ESTIMATING BENEFITS FROM SPECIFIC HIGHWAY SAFETY IMPROVEMENTS: PHASE III SAFETY BENEFITS FROM LEFT TURN TREATMENT

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16. Abstract

Sixteen Connecticut intersections which have recently had left turn lanes installed were selected for study. The objective of this project is to quantify the benefits of such treatment. The study is based on an Empirical Bayesian model, in order to mitigate the effects of regression to mean. Comparison sites with similar geometric characteristics, control types, and land uses to the study sites were selected. Data from the comparison intersections was used to estimate what the crash rate during the post-treatment period would have been, had no treatment taken place. These crash rates are then compared to the actual crash rate of the treated intersections. The comparison shows that the regression to mean bias is minimal and therefore the simpler before and after analysis may be preferable. Safety benefits of left turn lanes were also analyzed. Left turn lane installation appears to have had varying effects on different crash types. The effects of control type, number of lanes, and number of legs on the success of a left turn lane were studied. Finally, a severity analysis was performed.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

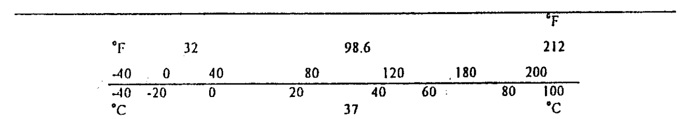
NOTE: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5(F-32)/9	Celcius temperature	^oC

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F



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GLOSSARY OF TERMS

ADT – average daily traffic

Comparison sites – sites used to guard against the possibility that any change in accident frequency is due to factors other than the treatment

Empirical Bayesian method – method which provides an estimate of what the crash rate would have been during the post-treatment time period, had no treatment occurred

F-statistic – statistic used to compare the population variance of each pair of samples

Land use – the socio-economic description of an area

Poisson distribution – a mathematical statement of the probability that an exact number of discrete events will take place during an interval of length t

Population density – the number of inhabitants per unit of total area

Reduction factors – the percentage of the original crashes that is prevented by the treatment

Regression to mean – a bias observed in before and after analyses when a site is selected for improvement due to a high before period crash rate

Time trends – factors such as the improvements in vehicle designs, which impact crash rates

Severity – the seriousness of a crash based on the degree of injury

SYMBOLS

Φ_i - the crash reduction factor at a location *i* for a specific type of crash,

N_{B_i} - the number of crashes of that type at site *i* before the improvement

N_{A_i} - the number of crashes of that type at site *i* after the improvement

V_{B_i} - the traffic entering site *i* in millions of vehicles for the before period

V_{A_i} - the traffic entering site *i* in millions of vehicles, for the after period

m - the expected number of crashes

ε - the estimator of *m* for an intersection that recorded *x* crashes

x - the crash count,

E {m} - the expected value of *m*, based on data from comparison sites

VAR {m} - the variance of *m*

1. Introduction

The National Highway Traffic Safety Administration reports that each year nearly 25% of all fatal crashes in the U.S. occur in or near some type of intersection. Each year, half of all crashes resulting in an injury were intersection related[1]. Given the very small percentage of surface mileage that intersections represent in the 3.94 million miles of road and streets in the United States, it is clear that the inherent design and operational function of intersections present very high opportunities for vehicle conflicts leading to serious crashes. Side impacts are most likely to occur at intersections. Such collisions have higher death and injury rates due to the lack of protection in this part of the vehicle.

Safety at intersections can be improved through three different approaches known as the three E's—education, enforcement, and engineering[2]. Through education, drivers can be taught how to properly obey the rules of the road and be better informed about the consequences of breaking these rules. This can be accomplished through driver education classes, community alerts, and public service announcements. Enforcement is another effective means for improving safety. Drivers who commit violations such as running red lights or speeding are more likely to change their behavior if they are caught and punished. Increasing fines and heightening surveillance are possible answers to some safety concerns.

This paper will focus on the engineering approach to accident reduction. Intersections may be engineered to be safer through improvements such as adding turn lanes or realigning an approach. Such engineering improvements may be involved and expensive, but they also tend to be very effective. Whereas education may be ignored and enforcement can be avoided, engineering improvements tend to have a more direct effect on driver behavior. For example, narrowing a roadway often causes drivers to feel less comfortable at high speeds and therefore may be a more effective means of traffic calming than heightened police surveillance or public service announcements. It is important to have a complete understanding of the impact of such major highway treatments. Before and after comparisons are used to obtain this understanding. A before and after comparison may be used once the treatment has been implemented and used for a sufficient observation period. Then crash rates can be computed and compared for the pre-treatment and post-treatment periods. If the treatment has the intended effect, the crash rate should decrease for the after period. Reduction factors are a measure of the change in crash rate and are used to demonstrate the magnitude of the improvement.

