, the log-likelihood values are lower for RENB models for each treatment type. Moreover, the safety functions confirm the nonlinear relationship between crashes and volume and road characteristics. Specifically, as the traffic volume and the section length increase the crash rate increases as well at all road sections. For median barrier installation, and improvements in the road alignment countermeasures availability of shoulder on the road side, and increasing the width of the shoulder result in a reduction in the accident rate, while for other treatment types this parameter is found to be statistically insignificant. The relative influence of the model parameters on the crash rate due to different treatment types is consistent with the existing models [50, 55, 93].

Table 45. NB model estimation via EB methodology

Parameter	Negative Binomial			
	Lane width increase (acc/year/lane)	**Median barrier (acc/year/lane)**	**Road alignment (acc/year/lane/mile)**	**Guide rail (acc/year/lane)**
Constant	-3.69 (0.45)	-3.71 (0.61)	-2.87 (0.67)	-5.105 (1.47)
traffic volume	0.71 (0.045)	0.7 (0.065)	0.59 (0.07)	0.77 (0.16)
shoulder width		-0.016 (0.076)	-0.18 (0.019)	
road length	0.59 (0.045)	0.49 (0.093)		0.41 (0.13)
log likelihood	-372.57	-291.42	-193.75	-115.46

Table 46. RENB model estimation via EB methodology

Parameter	Random Effects Negative Binomial			
	Lane width increase (acc/year/lane)	**Median barrier (acc/year/lane)**	**Road alignment (acc/year/lane/mile)**	**Guide rail (acc/year/lane)**
constant	-4.73 (0.35)	-3.43 (1.29)	-2.68 (0.41)	-4.12 (0.89)
traffic volume	0.73 (0.036)	0.66 (0.051)	0.63 (0.05)	0.65 (0.12)
shoulder width			-0.14 (0.011)	
road length	0.64 (0.042)	0.49 (0.082)		0.46 (0.08)
log likelihood	-360.47	-282.67	-175.28	-110.84

A similar analysis was conducted for the countermeasures obtained from other states, i.e. “add shoulder” treatment. The treatment sites were obtained from Ohio HSIS database. These road sections are CLI134, COL344, HOC664 and UNI038. While performing before-and-after analysis via EB methodology 56 control sites are considered. Table 47 summarizes the NB and RENB models estimated via EB methodology. The analysis results confirm a nonlinear relationship between crash rate and volume, lane width and road length. As with other models RENB model provides parameters with lower standard deviations and better model performance in terms of log likelihood values.

Table 47. Estimation results via EB methodology, countermeasure 2

Parameters	NB-EB	RENB-EB
constant	-3.13 (1.22)	-2.62 (1.11)
traffic volume	0.49 (0.14)	0.51 (0.12)
lane width	0.85 (0.47)	0.67 (0.42)
road length	0.28 (0.07)	0.24 (0.05)
loglikelihood	-208.23	-183.56

Estimation of Crash Reduction Factors and Accident Modification Factors

While calculating the crash reduction factors (CRF) values via EB approach, the methodology provided in (23) is followed. The main idea behind EB method is to predict the number of crashes that would have been expected to occur during the after period had the treatment not been implemented. In this approach evaluation the effect of the specific safety treatment is given by (23):

$$B - A \tag{15}$$

where *B* is the expected number of crashes that would have occurred no treatment have been implemented and *A* is the number of reported crashes in the after period when the treatment is implemented. *B* is estimated based on the safety performance function which estimates the number of crashes that would be expected in each period at locations with characteristics similar to the treatment sites.

The sum of these safety performance function estimates (*P*) is then combined with the count of crashes (*x*) at the specific toll area site to obtain an estimate of the expected number of crashes (*m*). This estimate of *m* is (23):

$$m = w \sum_t P + (1 - w) \sum_t x \tag{16}$$

where;

$$w = \frac{1}{k(\sum_t P + 1/k)}$$

The weight *w* depends on the dispersion parameter (k) of the negative binomial distribution used in estimating the safety performance function. A factor is then applied to m to account for the length of the after period as well as the differences in traffic volumes and general trends in crash risk due to factors such as weather, reporting practices and the other safety countermeasures between the before-and-after periods (*23*).

Then, the expected crash reduction factors (CRF) are calculated for each treatment type using the following formula:

$$CRF_i = 1 - \frac{\sum_t Y_{it}}{\sum_t m_{it}} \tag{17}$$

where;
CRF_i: Crash reduction factor for treatment type *i*
t: Index for the time period
Y_{it}: Observed total number of crashes for treatment type *i*
m_{it}: Expected number of crashes without the treatment (obtained from NB and RENB models)

Based on the calculated CRF values accident modification factors (AMF) can easily be calculated based on the following equation:

$$AMF_i = \frac{\sum_t Y_{it}}{\sum_t m_{it}} = 1 - CRF_i \tag{18}$$

where;
AMF_i: Accident modification factor for treatment type *i*

AMF less than 1.0 indicate fewer crashes due to the safety measures.

Table 48 summarizes the observed and estimated annual crash rates along with the CRF values for each treatment site. Results are consistent across the road sections, with all showing a decrease in crash rates after the specific treatment, except NJ Route 71 (RENB model). The highest decrease in the crash rate is observed at NJ Route 322, after the improvement in vertical and horizontal alignment. Adding shoulder, increase in lane width, and installation of median barriers also cause reductions of 18% (20%) 10% (6.5%) and 39% (30.3%) in the crash rate for NB model (RENB model), respectively. On the other hand, installation of guide rails does not reduce the crash rates, significantly. The overall decrease among NJ Route 35 is 15% for NB model and 5.6% for RENB model.

Overall the difference in the annual crash rates between NB and RENB models change from 2 acc/lane/mile/year to 5 acc/lane/mile/year.

Table 48. Crash reduction factors for all countermeasures– EB methodology

Countermeasure	Road	Observed (acc/lane/mile/year)		Estimated (acc/lane/mile/year)		CRF values		
		Before	After	NB	RENB	NB	RENB	Naïve
Install median barrier (countermeasure 4)	NJ Route 4	75	72	80	77	0.1	0.065	0.04
Increase lane width (countermeasure 1)	NJ Route 30	40	23	38	33	0.39	0.303	0.425
Improve vertical & horizontal alignment (countermeasure 4)	NJ Route 517	30	20	22	25	0.09	0.186	0.333
	NJ Route 322	12	5	6	8	0.16	0.375	0.583
Install guide rail (countermeasure 4)	NJ Route 35	21	17	20	18	0.15	0.056	0.190
	NJ Route 71	8	11	8	12	-0.375	0.083	-0.375
Add Shoulder (countermeasure 2)	CLI134R2	26	21	22	23	0.05	0.08	0.19
	COL344R1	9	5	10	10	0.49	0.51	0.44
	HOC664R1	37	35	36	37	0.03	0.04	0.05
	UNI038R1	14	12	14	15	0.16	0.18	0.14

Similarly, Table 49 summarizes the AMF values calculated from EB methodology. The individual AMF values indicate that apart from Route 71, for all treatment types the crash rate has been reduced after the countermeasure.

Table 49. Accident modification factors for all countermeasures – EB methodology

Countermeasure	Road	AMF values		
		NB	RENB	Naïve
install median barrier (countermeasure 4)	NJ Route 4	0.9	0.935	0.96
increase lane width (countermeasure 1)	NJ Route 30	0.61	0.697	0.575
improve vertical & horizontal alignment (countermeasure 4)	NJ Route 517	0.91	0.814	0.667
	NJ Route 322	0.84	0.625	0.417
install guide rail (countermeasure 4)	NJ Route 35	0.85	0.944	0.81
	NJ Route 71	1.375	0.917	1.375
Add Shoulder (countermeasure 2)	CLI134R2	0.95	0.92	0.81
	COL344R1	0.51	0.49	0.56
	HOC664R1	0.97	0.96	0.95
	UNI038R1	0.84	0.82	0.86

BEFORE-AND-AFTER ANALYSIS VIA FB METHODOLOGY

Recently, with the computational advances in statistics, the Fully Bayesian (FB) approach has gained interest for treatment effect analysis (62, 99, 100, 101). FB approach allows including more uncertainty in the analysis and is usually implemented via the hierarchical Bayesian models. This approach is also attractive because it may require less data by incorporating past experiences and practitioner's knowledge. Note that this issue is important since crash data collected for safety studies often have the unusual attributes of being characterized by high-accident frequency and small sample sizes, due to the prohibitive costs of collecting data (102, 103, 104). That is, crash data for before-and-after studies are sometimes collected from a small number of sites during short periods of time. Previous studies have shown that under these conditions the model parameters can be misestimated when using the maximum likelihood (ML) technique – which affects the accuracy of the EB estimates (102). In transportation area, several researchers have conducted FB methodology to model the safety of intersections and freeways (62, 101, 103, 105, 106).