It is critical that the before and after study provides an accurate evaluation of safety improvements. If safety improvements are analyzed inaccurately, they will be misused in the future. So it is required that any bias be removed from the procedure. One significant source of bias is an effect known as "regression to mean"[3]. Intersections are generally selected for treatment because they have a high crash rate during the years prior to their being targeted for improvement. While this probably reflects problems with design or usage, the high crash rate may also be caused in part by a natural fluctuation. Such a fluctuation would eventually level off, and the crash rate would decrease whether or not the intersection was treated.

In other words, the intersections that have been treated are more likely to have high crash rates during the before period, because this was the criteria used for their selection. The regression to mean effect must be mitigated to ensure the most accurate model possible. Therefore, the simple before and after analysis method cannot be used. Instead, the Empirical Bayesian (EB) method[4] is used. This method provides an estimate of what the crash rate would have been during the same post-treatment time period, had no treatment occurred. This rate can then be compared to the actual "after" rate with treatment.

This document describes work on an ongoing project funded by the Connecticut Cooperative Highway Research Program. The first phase of this project was aimed at determining the feasibility of collecting the required information and evaluating the safety effect of intersection improvements using the Empirical Bayesian method. The issues addressed at this phase were an assessment of the availability and reliability of data and development of a comprehensive procedure for the overall study, including suitable analytical methodologies. It was determined that reliable data was indeed available for such analysis. The Second Phase focused on measuring the benefits of intersection realignment and straightening curves. The crash rates estimated via the EB method tended to be lower than the actual pre-treatment crash rates, as expected. This indicates that the simple before and after method would have overestimated the benefits of treatment.

In this, the third phase of the project, fifteen Connecticut intersections were selected for study. Each intersection recently had at least one left turn lane installed on its main approach. Because the left turn lanes were installed mainly to improve capacity rather than safety, it is unclear what role the regression to mean effect may play. EB and simple before and after analyses will be performed in order to quantify the bias.

Once the methods for evaluating the safety of these intersections are understood, the next objective will be to quantify the benefits of adding left turn lanes. This involves calculating reduction factors for all crashes during the study period, as well as for individual crash types. In cases where the comparison cases are statistically shown to be representative of the study site, the EB method is used for the analysis. However, in situations where the comparison sites are not sufficiently representative, the simple before and after analysis results will be used. In the study we will also attempt to determine the condition under which left turn lane installation may be most successful. This involves examining the effects of volume, signal control type, number of lanes, and number of legs on crash reduction. Finally, crash severity levels will be examined.

The following chapter provides a summary of the EB method. Several papers comparing the EB method to before and after methods are discussed. Chapter three includes a detailed discussion of the study design for this research. It explains the site selection procedure, data collection methods, and crash type definitions. Chapter four contains the results and a discussion of the analysis. Crash rates and reduction factors are reported for each crash type by intersection. In the final chapter, we summarize the findings and make recommendations for future work.

2. Methodology

2.1 Crash Reduction Factors

Identifying locations which experience high crash rates and applying treatments such as adding left turn lanes is a routine exercise in traffic safety engineering. Simple before-and-after studies estimate the benefits of an improvement by comparing the crash count at a location before and after improvement. The comparison can be best expressed with a reduction factor, which represents the percentage of the original crashes that is prevented by the treatment. The crash reduction factor is defined by the following equation:

$$\Phi_i = \frac{(\mathrm{N}_{\mathrm{B_i}} / \mathrm{V}_{\mathrm{B_i}}) - (\mathrm{N}_{\mathrm{A_i}} / \mathrm{V}_{\mathrm{A_i}})}{(\mathrm{N}_{\mathrm{B_i}} / \mathrm{V}_{\mathrm{B_i}})} \tag{1}$$

Where

Φ_i denotes the crash reduction factor at a location *i* for a specific type of crash,
N_{B_i} and N_{A_i} are the number of crashes of that type at site *i* before and after the improvement respectively,
V_{B_i} and V_{A_i} represent the traffic entering site *i* in millions of vehicles, for the before and after period, respectively.

Reduction factors can be used to evaluate the effectiveness of a treatment at a single location or to estimate the benefit a type of treatment has in general. To obtain a crash reduction factor for a specific type of improvement, a large number of sites with that treatment should be evaluated. Once a reduction factor is calculated for an improvement, the factor can be applied to untreated sites to predict their performance with improvement. There is some difficulty in obtaining a generalized reduction factor for a treatment, due to the suspected locality of crash reduction factors. The success of a treatment may vary from intersection to intersection due to factors such as geometry and volume. Also, the same highway improvement in Connecticut can have a different safety effect in Florida, for example. Therefore, it is preferable for states to develop their own factors or, at least, evaluate the transferability of such factors from other states[5]. One of the aims of this study is to provide a crash reduction factor for left turn lane installation in Connecticut.

2.2 Regression to Mean

Roadways are generally selected for safety improvements based on their accident history. In Connecticut, the Suggested List of Surveillance Study Sites is the basis for identifying locations in need of improvement. All locations exceeding a critical rate and having a minimum of 15 crashes over a 3-year period appear on the list. The list is sorted by an index determined by rate, type, and severity. Locations which are determined to be in need of a study are assigned to an engineer who plots collision diagrams for the site.

Other information such as photologs, traffic volumes, and speed data are also used. Crash rates are calculated for a fixed time period at all sites within an area of interest.[6]

Because crash rates are heavily weighted in determining which locations are altered, it follows that sites that have been treated are likely to have a greater than average number of crashes during the pre-improvement period. However, this does not necessarily point directly to a faulty design or unsafe conditions. The high crash rates may also be a result of the random nature of accident occurrence. A high crash rate is often part of a natural fluctuation, and will decrease with time, with or without treatment. When sites have been selected because of a high crash rate during the period prior to treatment and this before rate is used to estimate the reduction factor, random variation will lead to exaggerated estimates of the treatment's effectiveness. This bias is known as regression to mean.

An additional source of error associated with before and after studies is the effect of time trends. Improvements in vehicles, such as an increased presence of antilock brakes may cause crash rates to drop throughout an entire network. If this is the case, then the benefits of the vehicular improvements should not be attributed to specific highway improvements. Similar effects may be observed at a more local level due to changes in the level of enforcement or quality of driver education. These factors alter driver behavior and may cause crash rates to change over time. This change should not be mistaken for an effect of the safety improvement.

2.3 EB method

An alternative method must be used in order to isolate the benefits associated with the treatment in question and avoid these biases. One alternative is to use a regression model. Regression models provide crash rates based on better estimates of the long-term mean accident frequencies. A regression model may be very simple, using exposure as the explanatory variable, or more complex, including additional explanatory variables such as geometric measurements. Although adding explanatory variables increases the accuracy of the regression model, it also complicates data collection. Also, regression models are never completely accurate because it is impossible to take into account every factor that influences the occurrence of a crash[7].

Another method is to carefully select a group of comparison sites with geometric and site characteristics similar to the site being studied. Crash data at the comparison sites is collected for the time period before and after treatment, and used for study. The comparison sites guard against the possibility that any change in accident frequency is due to factors other than the treatment. The before and after with comparison group method effectively avoids the bias associated with regression to mean and systemic improvements. It allows the engineer to estimate mean crash counts and their variance for the study sites, and obtain a better estimator of the expected number of crashes for the before period. However, it is often difficult to determine which site characteristics should be similar for comparison sites. Ideally, the comparison sites should have geometric characteristics, volumes, and land use characteristics identical to that of the study site.

However, it may be difficult to find a sufficient number of comparison sites with the required characteristics. Therefore, the similarity of the comparison sites to the study site may have to be compromised somewhat. Statistical tests may be performed to determine if the comparison sites appropriately represent their respective study sites.

The EB method is the preferable method for mitigating bias, because it combines the strengths of the regression and comparison group approaches. Originally proposed by Ezra Hauer[8], the EB analysis assumes that traffic crashes at any particular location in the absence of any highway improvement fit the Poisson distribution. The expected number of crashes is a random variable with a gamma probability distribution over the population of a number of sites, and the expected crash rate is a random variable with a gamma probability distribution. The EB method uses data from a group of similar comparison sites, as well as pre-treatment data from the study site, to estimate how many crashes would have occurred at the study site had no improvements been made. This allows the engineer to compare the "after treatment" crash rate at the site to an estimate of the crash rate for the same site, during the same time period, had no treatment been done. Such a comparison mitigates the bias associated with regression to mean and time trends.

Hauer defines 'x' as the number of crashes at a location, which is subject to random variation, and 'm' as the expected number of crashes at the location. The distribution of m's in a group of sites can be described by a gamma probability distribution function. The distribution function makes it possible to estimate the crash count for the study site had no treatment been applied. The estimate can then be used to calculate a more accurate reduction factor.

The estimate for 'm' is obtained with the following formula[9]:

$$\varepsilon = x + \left[E\{m\}/\left(VAR\{m\} + E\{m\}\right)\right]\left[E\{m\} - x\right] \qquad (2)$$

Where

ε is the estimator of m for an intersection that recorded x crashes,
x is the crash count,
$E\{m\}$ is the expected value of m, based on data from comparison sites,
$VAR\{m\}$ is the variance of m

Once the estimate for the number of crashes during the after period without treatment has been obtained, a crash reduction factor can be computed. Although the crash reduction factor is based on an estimate that mitigates the regression to mean effect, the bias must again be taken into consideration when the reduction factor is applied to an untreated site. If the site is being considered for treatment due to a high crash rate, then the crash reduction factor should be applied to the expected crash rate, rather than the actual crash rate for the pre-improvement time period. If the actual crash rate were used instead, the occurrence of one fatal crash could dramatically increase the predicted benefit, due to the high cost of one random fatality. However, applying the reduction factor to the estimated before rate would mitigate this bias[10].