The main idea behind FB method is to predict the number of crashes that would have been expected to occur during the after period had the treatment not been implemented. Unlike the classical approach (EB methodology), in Bayesian statistics, parameters are treated as random variables, and prior knowledge about parameter vector is represented by a prior distribution. The prior distribution can either be based on previous empirical work, or researcher's subjective beliefs.

In RENB model, the relationship between the accident occurrence rate and the roadway characteristics is given by the following:

$$P(y_{it}|\gamma_{it},\delta_i) = \frac{e^{-\gamma_{it}}\gamma_{it}{}^{y_{it}}}{\gamma_{it}!} \tag{19}$$

$$\gamma_{it} = \mu_{it}\delta_i \tag{20}$$

$$log(\mu_{it}) = \boldsymbol{X}_{it}\boldsymbol{\beta} \rightarrow \mu_{it} = e^{\boldsymbol{X}_{it}\boldsymbol{\beta}} \tag{21}$$

$$\delta_i \sim Gamma(\alpha,\alpha) \tag{22}$$

$$\boldsymbol{\beta} \sim Normal(\widehat{\boldsymbol{\beta}}, \Sigma_{\boldsymbol{\beta}}) \tag{23}$$

$$\alpha = e^{\tilde{\alpha}} \tag{24}$$

$$\tilde{\alpha} \sim Normal(\hat{\tilde{\alpha}}, \sigma_{\tilde{\alpha}}) \tag{25}$$

where;

y_{it}: Number of observed crashes at site *i* in year *t*

μ_{it}: Estimated number of crashes at site *i* in year *t*

$\boldsymbol{X}_{it}$: Vector of explanatory variables including traffic volume and geometric characteristics

$\boldsymbol{\beta}$: Regression parameter vector

δ_i: Dispersion parameter

$\alpha, \tilde{\alpha}$: Hierarchical prior distribution parameters of the dispersion parameter ($\alpha > 0$)

$\widehat{\boldsymbol{\beta}}$: Initial mean vector for the regression parameter vector $\boldsymbol{\beta}$

$\Sigma_{\boldsymbol{\beta}}$: Initial covariance vector for the regression parameter vector $\boldsymbol{\beta}$

$\hat{\tilde{\alpha}}$: Initial mean value for the hyper parameter $\tilde{\alpha}$

$\sigma_{\tilde{\alpha}}$: Initial standard deviation value for the hyper parameter $\tilde{\alpha}$

In the above formulation, eqn-18 to eqn-22 contain the functional form required for the regular RENB model (92, 93, 94). Eqn-23, eqn-24, and eqn-25 are the hierarchical prior distributions for unknown regression parameter vector and the dispersion parameter of the RENB model. These hierarchical prior distributions form the basis of the FB methodology. In this study, by letting the hyper-priors to be noninformative, their influence on the posterior distribution is reduced. The normal prior distributions are selected for all model parameters ($\boldsymbol{\beta}$, $\tilde{\alpha}$). Since the parameters of the gamma distribution is always positive, by taking the exponential of the parameter $\tilde{\alpha}$ via eqn-24 this constraint is satisfied.

Given this information posterior distribution of the unknown parameters ($\boldsymbol{\beta}, \delta$) can be written as the multiplication of the likelihood function and the prior distributions (the indices are omitted for simplicity) $^{(107)}$:

$$posterior\ distribution \sim Likelihood\ function\ x\ prior\ distribtuion \tag{26}$$

$$P(\boldsymbol{\beta}, \delta|\boldsymbol{Y}, \boldsymbol{X}) = \frac{L(\boldsymbol{Y}|\boldsymbol{X},\gamma,\delta,\boldsymbol{\beta})L(\gamma|\delta,\boldsymbol{\beta})P(\delta|\alpha)P(\alpha)P(\boldsymbol{\beta})}{\int L(\boldsymbol{Y}|\boldsymbol{X},\gamma,\delta,\boldsymbol{\beta})L(\gamma|\delta,\boldsymbol{\beta})P(\delta|\alpha)P(\alpha)P(\boldsymbol{\beta})} \tag{27}$$

Since the denominator in eqn-26 is just a normalizing constant, posterior distribution can easily be written as follows:

$$P(\boldsymbol{\beta}, \delta|\boldsymbol{Y}, \boldsymbol{X}) \sim L(\boldsymbol{Y}|\boldsymbol{X}, \gamma, \delta, \boldsymbol{\beta})L(\gamma|\delta, \boldsymbol{\beta})P(\delta|\alpha)P(\alpha)P(\boldsymbol{\beta}) \tag{28}$$

$$P(\boldsymbol{\beta}, \delta|\boldsymbol{Y}, \boldsymbol{X}) \sim \prod_{i,t} \frac{e^{-\gamma_{it}}{\gamma_{it}}^{y_{it}}}{\gamma_{it}!} . e^{\boldsymbol{X}_{it}\boldsymbol{\beta}}\ Gamma(\alpha, \alpha) e^{Normal(\hat{\tilde{\alpha}}, \sigma_{\tilde{\alpha}})} Normal(\hat{\boldsymbol{\beta}}, \Sigma_{\boldsymbol{\beta}}) \tag{29}$$

where $P(\boldsymbol{\beta}, \delta|\boldsymbol{Y}, \boldsymbol{X})$ is the posterior distribution for all the unknown parameters given the complete data set, $L(\boldsymbol{Y}|\boldsymbol{X}, \gamma, \delta, \boldsymbol{\beta})L(\gamma|\delta, \boldsymbol{\beta})$ is the likelihood function of the data, $P(\delta|\alpha)$, and the $P(\boldsymbol{\beta})$ are the prior distributions of the model parameters, and $P(\alpha)$ is the hyper prior distribution for the dispersion parameter. The advantage of this approach over the EB methodology is that it provides the entire posterior distributions of the model parameters, allowing a wide range of inference beyond the first two moments.

In practice, posterior distribution is usually a complex multidimensional function which requires integrating. Thus, sampling methods such as modern Bayesian Monte Carlo algorithms are needed to summarize the posterior distribution via sampling methods. In this project, using Gibbs sampling algorithm we produce Markov Chain Monte Carlo (MCMC) samplers using WINBUGS free software $^{(114)}$. Gibbs sampling generates a sequence of samples from the joint probability distribution of two or more random variables. Gibbs algorithm, developed by $^{(108)}$ is a special case of the Metropolis-Hastings algorithm, and applicable when the joint posterior distribution is not known explicitly, but the conditional distribution of each variable is known.

The Gibbs sampler can draw samples from any probability distribution $P(x)$. The only requirement is that a function proportional to the density can be calculated at *x*. The algorithm generates a Markov chain for which each state x^{t+1} depends only on the previous state x^t. Then, using a proposal density $Q(x'; x^t)$, a new proposed sample x' is generated. This proposed sample is accepted as the next value $(x^{t+1} = x')$ with probability one. A more detailed explanation of the Gibbs sampling algorithm can be found in $^{(107)}$.

MCMC samples from Gibbs sampling converges when the posterior inferences do not depend on the initial starting values of the chains. Thus, to ensure convergence of the RENB models multiple chains are run from different starting values. When the convergence is reached the chains intertwines with one another. Then the Gelman-Rubin convergence statistic $^{(109)}$ is conducted to compare the ratio of the pooled chain variance to the within chain variance.

Bayesian Model Selection

In this study, in order to determine the independent variables to be included in the RENB models and compare the performance of these models with the regular NB models, Bayesian model selection approach is considered. In particular, the Deviance Information Criterion (DIC) is used to compare different Bayesian RENB and Bayesian NB models $^{(110,\ 111)}$. While selecting the best model with DIC, the lower the DIC value the better the estimated model is.

The DIC is a hierarchical modeling generalization of Akaike information criterion $^{(112)}$ and Bayesian information criterion $^{(113)}$. It is particularly useful in Bayesian model selection problems where the posterior distributions of the models have been obtained by MCMC simulation. The DIC is calculated as:

$$\mathrm{DIC} = \mathrm{p_D} + \overline{\mathrm{D}} \tag{30}$$

where

$$\overline{\mathrm{D}} = \mathrm{E}[\mathrm{D}(\beta)] = -2\log\big(\mathrm{p}(\mathrm{y}|\beta)\big)$$

$$\mathrm{p_D} = \overline{\mathrm{D}} - \mathrm{D}\big(\overline{\beta}\big)$$

In the above formulation $\mathrm{D}(\beta)$ is the deviance, where y are the data, β are the unknown parameters of the model and $\mathrm{p}(\mathrm{y}|\beta)$ is the likelihood function. $\overline{\mathrm{D}}$ is the expectation which measures how well the model fits the data; the larger this is the worse the fit. $\mathrm{p_D}$ is the effective number of parameters, and $\overline{\beta}$ is the expectation of β.

Estimation Results

Similar to EB methodology, collected control sites are used to estimate the safety performance functions via FB methodology. The functions are estimated in WinBUGS free software (114).