2.4 Previous Use of EB method

Several notable studies have compared the performances of these various methods. Al-Masaeid[4] examined the performances of simple before-and-after, "before and after with comparison group" and Empirical Bayesian methods, in a study which estimated the safety benefits of street bumps, divisional islands and, closing median openings. The analysis indicates that the results of the Empirical Bayesian were generally comparable with the results obtained from analysis using the before and after with comparison group method. Kulmala studied the safety effect of road measures at junctions such as road lighting, stop sign, signal control, and road widening and concluded that the magnitude of the regression-to-the-mean effect was on average 20 percent and varied greatly between the different measures[11].

Mountain, Fawaz, and Jarrett[12] compared the quality of estimates based on the 'before' period accident counts, the predictive models, and the EB method for links with minor junctions. On the basis of a before and after comparison, the effects of any remedial treatment at these sites would have been exaggerated by some 35 percent. For the predictive models, on the other hand, the effects of any remedial treatment would have been underestimated by between 30 and 40 percent.

Sayed, Abdelwahab, and Newpomuceno[13] conducted a before and after safety evaluation of the installation of larger signal heads. The simple before and after method suggested that the total number of accidents reduced by approximately 33 percent, compared to an EB estimate of 24 percent. The simple before and after method overestimated the reduction in accident severity at 21 percent, compared with the EB reduction of 16 percent. The simple, naïve approach seems to overestimate the safety benefits of new signal head design by approximately one third.

2.5 Application of the EB method to this study

Phase II of this project measured the effectiveness of intersection realignments at a group of intersections. The results obtained with the EB method in Phase II were compared with simple before and after analysis and found to have a lower crash reduction factor with narrower confidence intervals. This implies that once again, more accurate results were obtained by mitigating the regression to mean effect.

Most of the treatments investigated in these studies; street bumps, divisional islands, closing median openings, road lighting, and road widening, are used mainly for safety. Therefore, the sites where the treatment occurred were likely chosen based on their crash rates only. This would maximize the regression to mean effect. Left turn lanes, on the other hand, are generally used as a means for increasing an intersection's capacity. For the intersections studied in this project, it was unclear whether the left turn lanes were installed primarily as a safety measure or to increase capacity. Because the intersection treatments in this study were targeted to improve capacity rather than safety, regression to mean is not as likely to be an issue. However, natural fluctuations are present in the crash data. As a result, comparison groups are used to mitigate the effects of such fluctuations.

The effect of regression-to-mean as well as the benefits of left turn lane installation will be studied at fifteen Connecticut intersections. The following section contains information regarding the selection of these study and similar comparison sites. It also describes the collection of crash, volume, and geometric data. Finally, crash types and levels of accident severity are defined.

3. Study Design

3.1 Study Design

In this study, the benefits of left turn lanes will be quantified. This study design also calls for an examination of their effects on various collision types and on different severity levels. The data collected in this study will also help to indicate under which circumstances left turn lanes produce the maximum benefits. The first step was to determine which areas should be studied. The intersections selected for the study have all had left turn lanes recently constructed. These sites were selected from the ConnDOT Pre-Construction Management System, a list of projects implemented in recent years. The system provided a short description of the construction performed, as well as the projects' start and completion dates. In order to ensure that sufficient crash data would be available for both the before and after construction periods, it was required that all study intersections must have experienced construction between the years 1990 and 1999. Highway crash records were available electronically dating back to 1989. The year 1990 was used as a cutoff for study site selection in order to ensure that at least one year of pre-construction crash data would be available for the before period. Likewise, 1999 was used as the deadline for project completion, guaranteeing one year of after period data. These criteria resulted in the selection of sixteen study sites. The study sites are listed in Table 3-1.

ID#	Intersection	Town
1	Rt. 44 & Rt. 97	Pomfret
2	Rt. 229 & Pine Street	Bristol
3	Rt. 195 & Puddin Lane	Mansfield
4	Rt. 175 & Mountain Rd.	Newington
5	Rt. 104 & Buckingham Dr.	Stamford
6	Rt. 1 & Sound Beach Ave.	Greenwich
7	Rt. 1 & Rt. 81	Clinton
8	Rt. 529 & Shield St.	W. Hartford
9	Rt. 22 & Rt.5	N. Haven
10	Rt. 99 & Parsonage St.	Rocky Hill
11	Rt. 99 & Rt. 160	Rocky Hill
12	Rt. 110 & Long Hill Ave	Shelton
13	Rt. 44 & Mark St.	Coventry
14	Rt. 44 & Silver St.	Coventry
15	Rt. 44 & Cedar Swamp St.	Coventry

Table 3-1 Study Sites

Comparison sites were selected to adjust for the time trend and regression-to-mean effects. Crash rates from the comparison sites were used to estimate "expected without improvement" rates for the study sites. The comparison sites were selected based on their geometry, land use, and control type. The crash data for all comparison sites during the entire twelve-year period can be used to estimate the study sites' expected crash rate without improvement. This estimate should provide a more accurate interpretation of the intersection's safety, since it is based on a large set of data, rather than only a couple years of before data at the study site. Because comparison sites are selected without any knowledge of their crash history, the regression-to-mean effect will not impact the results.

Data was collected using ConnDOT's photolog software, which provides video images along approximately forty-foot intervals for all state highways. The photolog provides frontal and side views of the existing roadway, which make it possible to collect most types of geometric and land use data. For each study site, searches for comparison sites were conducted in towns with similar population densities. The concern was not the population density of the town per se, but this quantity helped locate areas with similar land use patterns. Considering population density also increased the likelihood of the comparison sites having similar traffic volumes as their study sites.

In each town with a similar population density, a search was conducted for intersections with land uses similar to that of the study site. These intersections were then either taken into further consideration or discarded, based on their geometric characteristics. The geometric characteristics considered include the number of lanes and the number of legs. All intersections studied had either two or four lanes on the main road and three or four legs. These features were considered important because they may affect the number of potential conflict types. Comparison sites were also selected to match the vertical alignments of their study sites. Since all of the study intersections were located on relatively flat roads, intersections on moderate or steep grades were not considered for the comparison group.

Other unique geometric features found in the study sites were controlled for in the comparison site selection. For example, one candidate study site was on a highway divided by a concrete median. Very few intersections had similar geometric characteristics and land use patterns, as well as a concrete median. Due to the lack of sufficient comparison sites, this intersection had to be dropped from the study. Fortunately, the remaining study sites did not feature any such unique characteristics which may have affected safety. Control type was the final consideration in finding a matching intersection to use as a comparison site. This criterion was used because the types of conflict observed at a signal controlled intersection are likely to be different from those of an intersection with only stop signs on the minor approaches.

The study sites were then grouped based on their population density, number of legs, number of lanes, and control types. These groups are shown in Table 3-2. Some study sites were unique and thus grouped by themselves. However, groups 2, 3, and 4 contain multiple study sites. Study sites in these groups share each other's comparison sites. This increases the total number of comparison sites for study intersections within the group, and allows for a more accurate estimate of the "after period without intervention" crash rate. Table 3-2 also shows the total number of comparison sites for each group. Although it was desirable to have as many comparison sites for each group as possible, some groups have a limited number. For example, only four comparison sites could be found for Group 1, because there are very few signalized intersections in towns with such low population densities. There is a tradeoff between the quantity and quality of the comparison sites. A greater emphasis was placed on the quality of the comparison sites. In order to obtain more comparison sites, the requirements (similar geometry, land use, and control type) would have to be relaxed.

GRP ID	DESCRIPTION		STUDY SITE ID	STUDY SITE NAME	TOWN (POP.DENSITY)	CONTROL SITES
1	# Lanes	2	1	Rt.44~Rt.97	Pomfret (79.9)	4
	# Legs	4				
	Traffic Sig.	Yes				
2	# Lanes	4	2	Rt.229~Pine St1	Bristol (2310.9)	47
			5	Rt.104~Buckingham Dr.	Stamford (2836.9)	
	# Legs	4	6	US.1~Sound Beach Ave	Greenwich (1194.5)	
			9	Rt.22~Rt.5(Rt.103)	N. Haven (1082.7)	
	Traffic Sig.	Yes	10	Rt.99~Parsonage St	Rocky Hill (1252.1)	
			11	Rt.160~Rt.99	Rocky Hill (1252.1)	
3	# Lanes	4	4	Rt.175~Mountain Rd	Newington (2214.6)	10
	# Legs	3	8	St.529~Shield St	W. Hartford (2675.4)	
	Traffic Sig.	Yes				
4	# Lanes	2	3	Rt.195~Puddin Lane	Mansfield (441.2)	13
	# Legs	3	13	Rt.44~Mark Dr.	Coventry (280.8)	
	Traffic Sig.	No	14	Rt.44~Silver St.	Coventry (280.8)	
5	# Lanes	2	7	Rt.81~US.11	Clinton (786.2)	6
	# Legs	4				
	Traffic Sig.	Yes				
6	# Lanes	2	12	Rt.110~Long Hill Ave	Shelton (1188.5)	14
	# Legs	3				
	Traffic Sig.	Yes				
7	# Lanes	2	15	Rt.44~Cedar Swamp Rd.	Coventry (280.8)	6
	# Legs	4				
	Traffic Sig.	No				

Table 3-2 Site Groupings and Characteristics

3.2 Data Collection

The next step was to define the study area. Crashes related to the intersection do not necessarily occur within the intersection's boundary. For example, rear end collisions involving two queued vehicles may occur some distance from the intersection, yet still be considered intersection-related. In order to include these crashes, we defined a larger intersection area comprising the distance required to come to a stop plus the length occupied by queued vehicles. Since the storage length varied widely from intersection to intersection, and stopping distance was easily estimated, the required stopping distance was used to define the study area. Stover gives maneuver distances and total distance

(Maneuver plus perception and reaction distance but excluding storage) for different driving speeds.[14]

The speed limit at the study intersections ranged from 35 to 45 miles per hour. Stover gives a required stopping distance of 465 to 630 feet for vehicles traveling at 45 miles per hour. Based on this stopping distance, the study area was defined as all sections of roadway within 0.1 miles (520 feet) of each intersection.