Table 50 and Table 51 summarize the estimation results for NB and RENB models based on FB methodology. The values in the parentheses are the standard deviation of each model parameter. All models based on FB methodology are estimated in WinBUGS free software (114). The DIC values show that RENB models perform better than NB models for the EB methodology. In particular, the DIC values are lower for RENB models for each treatment type. Moreover, the safety functions confirm the nonlinear relationship between crashes and volume and road characteristics. Specifically, as the traffic volume and the section length increase the crash rate increases as well at all road sections. For median barrier installation, and improvements in the road alignment countermeasures availability of shoulder on the road side, and increasing the width of the shoulder result in a reduction in the accident rate, while for other treatment types this parameter is found to be statistically insignificant. Moreover, “lanewidth” parameter is found to be statistically significant for all treatment types except for the improvements in the road alignment countermeasure.

Table 50. NB models via FB methodology

Parameter	Negative Binomial			
	Lane width increase (acc/year/lane)	**Median barrier (acc/year/lane)**	**Road alignment (acc/year/lane/mile)**	**Guide rail (acc/year/lane)**
constant	-2.18 (0.35)	-2.86 (0.46)	-1.25 (0.54)	-3.31 (0.92)
traffic volume	0. 58 (0.06)	0.79 (0.05)	0.53 (0.06)	0.54 (0.09)
lane width	-0.19 (0.048)	-0.15 (0.06)		0.12 (0.05)
shoulder width		-0.16 (0.06)	-0.11 (0.04)	
road length	0.65 (0.12)	0.49 (0.19)		0.69 (0.14)
DIC value	887.52	611.61	629.18	257.99

Table 51. RENB models via FB methodology

Parameter	Random Effects Negative Binomial			
	Lane width increase (acc/year/lane)	**Median barrier (acc/year/lane)**	**Road alignment (acc/year/lane/mile)**	**Guide rail (acc/year/lane)**
constant	-1.83 (0.23)	-1.94 (0.37)	-1.29 (0.17)	-3.84 (0.43)
traffic volume	0.52 (0.02)	0.67 (0.04)	0.45 (0.01)	0.49 (0.06)
lane width	-0.11 (0.01)	-0.21(0.04)		0.1 (0.04)
shoulder width		-0.15 (0.05)	-0.12 (0.03)	
road length	0.76 (0.08)	0.56 (0.09)		0.75 (0.15)
DIC value	760.16	568.15	579.39	242.31

The estimation results show that compared with EB methodology, for all variables the standard deviations are lower when FB methodology is used. Moreover, EB methodology has failed to identify the impact of “lane width” parameter. Specifically, this parameter became statistically significant when FB methodology has been employed. Moreover, coefficient of the “traffic volume” has increased while coefficient of the “road length” parameter has reduced. This observation can be interpreted such that the relative impact of traffic volume on the crash rate has increased, while impact of road length has reduced.

Overall, the Deviance Information Criteria (DIC) values and the standard deviations of the model parameters show that RENB models via FB methodology are the best among all candidate models. In general, “it will make little difference whether model parameters are estimated via a classical or a Bayesian framework, when large amount of data are available for each treatment site” (*115*). However, when the number of control sites or the years of observation is limited, the modeling and estimation aspects of the statistical analysis become more and more important. In our case, we have only three years of consecutive observation for each treatment site, and number of control sites is limited. Thus, performing a fully Bayesian approach may improve the accuracy of the models.

A similar analysis was conducted for the data related to the countermeasures obtained from other states, i.e. “add shoulder” treatment. The treatment sites were obtained from Ohio HSIS database. These road sections are CLI134, COL344, HOC664 and UNI038. While performing before-and-after analysis via EB methodology 56 control sites are considered. Table 52 summarizes the NB and RENB models estimated via FB methodology. The analysis results confirm a nonlinear relationship between crash rate and volume, lane width and road length. As other models RENB model provides parameters with lower standard deviations and better model performance in terms of DIC values.

Table 52. Estimation results via FB methodology, countermeasure 2

Parameters	NB-FB	RENB-FB
constant	-2.89 (1.25)	-3.38 (1.03)
traffic volume	0.61 (0.12)	0.68 (0.05)
lane width	0.64 (0.19)	0.65 (0.12)
road length	0.26 (0.18)	0.36 (0.16)
DIC	376.49	311.37

Estimation of Crash Reduction Factors and Accident Modification Factors

After determining the best performing RENB model via FB methodology, expected CRF values are calculated for each treatment type.

$$CRF_i = 1 - \frac{\sum_t Y_{it}}{\sum_t \tilde{\mu}_{it}} \qquad (31)$$

where;
CRF_i: Crash reduction factor for treatment type *i*
t: Index for the after period
Y_{it}: Observed total number of crashes in the after period for treatment type *i*
$\tilde{\mu}_{it}$: Expected number of crashes without the treatment in the after period (obtained from RENB models)

Unlike EB methodology, in FB approach all uncertainties are accounted for in the analyses and there is no need to pre-process data to obtain SPFs and other such prior estimates of the effect of covariates on the outcome of interest. Thus, the expected number of crashes without the treatment ($\tilde{\mu}_{it}$) can be predicted directly from the estimated SPF.

Table 53 summarizes the CRF values calculated via FB methodology. Results are consistent across the road sections, with all showing a decrease in crash rates after the specific treatment, except NJ Route 71. The highest decrease in the crash rate is observed at NJ Route 322, after the improvement in vertical and horizontal alignment. Adding shoulder, increase in lane width, and installation of median barriers also causes a reduction of 21%, 18.7% and 12.1% in the accident rate, respectively. On the other hand, installation of guide rails does not reduce the accident rates, significantly. The overall decrease among different road sections changes from 12.1% to 41.5%.

Consistent with the results of (*101*), compared with FB methodology, EB methodology generally underestimates the impacts of treatment measures on the road safety, except for NJ Route 30. This result may be explained by the control site data available for this treatment. The annual crash rate on this road section is exceptionally high compared with the similar control sites. Thus, it is possible that for this specific treatment site EB methodology may not enough to overcome the data problems, which emphasize the need for improved statistical tools when there are not enough data.

Table 53. CRF values, FB methodology

Countermeasure	Road	Observed (acc/lane/mile/year)		Estimated (acc/lane/mile/year)		CRF values		
		Before	After	NB	RENB	NB	RENB	Naïve
install median barrier (countermeasure 4)	NJ Route 4	75	72	86	82	0.162	0.121	0.04
increase lane width (countermeasure 1)	NJ Route 30	40	23	30	28	0.233	0.187	0.425
improve vertical & horizontal alignment (countermeasure 4)	NJ Route 517	30	20	24	27	0.166	0.267	0.333
	NJ Route 322	12	5	7	9	0.285	0.415	0.583
install guide rail (countermeasure 4)	NJ Route 35	21	17	22	20	0.227	0.15	0.190
	NJ Route 71	8	11	10	10	-0.1	-0.1	-0.375
Add Shoulder (countermeasure 2)	CLI134R2	26	21	22	23	0.05	0.10	0.19
	COL344R1	9	5	10	11	0.49	0.55	0.44
	HOC664R1	37	35	35	36	0.01	0.02	0.05
	UNI038R1	14	12	13	14	0.08	0.17	0.14

Similarly, Table 54 summarizes the AMF values calculated from EB methodology. The individual AMF values indicate that apart from Route 71, for all treatment types the crash rate has been reduced after the countermeasure.

Table 54. AMF values, FB methodology

Countermeasure	Road	AMF values		
		NB	RENB	Naïve
Install median barrier (countermeasure 4)	NJ Route 4	0.838	0.879	0.96
Increase lane width (countermeasure 1)	NJ Route 30	0.767	0.813	0.575
Improve vertical & horizontal alignment (countermeasure 4)	NJ Route 517	0.834	0.733	0.667
	NJ Route 322	0.715	0.585	0.417
Install guide rail (countermeasure 4)	NJ Route 35	0.773	0.85	0.81
	NJ Route 71	1.1	1.1	1.375
Add Shoulder (countermeasure 2)	CLI134R2	0.95	0.90	0.81
	COL344R1	0.51	0.45	0.56
	HOC664R1	0.99	0.98	0.95
	UNI038R1	0.92	0.83	0.86

Use of CRF Values

The following is an example of how CRFs could be used in safety studies. Say, on a highway section, average number of crashes per year is 90 and average ADT is 8400. It was determined that one of the causal factors for these crashes is due to road alignment. It was decided to improve the vertical and horizontal alignments of the road section, so that sight distance will no longer be a problem for this section of the highway. ADT after the improvement is estimated to be 9500. By using the CRFs of 34.1% (average of 26.7% and 41.5%) for all crashes, estimated reduction in total crashes could be computed using the following formula:

Crashes Prevented = N x CR x [(ADT after improvement)/(ADT before improvement)]
= 90 x 0.341 x (9500/8400)
= about 35 crashes

Next section provides a comparison of the estimation results with the existing studies.

COMPARISON WITH THE EXISTING STUDIES

This section focuses on the comparison of the estimation results with the existing studies.

Countermeasure 1 – Increase Lane Width

The first countermeasure is increase in lane width. From NJ based sources, research team identified one possible safety project located along NJ Route 30.

In the literature review, no studies related to the analysis of lane width increase to improve safety and reduce accidents for the urban collectors with speed limits 25-40 mph could not be identified. Several studies conducted by Bauer et al. (53), focused on increasing the number of lanes by restriping the traveled way with narrower lanes, and/or converting all or part of the shoulder to a travel lane. The treatment sites included a total of 48.9 mi of urban freeways converted from four to five lane conversions and from five to six lane conversions. The before-and-after study included 2-year before and 7-year after data for crash frequencies. The safety performance functions estimated from EB methodology are provided in the following equations:

$$crash\,rate = e^{-12.529} * AADT^{1.378} * segment\ length \quad \text{(four-to-five lane conversion)} \qquad (32)$$

$$crash\,rate = e^{-18.13} * AADT^{1.826} * segment\ length \quad \text{(five-to-six lane conversion)} \qquad (33)$$

The analysis results of this study by Bauer et al. (53) indicated that the four-to-five lane conversions resulted in a statistically significant increase in crash frequency of 10% to 11%. The five-to-six lane conversion projects resulted in an increase in crash frequency of 3% to 7%, which was not significant. Moreover, the AMF values for the treatment sites were found to be between 1.11 for four-to-five lane conversions and 1.03 for five-to-six lane conversion projects. These results confirm that, number of accidents increased slightly after the treatment. As indicated in NCHRP Report 617, the results of this study is not applicable to other road types (54)

Apart from the above study, in February 2002 Florida Department of Transportation has conducted a very detailed survey with 42 different state DOTs in order to develop CRF values for different countermeasures. Based on this survey, the authors determined that for lane width increase the existing CRF value used in the accident analysis ranges from 0.12 to 0.4 with an average CRF value of 0.26 (57).

Countermeasure 2 – Add Shoulders

In the literature, Huang et al. (2002) (37) have studied the impacts of shoulder addition to the road sections via before-and-after study with comparison group. The project focused on conversion of roadways from four-lane to three-lane with 5’ shoulders at each side (road diet) (Figure 7) (37). The authors analyzed 12 road diets and 25 comparison sites in California and Washington cities.

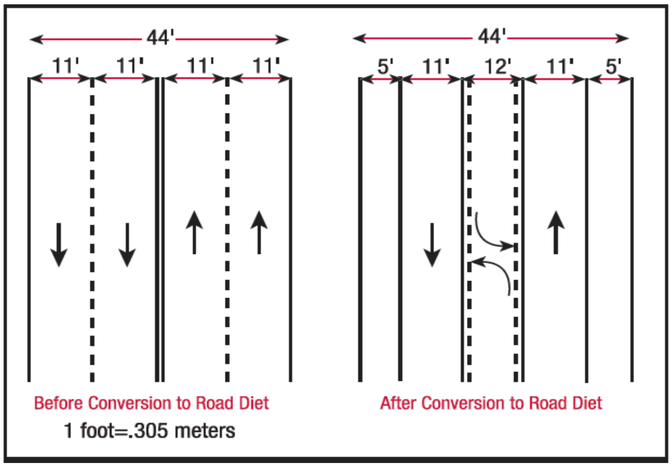

Figure 7. Representative road diet (37)

Before-and-after analysis results via yoked comparison method show that crash frequencies in the case of road diets during the after period were approximately six percent lower than at the corresponding comparison sites while road diet conversions did not affect the crash severity, or did not result in a significant change in crash types.

Pawlovich et al. (115) conducted a similar study on the impacts of the road diets. The authors investigated the road diets in Iowa via FB methodology. 15 treatment and 15 comparison sites were considered. Hierarchical Poisson models revealed 18.8% reduction in the annual crash rate. The difference between these two results was explained by the availability of a small sample size that might have led to contradictory results for the same type of safety improvement.

Apart from the above study, in February 2002 Florida Department of Transportation has conducted a very detailed survey with 42 different state DOTs in order to develop CRF values for different countermeasures. Based on this survey, the authors determined that for shoulder width addition the existing CRF value used in the accident analysis ranges from 0.08 to 0.57 with an average CRF value of 0.29 (57).

Countermeasure 3 – Removal of Trees in the Median and Border Areas

The research team has found a recent study performed in California regarding existence/nonexistence of trees in the median areas (85). Since this study was not a before-and-after study, the authors did not calculate CRF values. Instead, accident rates depending on the existence of the trees in the median were calculated. The collision, road characteristics and traffic volume data are available for all study sections for the six-year period from January 1996 through December 2001. The final dataset includes 24 road sections with trees in the median, and 12 road sections with no trees in the median areas. The study results revealed that, on the whole, hit-object accidents increase in the presence of median trees. The presence of median trees is obviously associated with more hit-tree collisions, and these are largely (but not entirely) balanced by fewer collisions with utility poles and similar objects. Overall, the accident rate along the road sections with trees in the median was found to be 0.18, while the accident rate without the trees in the median was 0.12. The accident rates were calculated only for the left-side crashes.

AASHTO (86) recommends that the trees should be removed or shielded if there is an area that is known to have a lot of accidents. If the area is not known to have many accidents then the trees will probably be allowed to stay. Also AASHTO (86) mentions being aware of large trees by themselves near to the road. Smaller vegetation with multiple trunks may also be considered a fixed object due to their extent. According to the AASHTO Guide, accidents on major highways with trees are rare, unlike rural roads, where this type of accident is more prevalent. The best types of protection against motorists hitting trees are: pavement markings, signs, delineators and roadway improvements.

Moreover, an NCHRP project conducted by McGinnis (88), states that very little information is available on the frequency, angle, and length of roadside encroachments by making it difficult to establish relationships between clear zone width and safety. Without this information, it is found to be "difficult to develop clear zone guidelines that consider both the benefits and costs of providing wider recovery zones" (pp. 3-6, NCHRP (88)).

Countermeasure 4 - Installation of Guide Rails, and Vertical & Horizontal Geometry Changes to Improve Sight Distances

The final countermeasure is "the installation of guide rails and vertical and horizontal geometry changes". From NJ related sources, research team identified 5 different possible safety projects. Among these road sections, NJ Route 4 is improved via median barrier installations, NJ Route 35 and NJ Route 71 are improved via guide rail installations, while vertical and horizontal alignments are implemented on NJ Route 517 and NJ Route 322 to improve sight distance and reduce accidents.

Installation of Median Barriers

From NJ based sources research team has identified one road section regarding median barrier installation, NJ Route 4.

In the literature Hovey et al. (55) has investigated the impacts of median barrier installations on the road safety. The authors included different road sections in the estimation of safety performance functions via EB methodology.

The safety performance function estimated from EB methodology is as follows:

$$crash\ rate = exp\left(-19.64 + D_y + 1.995 * lnAADT\right) \tag{34}$$

where;
D_y: Offset value for the duration of the time period

Based on the estimation results the CRF value for median barrier installation was found to be 0.863 with standard deviation of 0.029. The reduction in the crash rate was found to be statistically significant.

Apart from the above study, in February 2002 Florida Department of Transportation has conducted a very detailed survey with 42 different state DOTs in order to develop CRF values for different countermeasures. Based on this survey, the authors determined that for median barrier installation the existing

CRF value used in the accident analysis ranges from 0.05 to 0.36 with an average CRF value of 0.19 (57).

Installation of Guide Rails

In the literature Hovey et al. (55) has investigated the impacts of removing guardrails on the road safety. Unfortunately, the authors coupled this measure with the “flatten slope” countermeasure. Thus the safety performance functions and the CRF values reflect the joint impact of these two countermeasures. The authors included different road sections in the estimation of safety performance functions via EB methodology.

The safety performance function estimated from EB methodology is as follows:

$$crash\ rate = exp\left(-6.4369 + D_y + 0.5703 * lnAADT + 0.6545 * lnTrcks\right) \quad (35)$$

where;
D_y: Offset value for the duration of the time period
$Trcks$: Truck volume

Based on the estimation results the CRF value for total crashes after flattening slopes and removing guardrail was found to be 0.424 with standard deviation of 0.575.

In February 2002 Florida Department of Transportation has conducted a very detailed survey with 42 different state DOTs in order to develop CRF values for different countermeasures. Based on this survey, the authors determined that for guide rail installation the existing CRF value used in the accident analysis ranges from 0.04 to 0.19 with an average CRF value of 0.11 (57). This result is consistent with the CRF value for NJ Route 35, but higher than the CRF value of NJ Route 71. However, the total number of accidents along this road section is quite low and this increase can be solely due to the normal stochastic fluctuations in the system.

Vertical & Horizontal Geometry Changes to Improve Sight Distances

In the literature Hovey et al. (55) has investigated the impacts of median barrier installations on the road safety. The authors included different road sections in the estimation of safety performance functions via EB methodology.