A summary of all crashes occurring within the study area of each intersection from the years 1989 to 2000 was obtained from ConnDOT's Accident Experience database. This database contains information on all crashes that occurred on state maintained roads. Crash histories were collected for both the study sites and comparison sites. The summaries contained information such as the exact milepost of the collision, the time and date of the collision, the prevailing roadway and weather conditions, as well as any factors that influenced the crash (driver under the influence, driver distracted, etc.). The data for each intersection was read into SPSS, a statistical software program which simplified manipulation of the data. For each study intersection, separate crash databases were created for the "before" and "after" construction periods. Any crashes occurring during the construction period were discarded. Table 3-3 shows the before and after crash counts for each study site.

ID#	Intersection	Before period	# Years	# Crashes	After period	# Years	#Crashes
1	Rt. 44 & Rt. 97	01/89 - 05/90	1.4	2	11/90 - 12/00	10.2	20
2	Rt. 229 & Pine Street	01/89 - 06/91	2.5	79	06/92 - 12/00	8.5	275
3	Rt. 195 & Puddin Lane	01/89 - 04/93	4.3	31	07/93 - 12/00	7.4	19
4	Rt. 175 & Mountain Rd.	01/89 - 08/94	5.7	167	06/95 - 12/00	5.5	65
5	Rt. 104 & Buckingham Dr.	01/89 - 09/91	2.8	30	12/92 - 12/00	8.0	87
6	Rt. 1 & Sound Beach Ave.	01/89 - 09/93	4.8	95	08/96 - 12/00	4.3	84
7	Rt. 1 & Rt. 81	01/89 - 10/90	1.8	11	08/91 - 12/00	9.3	66
8	Rt. 529 & Shield St.	01/89 - 04/95	6.3	132	07/95 - 12/00	5.4	86
9	Rt. 22 & Rt.5	01/89 - 11/96	7.9	230	01/98 - 12/00	3.0	97
10	Rt. 99 & Parsonage St.	01/89 - 11/93	4.9	152	09/94 - 12/00	6.3	96
11	Rt. 99 & Rt. 160	01/89 - 8/95	6.7	152	06/96 - 12/00	4.5	43
12	Rt. 110 & Long Hill Ave	01/89 - 10/92	3.8	40	05/94 - 12/00	6.6	42
13	Rt. 44 & Mark St.	01/89 - 01/98	9.0	19	11/98 - 12/00	2.1	0
14	Rt. 44& Silver St.	01/89 - 01/98	9.0	12	11/98 - 12/00	2.1	2
15	Rt. 44 & Cedar Swamp St.	01/89 - 01/98	9.0	51	11/98 - 12/00	2.1	5

Table 3-3 Study Site Crash Counts

Data for each study and comparison site was further divided into four types, based on the pre-collision direction of the vehicles. The crash types were defined as follows:

Type 1 – same direction crashes, including rear ends, same-direction sideswipes, and same-direction turning crashes.
Type 2A – intersecting direction crashes where one vehicle makes a left turn.
Type 2B – intersecting direction crashes where no vehicles make left turns,

mostly angle crashes.

Type 3 – opposite direction crashes, including head-on, opposite-direction turning, and opposite-direction sideswipes.

Type 4 – all other types of collision, includes fixed objects, moving objects, pedestrian, parking, and backing crashes, as well as collisions in which the drivers involved disagreed on what had happened.

The separate lanes and phases eliminate several types of potential conflicts, potentially improving intersection safety. The crash rates for Type 1 (same direction), Type 2A (intersecting direction), and Type 3 (opposite direction) were expected to decrease when left turn lanes were constructed. Left turning crashes were not segregated for Type 1 and 3 crashes because the intended movement was not always clear as it was for Type 2 crashes. The drivers involved in these collisions may have been preparing to make a left turn. However, if they had not yet begun to do so, this may not be mentioned in the accident report. Therefore, some crashes categorized as Type 1 or 3 may be prevented by the turn lanes. However, this reduction was not expected to be as great as that of Type 2 collisions. The Type 4 collisions are those that are not as likely to be affected by the installation of left turn lanes. However, Type 4 collisions may be affected if speed is increased or decreased.

The crashes in the original database were also separated by severity. The National Safety Council and most state agencies use the following five severity classifications:

1. Fatal accidents – those where injuries resulted in one or more deaths.
2. Type A injuries – those that result in incapacitation
3. Type B injuries – injuries that are visible, but not incapacitating.
4. Type C injuries – where an involved party reports injuries, but they are not readily visible.
5. Property damage only – no injuries are reported, but at least $1000 worth of damage was reported

Crashes in which less than $1000 worth of property damage was reported were excluded from ConnDOT's database. Of course there is often more than one vehicle involved in a collision, and drivers often have passengers in their vehicles. Therefore it is possible that one person involved in a crash may suffer a Type B injury while another person suffers from a Type C injury. In this situation, the crash was categorized as being of the most severe injury type. No collision was counted twice, even if multiple injury severity levels existed.