The safety performance function estimated from EB methodology is as follows:

$$crash\ rate = exp\left(-2.94 + D_y + 0.54 * lnAADT + 0.88 * lnSL + SYS\_CL\right) \quad (36)$$

where;

D_y: Offset value for the duration of the time period
SL: Section length
SYS_CL: -0.82 for SYS_CL = A (Auxiliary), -0.18 for SYS_CL = L (Local) and 0 for SYS_CL = M (Major),

Based on the estimation results the CRF value for total crashes after flattening slopes and removing guardrail was found to be 0.196 with standard deviation of 0.191.

Apart from the above study, in February 2002 Florida Department of Transportation has conducted a very detailed survey with 42 different state DOTs in order to develop CRF values for different countermeasures. Based on this survey, the authors determined that for vertical & horizontal geometry changes the existing CRF value used in the accident analysis ranges from 0.35 to 0.59 with an average CRF value of 0.45 for horizontal geometry changes, and ranges from 0.4 to 0.57 with an average CRF value of 0.49 for vertical geometry changes (57).

Recommendations

Table 55 summarizes the recommended CRF values in the literature and the estimated CRF values in this study. The individual CRF values and their relative order among different countermeasures are similar to each other. In particular, improvements in vertical and horizontal alignment are found to result in highest reductions in the accident rate, followed by adding shoulders, median barrier installation, lane width increase, and guide rail installation. However, impacts of guide rail installation were mixed because for some sites it did not show positive results.

Table 55. Summary of CRF values

Countermeasure		CRF - in the Literature	CRF – Estimated in this study
Countermeasure 1 - Increase lane width		0.1-0.11 (4-to-5 lane conversion) (53) 0.03-0.07 (5-to-6 lane conversion) (53) 0.12-0.4 (avg 0.24) (57)	0.187
Countermeasure 2 - Add shoulder		0.06 (37), 0.188 (115), 0.08-0.58 (avg 0.29) (57)	0.02, 0.55
Countermeasure 3 - Remove trees in the median and border		0.18 (with trees in the median) 0.12 (no trees in the median) (85)	
Countermeasure 4	**Install median barrier**	0.863 (std:0.029) (55), 0.05-0.36 (avg 0.19) (57)	0.121
	Install guide rail	0.424 (std 0.575) (55), 0.04-0.19 (0.11) (57)	-0.1, 0.15
	Vertical & horizontal changes	0.196 (std 0.191) (55), 0.35-0.59 (avg 0.45, horizontal improvement) (57), 0.4-0.57 (avg 0.49 vertical improvement) (57)	0.267, 0.415

It should be noted that the total benefit of implementing a countermeasure includes the costs saved resulting from the number of crashes or crash severity reductions; and the total cost of implementing a countermeasure includes construction and possibly maintenance costs. The determination of benefits from countermeasures depends on projected crash reductions, which is calculated as the expected number of crashes without the countermeasures multiplied by a CRF. Thus, CRF is simply a quantitative statement of the percentage of crashes that a countermeasure is expected to reduce.

Moreover, when considering individual CRF values, the transportation planner should keep in mind that the estimated values depend on the specific characteristics of the treatment site, reference groups considered in the estimation process, time period included in the analysis and the statistical tools used to calculate the CRF values.

CONCLUSIONS

The main goal of this study is to quantify the impacts of different treatments on roadway operations and safety on urban collectors with access.

The safety treatments considered in this research are:

1. Increase in lane widths (10' or 11' to 12'),
2. Construction of 4,6,8, or 10 foot shoulders,
3. Removal of trees in median and border areas,

4. Installation of guide rails, and vertical & horizontal geometry changes to improve sight distances.

A number of sites along 25-40 mph urban collectors with access where safety improvements have been implemented were determined in close collaboration with NJDOT. The treatment sites required to conduct before-and-after analysis several different data sources were considered. The data sources include New Jersey Department of Transportation, Highway Safety Information System (HSIS), Ohio Department of Transportation, California Highway Patrol and Caltrans. From these sources, research team has identified seven different treatment sites from New Jersey, six different treatment sites from Ohio, and two different treatment sites from California.

Once the site selection process was completed, historical crash data for each of these sites were collected. Then, before-and-after analysis was conducted to investigate the impacts of different treatments on road safety. While conducting before and after analysis for the treatment sites four different methodologies were considered:

1. The simple (or naive) before-and-after study method
2. The before-and-after study with comparison group method
3. The before-and-after study with Empirical Bayes (EB) method
4. The before-and-after study with Full Bayes (FB) method

The before and after analysis conducted using these four different methodologies revealed that improvements in vertical and horizontal alignment resulted in highest reductions in the accident rate, followed by adding shoulders, median barrier installation, lane width increase, and guide rail installation. However, impacts of guide rail installation were mixed because for some sites it did not show positive results.

In traffic safety analysis, EB methodology is usually the first choice, since it deals with several different problems faced by naïve and control-group approaches, and it is relatively easy to implement. In recent years, with the advances in numerical methods, FB approach has become a strong statistical tool in safety analysis. FB approach has many advantages over EB approach. In FB analysis, prior information and all available data are seamlessly integrated into posterior distributions on which practitioners can base their inferences. All uncertainties are thus accounted for in the analyses and there is no need to pre-process data to obtain Safety Performance Functions and other such prior estimates of the effect of covariates on the outcome of interest. In this light, FB methods may well be less costly to implement and may result in safety estimates with more realistic standard errors.

However, it should be noted that, it will typically make little difference whether model parameters are estimated using EB or FB framework when a large amount of data are available for each site; in fact, when data are plentiful, a comparison of simple averages of the crashes before the intervention to those after it might suffice and provide reliable information about the impact of the intervention as long as the study includes both a treatment group and a comparison group of sites. The modeling and estimation components of the statistical analysis become more important when either the number of sites or the years of observation available for each site are small. In that case, both the classical and the Bayesian paradigms can lead to erroneous conclusions unless the model is reasonably well specified (115). Moreover, there may be some cases that one particular countermeasure is effective at someplace, and ineffective someplace else, leading different results. In this case, transportation planner should investigate these countermeasures in detail and consider several different locations where the countermeasures are implemented.

Moreover, when specifying the model to predict the crash records at the treatment site via EB or FB methodology, the researcher needs to consider different correlations in the dataset. In general, two types of correlations may be observed in crash record data: correlation among observations from the same section across time (temporal effects) and correlation among different sections from the same time period (spatial effects). Thus, when developing statistically advanced models (such as, negative binomial and random effects negative binomial models) the researcher should consider the nature of the crash data available. The data used in this research is somewhat limited in its coverage of geographic and geometric effects. Moreover, the time period used for the analysis covers three consecutive years. In situations like these with sections that are close to each other geographically, and limited time periods, the impacts temporal and spatial effects is likely to be minimal.

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APPENDIX A – DERIVATION OF EMPIRICAL BAYES METHODOLOGY

This section focuses on calculation of CRF's via Empirical Bayes (EB) methodology. Unlike other methodologies, EB takes care of regression-to-mean, crash migration, and maturation problems.

The Empirical Bayes (EB) estimation in roadway safety analysis has been adopted by several researchers (45, 46). The underlying theory of the EB analysis is that the crash rate at a specific site comes from a distribution that can be estimated by collecting crash data from a number of similar sites. EB estimation combines information about this distribution with data collected from a treatment site to offset the impact of a temporary, random increase in crashes.

In EB, evaluation of the effect of a treatment, the change in safety for a given crash type at a treated intersection is calculated as the difference between the mean number of crashes that would have occurred in the "after" period without the treatment and mean number of reported crashes in the after period. While calculating the number of accidents for the "after" period, number of crashes that would be expected in "before" period at locations with characteristics similar to the treatment site is estimated. This function gives an estimate of the average accidents/ km-year, as a function of some trait values (e.g., ADT, lane width, etc) and several regression parameters.

The negative binomial distribution has been shown to be a reasonable model for the calculating the number of crashes from year to year or site to site. Assuming that the number of crashes at each individual site can be modeled as a Poisson random variable, the negative binomial model can be derived as a mixture of Poisson random variables with different rates.

The basic formula for the EB estimate of the mean number of crashes for a site, based on the negative binomial model is:

$$\hat{\mu}_{EB} = \alpha\mu_{NB} + (1-\alpha)K \qquad \text{(A. 1)}$$

where;

$$\alpha = \frac{\mu_\lambda}{\mu_\lambda + \sigma_\lambda^2} = \frac{\mu_{NB}}{\sigma_{NB}^2}$$

μ_λ : mean of crash rates

σ_λ^2 : variance of crash rates

μ_{NB} : mean of the negative binomial distribution

σ_{NB}^2 : variance of the negative binomial distribution

K: site count

The general form for the model in negative binomial regression is:

$$\mu = \exp(\beta_0 + \sum \beta_i X_i) \qquad \text{(A. 2)}$$

where μ is the mean and the X_i's are the traits that are used to predict the mean.

The next step in the process of calculating CRFs is to project what the crash rates for the treatment sites would have been if the treatment had not been applied. The projections are based on the assumption that crash rates for an individual site maintain the same proportion to the average crash rates for all sites across time. The projections are calculated by picking a base year from the time periods before construction and normalizing the mean crash rates for all time periods to the mean crash rate for the base. The projections of crash rates for the post construction period are independent of the choice of the base year. The normalized mean crash rate for year *y* is denoted by C_y and is calculated as $C_y = \lambda_y / \lambda_b$ where λ_y and λ_b are the predicted crash rates from the regression model for year *y* and the base year.

The base value for predicting the expected post treatment crash rate is the weighted average of the EB estimates of crash rates of all years prior to the treatment. The formulae for the estimate of the base rate and an estimate of the sampling variance are:

$$\hat{\lambda}_b = \frac{\sum_{before} \hat{\lambda}_{EB,y}}{\sum_{before} C_y} \qquad \text{(A. 3)}$$

$$V\left(\hat{\lambda}_b\right) = \frac{\sum_{before} V\left(\hat{\lambda}_{EB,y}\right)}{\left(\sum_{before} C_y\right)^2} \qquad \text{(A. 4)}$$

The projected crash rate for the treatment site in year *z* after the treatment is given by the following equations:

$$\hat{\lambda}_z = C_z \hat{\lambda}_b \qquad \text{(A. 5)}$$

$$V\left(\hat{\lambda}_z\right) = C_z^2 V\left(\hat{\lambda}_b\right) \qquad \text{(A. 6)}$$

The crash reduction factors are calculated by comparing the actual crash counts after the treatment with the projected crash rates as calculated above. The crash reduction factor is derived from the index of effectiveness denoted by θ. The index of effectiveness is the crash rate for an improved site divided by the crash rate for an untreated site. The maximum likelihood estimate (MLE) of the index of effectiveness is

$$\hat{\theta} = \frac{\sum_{after} K_z}{\sum_{after} \hat{\lambda}_z} \qquad \text{(A. 7)}$$

Since MLE of θ is the ratio of random variables, there is an inherent bias, estimated by:

$$\hat{b} = 1 + \frac{\sum_{after} \hat{\lambda}_z}{\sum_{after} V\left(\hat{\lambda}_z\right)} \qquad \text{(A. 8)}$$

The unbiased estimate of θ is given by

$$\hat{\theta}_u = \frac{\hat{\theta}}{\hat{b}} \tag{A. 9}$$

$$V\left(\hat{\theta}_u\right) = \left(\frac{\hat{\theta}}{\hat{b}}\right)^2 \left(\frac{1}{\sum\limits_{after} K_z} + \frac{\sum\limits_{after} V\left(\hat{\lambda}_z\right)}{\left(\sum\limits_{after} \hat{\lambda}_z\right)^2} \right) \tag{A. 10}$$

The estimate of crash reduction factor is then calculated as $CRF = 100\left(1 - \hat{\theta}_u\right)$ with the standard error given by $100\sqrt{V\left(\hat{\theta}_u\right)}$. The standard error represents the maximum error that will occur.

APPENDIX B – CONTROL SITES FOR BEFORE-AND-AFTER ANALYSIS VIA COMPARISON GROUP

Countermeasure 1 – Increase Lane Width

NJ based Road Sections

In order to conduct before-and-after analysis via control groups, research team has identified eight different road sections. Table B. 1 summarizes the road characteristics of the control sites. Similarly, Table B. 2 summarizes the accident information for these control sites.

Table B. 1 Control sites for route 30

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
Route 511	Urban Collector	10.2-12.7 16-16.9	35-45	2	11' - 12'	0	0'
Route 527	Urban Collector	2.9-4.1 22.4-26.6 39.1-40	35-50	2	12' - 15'	0	2' - 6'
Route 617	Urban Collector	0.9-1.0 2.7-2.9 3.2-3.7	40-45	1-3	11' - 20'	0' - 8'	0' - 11'
Route 525	Urban Collector	0.7-2.7	40	2	11' - 15'	0'	0' - 2'
Route 540	Urban Collector	32.5-34.5	35-45	2-5	12' - 16'	0'	0' - 8'
Route 579	Urban Collector	0.1-0.8 1.3-1.6 15-15.6 36.7-37	35-40	2	12' - 15'	0'	0' - 6'
Route 620	Urban Collector	0-1.6 2.9-4.8	35-40	2	10' - 12'	0'	2' - 4'
Route 581	Urban Collector	16.3-17.2	40	2	12'	0'	0

Table B. 2 Accident information for control sites, route 30

Route	Before			After			Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality		Total	Injury	Fatality	Total	Injury	Fatality
511-1	6	2	0	5	2	0	**620-2**	4	2	0	6	1	0
511-2	4	1	0	6	2	0	**525**	21	10	1	18	4	0
527-1	12	8	1	11	4	0	**540**	17	12	1	24	12	1
527-2	14	7	0	10	4	0	**579-1**	6	1	1	9	3	0
527-3	18	8	0	17	7	0	**579-2**	13	7	3	20	10	0
617-1	100	70	10	130	40	0	**579-3**	5	0	0	10	2	0
617-2	80	45	5	40	10	0	**579-4**	13	7	0	10	7	3
617-3	38	26	0	32	10	0	**581**	3	0	0	9	6	0
620-1	6	2	1	14	3	0							

After identifying the control sites and accident information on these sites, following the estimation process provided in Section 3 – eqn-(2), before-and-after analysis results via control groups is conducted. Table b. 3 presents the individual control rates.

Table b. 3 Control rates, route 30

Route	Total	Injury	Fatality	Route	Total	Injury	Fatality
511-1	0.95	0.76	NA	**620-2**	1.57	0.44	NA
511-2	1.25	1.5	NA	**525**	0.83	0.42	NA
527-1	0.98	0.55	NA	**540**	1.42	1	NA
527-2	0.73	0.58	NA	**579-1**	1.42	5	NA
527-3	0.96	0.81	NA	**579-2**	1.55	2	NA
617-1	1.27	0.5	NA	**579-3**	2.53	NA	NA
617-2	0.53	0.18	NA	**579-4**	0.91	0.71	NA
617-3	0.82	0.35	NA	**581**	2.56	NA	NA
620-1	2.41	1.75	NA				
Average	**1.33**	**1.103**	**NA**				

Countermeasure 2 – Add Shoulders

Analysis Results from Other States

From HSIS data, the research team has identified four possible safety projects. For each of these treatment sites, control sites have been identified from HSIS database. Table B. 4, Table B. 5, Table B. 6 and Table B. 7 summarizes the road characteristics of the control sites for each treatment site.

Similarly, Table B. 8, Table B. 9, Table B. 10 and Table B. 11 provide the accident information for each control site.

Table B. 4 Control sites for Ohio route 664

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
ATH0278R	Urban Collector	3.15-3.66	35	2	10.5	0’	0’
AUG0066R	Urban Collector	0.5-1.46	35	3	12	0’	0’
CRA0061R	Urban Collector	7.37-8.26	35	4	10-12.5	0’	0’
HAM0561R	Urban Collector	3.04-3.24	35	4	12	0’	0’
LUC0064R	Urban Collector	0.52-1.42	35	2	12	0’	0’
MER0118R	Urban Collector	9.21-9.6	35	2	12	0’	0’
SUM0241J	Urban Collector	9.88-10.37	35	2	11	0’	0’

Table B. 5 Control sites for Ohio route 134

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
ATB0531R	Urban Collector	0-0.71	25	4	10	0’	0’
LAK0174R	Urban Collector	5.15-5.4	25	2	13.5	0’	0’
LIC0040R	Urban Collector	15.3-15.65	25	4	10.5-12.5	0’	0’
LIC0661R	Urban Collector	0.42-1.27	25	2	11.5-15	0’	0’
LUC0064R	Urban Collector	0-0.32	25	2	12-15	0’	0’
SEN0613R	Urban Collector	0.16-0.57	25	2	10-15	0’	0’
SUM0162R	Urban Collector	8.83-9.26	25	2	14-15	0’	0’

Table B. 6 Control sites for Ohio route 344

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
COL0164R	Urban Collector	24.46-24.83	25	2	15	0’	0’
CRA0030R	Urban Collector	20.39-20.7	25	2	14	0’	0’
CUY0291R	Urban Collector	1.51-2.05	25	4	13	0’	0’
HIG0247R	Urban Collector	11.88-12.17	25	2	14	0’	0’
JAC0776R	Urban Collector	12.19-12.59	25	2	14-15	0’	0’
MER0219R	Urban Collector	8.86-9.69	25	2	13-15	0’	0’