Traffic volumes were used to compute the crash rates corresponding to each crash count. The volumes used are based on the total ADT of vehicles entering the intersection. The major roads for each study and comparison intersection are state roads, and their ADTs were available through ConnDOT's Traffic Count Locator software. The Traffic Count Locator also provided volume data for some of the intersecting roads. The counts obtained from this program were performed by the state and were generally available in three-year increments. Therefore, it was necessary to make assumptions about the ADTs for the years where no data was recorded. It was assumed that a year with no volume recorded had the same ADT as the next year in which data was collected. For the most recent years with no traffic counts, there may be no new volume data. In these situations, the most recent traffic count was used (i.e. if no count was available for the year 2000, a 1999 traffic count may be used.) One may assume that the amount of traffic would increase slightly over the twelve-year period covered by the study. If this is the case, the volumes used during earlier years may slightly overestimate the actual volumes, since they were based on future data. Volume estimates for later years may be slightly lower than the actual volumes, because they are based on previous data. This could cause the "after" period crash rate for the study sites to be somewhat higher. Therefore, the effects of the left turn lane installation may be slightly underestimated. Had additional traffic counts been available, this bias could have been reduced.

Many of the intersecting roads were local roads with no available counts. Traffic counters were placed on each of these intersecting roads for a minimum of 24 hours at a time. The resulting 24-hour volumes were then converted to ADTs using factors to account for day of the week and month.

Once this data was collected, the Empirical Bayesian method described in the previous chapter was used to predict the estimated crash rate during the after period without improvement. These rates were then compared with the actual after period crash rates and reduction factors were computed to evaluate the success of the left turn lane installation. This method was applied to the overall crash rates, as well as to crash rates for each crash type and each level of severity.

4. Results and Discussions

4.1 Analysis of Regression to Mean Effect

Figure 4-1 shows the observed "before" crash rates, the crash rate expected without improvement, and the observed "after" crash rate for all crashes occurring within the boundaries of the study area. The "expected after" crash rate is the estimate based on the EB method and selected comparison sites. If a regression to mean effect existed, the "observed before" crash rates would tend to be somewhat larger than the "expected after" crash rates. This would lead to the benefits of the improvement to be exaggerated.