Table B. 7 Control sites for Ohio route 38

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
PIK220	Urban Collector	8.34-8.57	25	2	18	0’	0’
PIC316	Urban Collector	13.03-13.68	25	2	17-19	0’	0’
LUC64	Urban Collector	0.18-0.32	25	4	15	0’	0’
LIC661	Urban Collector	0.42-0.86	25	2	15	0’	0’
ERI101	Urban Collector	3.17-3.4	25	2	18	0’	0’
COL165	Urban Collector	5.09-5.25	25	2	16.5	0’	0’
COL164	Urban Collector	25.31-25.69	25	2	16-19	0’	0’
AUG274	Urban Collector	3.75-4.05	25	2	15-17	0’	0’

Table B. 8 Accident information for control sites, Ohio route 664

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
278	22	10	0	20	2	0
66	10	8	0	13	1	0
61	10	4	0	9	2	0
561	45	35	0	95	30	0
64	12	6	0	9	3	0
118	11	4	0	13	9	0
241	18	12	0	41	22	0

Table B. 9 Accident information for control sites, Ohio route 134

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
278	8	1	0	4	1	0
66	36	8	0	40	16	0
61	49	17	0	11	3	0
561	19	2	0	22	2	0
64	22	3	0	25	6	0
118	28	0	0	38	13	0
241	12	5	0	14	7	0

Table B. 10 Accident information for control sites, Ohio route 344

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
164	22	5	0	19	11	0
30	45	35	0	52	26	0
291	41	11	0	20	7	0
247	10	0	0	10	0	0
776	23	7	0	23	3	0
219	14	2	0	17	6	0

Table B. 11 Accident information for control sites, Ohio route 38

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
220	78	9	0	65	9	0
316	8	0	0	17	3	0
64	79	14	0	71	14	0
661	30	2	0	27	2	0
101	23	0	0	31	8	0
165	19	6	0	63	6	0
164	34	13	0	37	5	0
274	27	7	0	37	7	0

Based on the accident information provided above, Table B. 12, Table B. 13, Table B. 14, and Table B. 15 provide the individual control rates for each of the control sites.

Table B. 12 Control rates, Ohio route 664

Route	Total	Injury	Fatality
278	0.88	0.2	NA
66	1.2	0.67	NA
61	0.82	0.42	NA
561	2.15	0.9	NA
64	0.73	0.67	NA
118	1.13	2.17	NA
241	2.26	1.83	NA
average	1.31	0.98	

Table B. 13 Control rates, Ohio route 134

Route	Total	Injury	Fatality
531	0.50	1.00	NA
174	1.18	2.33	NA
40	0.24	0.18	NA
661	1.15	1.33	NA
64	1.23	1.50	NA
613	1.36	NA	NA
162	1.33	1.67	NA
average	1.00	1.34	

Table B. 14 Control rates, Ohio route 344

Route	total	injury	fatality
164	0.81	2.33	NA
30	1.15	0.76	NA
291	0.5	0.73	NA
247	1	NA	NA
776	1	0.25	NA
219	1.12	2.25	NA
average	0.93	1.264	

Table B. 15 Control rates, Ohio route 38

Route	Total	Injury	Fatality
220	0.83	1.33	NA
316	2.1	NA	NA
64	0.9	0.75	NA
661	0.92	1	NA
101	1.33	NA	NA
165	3.16	0.5	NA
164	1.07	0.4	NA
274	1.4	1	NA
average	1.46	0.83	

Countermeasure 4 - Installation of Guide Rails, and Vertical & Horizontal Geometry Changes to Improve Sight Distances

NJ Based Road Sections

Table B. 16, Table B. 17, Table B. 18, Table B. 19 and Table B. 20 summarize the road characteristics of the control sites for each treatment type. Similarly, Table B. 21, Table B. 22, Table B. 23, Table B. 24 , and Table B. 25 present the accident information for each of these control sites. Finally, Table B. 26, Table B. 27, Table B. 28, Table B. 29 and Table B. 30 provide the individual control rates for each of the control sites estimated based on the annual crash rates.

Table B. 16 Control Sites, route 4

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
511	Urban Collector	10.4-11	40	2	12	0’	2’
525	Urban Collector	0.7-2.7	40	2	11-12	0’	0-2’
620	Urban Collector	0.6-1.16 2.9-3.5	40	2	12	0’	2’
512	Urban Collector	14.3-15.1	40	2	11-13	0’	0-2’
514	Urban Collector	8.9-9.7	40	2	12	0’	0-2’
518	Urban Collector	13.7-14.1	40	2	12	0’	0’

Table B. 17 Control sites, route 35

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
610	Urban Collector	0.6-1	40	2	12	0’	1-2’
606	Urban Collector	0.3-1.3	40	2	11.5-13	0’	0-2’
514	Urban Collector	28.6-29.1	45	2	12	0’	0’
614	Urban Collector	12.2-12.7	40	2	11	0’	1’
615	Urban Collector	11.5-11.9	45	2	11	0’	2-3’
619	Urban Collector	3.45-4.2	45	2	12-12.5	0’	0-1’

Table B. 18 Control sites, route 71

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
605	Urban Collector	0-1	35	2	13.5	0’	2-4’
514	Urban Collector	26.8-27	35	2	13	0’	0’

Table B. 19 Control sites, route 517

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
511	Urban Collector	10.4-11	40	2	12	0’	2’
525	Urban Collector	0.7-2.7	40	2	11-12	0’	0-2’
620	Urban Collector	0.6-1.16 2.9-3.5	40	2	12	0’	2’
512	Urban Collector	14.3-15.1	40	2	11-13	0’	0-2’
514	Urban Collector	8.9-9.7	40	2	12	0’	0-2’
518	Urban Collector	13.7-14.1	40	2	12	0’	0’

Table B. 20 Control sites, route 322

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
511	Urban Collector	14-14.7	45	2	12	0’	2’
512	Urban Collector	12.2-13.2	45	2	10-11	0’	0-2’
514	Urban Collector	2.7-3.9	45	2	10-12	0’	0-2’
518	Urban Collector	13.7-15	45	2	11-12	0’	0’-3’
522	Urban Collector	10.5-13	45	2	12	0’	2’
533	Urban Collector	19-22.1	45	2	12	0’	0’

Table B. 21 Accident information, route 4

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
511	19	7	0	21	6	0
525	21	10	0	22	6	0
620-1	16	4	0	48	9	0
620-2	12	5	0	23	3	0
512	6	1	0	13	4	0
514	16	4	0	26	6	0
518	20	5	0	25	8	0

Table B. 22 Accident information, route 35

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
610	28	15	0	20	10	0
606	37	14	0	49	24	0
514	80	42	0	62	24	0
614	10	0	0	14	10	0
615	15	5	0	10	0	0
619	32	16	0	29	16	0

Table B. 23 Accident information, route 71

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
605	22	12	0	18	6	0
514	95	28	0	85	43	0

Table B. 24 Accident information, route 517

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
511	17	6	0	21	7	0
525	21	9	0	15	6	0
620-1	14	5	0	14	4	0
620-2	12	0	0	28	10	0
512	6	0	0	10	5	0
514	16	5	0	24	8	0
518	15	0	0	28	10	0

Table B. 25 Accident information, route 322

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
511	9	1	0	9	1	0
512	21	10	0	20	7	0
514	8	3	0	14	7	0
518	15	2	0	23	8	0
522	16	14	0	15	7	0
533	16	6	0	22	6	0

Table B. 26 Control rates, route 4

Route	Total	Injury	Fatality
511	1.15	0.84	NA
525	1.03	0.58	NA
620-1	2.5	2.62	NA
620-2	2.04	0.56	NA
512	2.07	3.37	NA
514	1.6	1.4	NA
518	1.35	1.18	NA
average	1.677143	1.507143	NA

Table B. 27 Control rates, route 35

Route	Total	Injury	Fatality
610	0.77	0.67	NA
606	1.34	1.71	NA
514	0.77	0.57	NA
614	1.3	NA	NA
615	0.79	NA	NA
619	0.92	1.01	NA
average	**0.98**	**0.99**	**NA**

Table B. 28 Control rates, route 71

Route	Total	Injury	Fatality
605	0.85	0.5	NA
514	0.89	1.55	NA
average	0.87	1.025	NA

Table B. 29 Control rates, route 517

Route	Total	Injury	Fatality
511	1.35	1.36	NA
525	0.72	0.67	NA
620-1	0.96	0.71	NA
620-2	2.63	NA	NA
512	1.64	NA	NA
514	1.45	1.7	NA
518	1.68	NA	NA
average	**1.49**	**1.11**	**NA**

Table B. 30 Control rates, route 322

Route	Total	Injury	Fatality
511	1.06	0.66	NA
512	0.95	0.69	NA
514	1.82	2.3	NA
518	1.59	3.67	NA
522	0.95	0.51	NA
533	1.33	0.92	NA
average	1.28	1.45	NA

Analysis Results from Other States

Table B. 31 summarizes the road characteristics of the control sites for the Ohio Route 676. Similarly, Table B. 32 and Table B. 33 provide the total accident information and individual crash rates for these control sites.

Table B. 31 Control sites, Ohio route 676

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width
LIC310	Urban Collector	4.96-8.56	35	2	10	0’	8’
FUL20	Urban Collector	16.94-18.04	45	2	18	0’	8’
DEF2	Urban Collector	9.7-13.3	45	2	11.5-12	0’	2’
RIC13	Urban Collector	2.54-4.54	45	2	12	0’	2’

Table B. 32 Total accident information, Ohio route 676

Route	Before	After
310	19	24
20	21	14
2	13	14
13	17	15

Table B. 33 Control rates, Ohio route 676

Route	Total
310	1.28
20	0.67
2	1.08
13	0.86
Average	0.9725

APPENDIX C – TUTORIAL ON CONDUCTING A BEFORE-AND-AFTER ANALYSIS

This section focuses on how to conduct before-and-after analysis via naïve and control group approach using specific examples, and on how to calculate the CRF & AMF values based on the estimated before-and-after crash rates.

For illustration purposes each analysis type is conducted using Route 4 (Table C. 1).

Table C. 1 Characteristics of route 4

Route	Road Type	Mile Post	Speed Limit	No Lanes	Lane Width	Med. Width	Shoulder Width	Start Date	End Date
Route 4	Urban Arterial	1.82-2.7	40	2-4	11	6	5	12/27/2000	7/25/2003

Before-and-After Analysis via Naïve Approach

Before-and-after analysis via Naïve approach requires only the crash counts in the before and after periods of the treatment site.
Step 1: Identify the before and after periods:

Since the treatment site was under construction between years 2000 and 2003, the before period is selected as years 1997-1999, and the after period is selected as 2004-2006.

Step 2: Calculate the crashes during before and the after period

From the accident database available on NJDOT website, the annual accidents during before and after periods are counted (Table C. 2).

Table C. 2 Accident counts, route 4

Period		Before			After		
Year		1997	1998	1999	2004	2005	2006
Total accidents (acc/section)	**Total**	124	139	132	142	113	125
Injuries (acc/section)	**Total**	69	52	40	52	53	46
Fatalities (acc/section)	**Total**	1	1	0	1	0	0

Step 3: Calculate the CRF and AMF values.

CRF:

$$CRF = 1 - \frac{\sum_{after} accident}{\sum_{before} accident} = 1 - \frac{142 + 113 + 125}{124 + 139 + 132} = 0.038$$

AMF:

$$AMF = \frac{\sum_{after} accident}{\sum_{before} accident} = \frac{142 + 113 + 125}{124 + 139 + 132} = 0.962$$

Before-and-After Analysis via Control Group Approach

Before-and-after analysis via control group approach requires control sites with no treatment and similar road characteristics.

Step 1: Identify the control sites with similar road characteristics and count the annual accidents on these road sections during the before and after period (Table C. 3).

Table C. 3 Accident counts, control sites for route 4

Route	Before			After		
	Total	Injury	Fatality	Total	Injury	Fatality
511	19	7	0	21	6	0
525	21	10	0	22	6	0
620-1	16	4	0	48	9	0
620-2	12	5	0	23	3	0
512	6	1	0	13	4	0
514	16	4	0	26	6	0
518	20	5	0	25	8	0

Step 2: For each control site calculate the crash rate.

For instance, for control site Route 511 total annual accidents during the before period is 19 acc/lane/mile/year, and 21 acc/lane/mile/year during the after period. Thus the crash rate is:

$$crash\ rate = \frac{(annual\ accident)_{after}}{(annual\ accident)_{before}} = \frac{21}{19} = 1.11$$

This value refers to the first entry of Table C. 4. Using this formulation crash rates are calculated for each control site and Table C. 4 is obtained.

Table C. 4 Crash rates for the control sites

Route	Total	Injury	Fatality
511	**1.11**	0.84	NA
525	1.03	0.58	NA
620-1	2.5	2.62	NA
620-2	2.04	0.56	NA
512	2.07	3.37	NA
514	1.6	1.4	NA
518	1.35	1.18	NA
average	1.677	1.507	NA

Step 3: After calculating the crash rates for each control site, take the average of individual rate and obtain the mean crash rate:

$$mean\ crash\ rate = \frac{1.11 + 1.03 + 2.5 + 2.04 + 2.07 + 1.6 + 1.35}{7} = 1.677$$

Step 4: Using the mean crash rate calculate the accidents in the after period. This value would be the accidents that would occur if the treatment had not been implemented.

$$(expected\ accidents)_{after} = (mean\ crash\ rate) * (observed\ accidents)_{before}$$
$$(expected\ accidents)_{after} = 1.677 * 150 = 252\ acc/year$$

This value refers to the bold value under the “Expected Accidents After” column (Table C. 5).

Table C. 5 Before-and-after analysis results

Route	Accident	Observed accidents (acc/year)		Comparison Method			
		Before	After	Before	Rate	Expected Accidents After	CRF
4	**Total**	150	144	150	1.68	**252**	0.4286
	Injury	62	57	62	1.51	94	0.3912

Step 5: Calculate the CRF and AMF values.

CRF:

$$CRF = 1 - \frac{\sum_{after} expected\ accidents}{\sum_{after} observed\ accident} = 1 - \frac{144}{252} = 0.4286$$

AMF:

$$AMF = \frac{\sum_{after} accident}{\sum_{before} accident} = \frac{144}{252} = 0.5714$$

Before-and-After Analysis via Empirical Bayes Approach

Before-and-after analysis via EB approach requires safety performance function and the road characteristics of the treatment site. In Section 10, safety performance function based on negative binomial (NB) model was estimated as shown in Table C. 6.

Table C. 6 NB model based on EB methodology

Parameters	Constant	Traffic volume	Shoulder width	Road length
	-3.71	0.7	-0.016	0.49

Based on this result, the functional form of the NB model is:

$$crash\,rate = exp\big(-3.71 + 0.7 * ln(TrafficVolume) - 0.016 * ln(Shoulder\ width) + 0.49 * ln(Road\ Length)\big)$$

Dispersion parameter: 0.06
where:
$crash\,rate$: Annual crash rate (acc/year/lane/direction)
$TrafficVolume$: Annual average traffic volume (veh/hour/lane/direction)
$Shoulder\ width$: Length of the shoulder width (ft)
$Road\ Length$: Length of the road section (ft)
$ln(\quad)$: Natural logarithm of the variable

Using the above crash rate function and the dispersion parameter annual crash rate can be estimated as follows:

Step 1: Determine the road characteristics of the treatment site

From straight line diagrams and the traffic volume information available from NJDOT website road characteristics can be determined (Table C. 7).

Table C. 7 Road characteristics, route 4

Characteristics	Traffic volume	Shoulder width	Road length	No of Lanes
	45780 (1997) 46924 (1998) 48097 (1999)	5	0.88	2

Step 2: Using the NB model calculate the crash rate based on EB methodology
Year 1997:

$$crash\ rate = exp\left(-3.71 + 0.7 * ln(45780) - 0.016 * ln(5) + 0.49 * ln(0.88)\right)$$
$$crash\ rate = 41\ acc/year/lane/direction$$

Crash rate acc/year/mile=41*2/0.88=95 acc/year/mile/lane

Year 1998:

$$crash\ rate = exp\left(-3.71 + 0.7 * ln(46924) - 0.016 * ln(5) + 0.49 * ln(0.88)\right)$$
$$crash\ rate = 42\ acc/year/lane/direction$$

Crash rate acc/year/mile=42*2/0.88=96 acc/year/mile

Year 1999:

$$crash\ rate = exp\left(-3.71 + 0.7 * ln(48097) - 0.016 * ln(5) + 0.49 * ln(0.88)\right)$$
$$crash\ rate = 43\ acc/year/lane/direction$$

Crash rate acc/year/mile=43*2/0.88=98 acc/year/mile/lane

$$Average\ crash\ rate\ (P) = \frac{95 + 96 + 98}{3} = 97\ acc/year/mile/lane$$

Step 3: Combine the EB estimate with the observed values to obtain the overall crash rate

From Section 10 we know the equation for the overall crash rate:

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

where;

$$w = \frac{1}{k(P + 1/k)}$$

k: Dispersion parameter=0.056

x: Observed crash rate in the before period

$$x = \frac{124 + 139 + 132}{3} = 132\ acc/year = \frac{132}{2 * 0.88} = 75\ acc/year/lane/mile$$

$$w = \frac{1}{0.056(97 + 1/0.056)} = 0.17$$

$$m = 0.17 * 97 + (1 - 0.17) * 75 = 80\ acc/year/lane/mile$$

Step 4: Calculate the CRF and AMF

CRF:

$$CRF = 1 - \frac{\sum_{after} observed\ accidents}{\sum_{before} expected\ accident} = 1 - \frac{72}{80} = 0.1$$

AMF:

$$AMF = \frac{\sum_{after} observed\ accidents}{\sum_{before} expected\ accident} = \frac{72}{80} = 0.9$$

Using the above steps CRF and AMF values can be estimated for the other treatment sites.