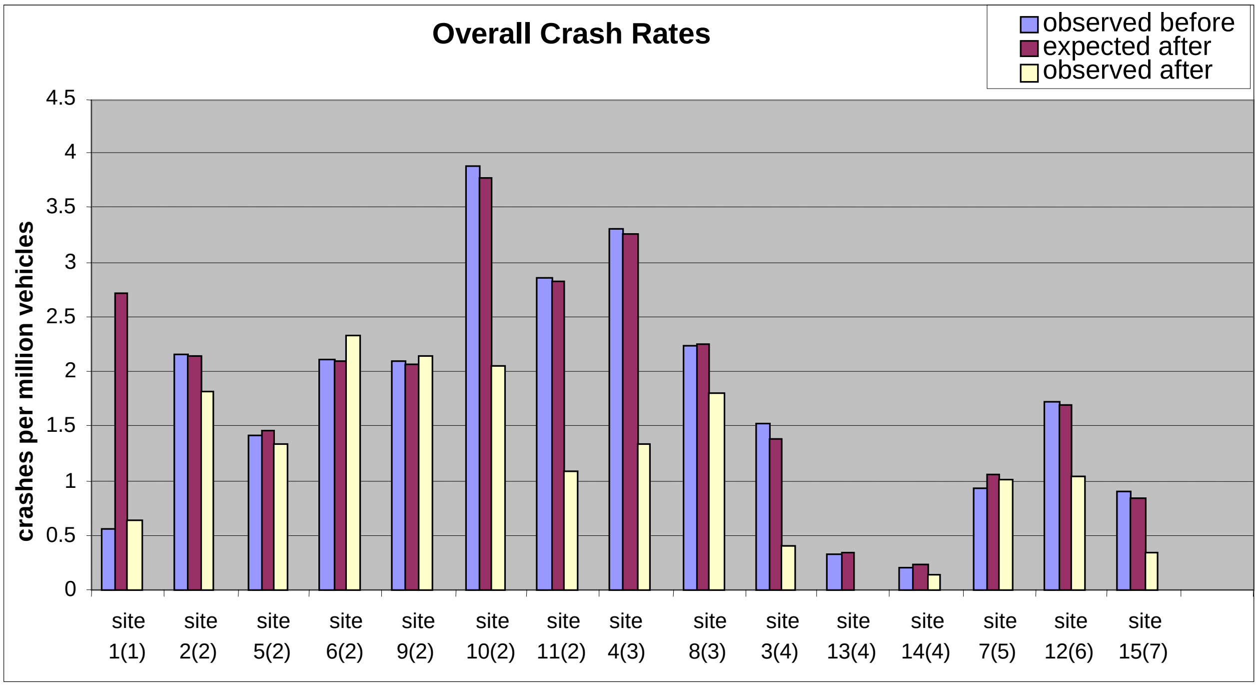


Figure 4-1 Overall Crash Rates

However, Figure 4-1 shows that there is no obvious regression to mean effect. Of the fifteen intersections studied, eight recorded "before" crash rates that were greater than the "expected after" crash rate. For the other seven intersections, the "expected after" crash rate was greater. The average "before" crash rate per million entering vehicles for all fifteen intersections was 1.740, and the average "expected after" crash rate per million entering vehicles was 1.862. The difference between these two crash rates is largely caused by study site one, which has an "expected after" crash rate nearly five times greater than the "observed after" crash rate. This difference may be explained by two factors. Study site one had the shortest pre-construction period, approximately 1.4 years. It also had the fewest comparison sites, only four, due to reasons discussed in the previous chapter. These comparison sites may not appropriately represent the study site, as illustrated by Figure 4-2. Each of the four comparison sites has a crash rate much greater than that of the study site. Therefore, neither the "observed before" nor "expected after" crash rates can be considered accurate. For all other groups, the comparison sites were representative of the study site. The accuracy of the "observed before" crash rate is also compromised by the short observation period, while the "expected after" result is affected by both the short before period and the small number of comparison sites.

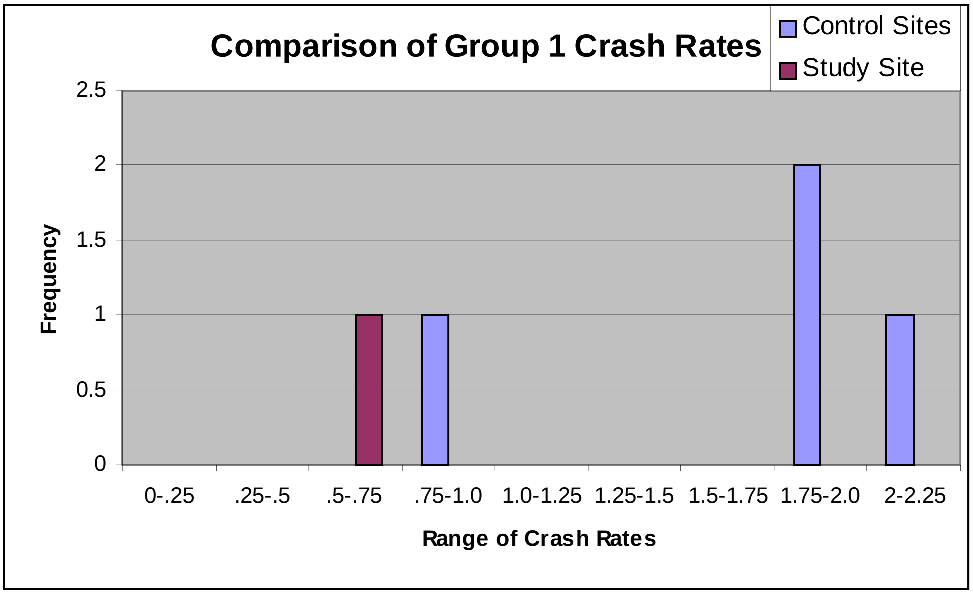


Figure 4-2 Comparison of Group 1 Crash Rates

Because of the questionable results for Study Site 1, the average crash rates for all intersections were recalculated without this data. This resulted in an "observed before" rate of 1.818 crashes per million entering vehicles. The "expected after" rate was found to be 1.805 crashes per million entering vehicles. Still, the "expected after" rate is only 0.7% less than the "observed before" rate. The difference may be due to a very minor regression to mean effect, or it may simply be due to chance. In either case, the difference cannot be taken to be statistically significant. The lack of a significant regression to mean effect may indicate that the left turn lanes were not installed solely as a safety measure. The main purpose of the turn lanes may have been to increase the capacity of the intersections. If this was the purpose of the construction, no regression to mean effect would be observed, since the before period crash rates were not the basis of site selection. If the pre-construction crash data was taken into consideration, but only secondarily to the capacity, a smaller regression to mean effect may be observed. It is also likely that the motivation behind the construction of left turn lanes varied from site to site. This could also minimize regression to mean.

Overall, no significant regression to mean effect was observed, and in most cases sufficient before period data was available. Therefore, a simple before and after analysis may be used for this study. A simple before and after analysis is also much easier than using the Empirical Bayesian method. The EB method will also be considered, even though the effects of regression to mean are minimal. It may still be useful as it provides a comparison to intersections with similar land use, geometry, and control. The EB method may also minimize error associated with some of the shorter pre-construction periods. Since these two methods yielded rather different results it is important to examine the results of each.

4.2 Analysis of Crash Types

Crash rates were calculated for each of the crash types. The crash types, which are based on the pre-collision vehicle directions, are summarized in Table 4-1. Group numbers are shown in parentheses. Crash rates for the various crash types are shown in Figure 4-3 through Figure 4-7. Table 4-2 shows the reduction factors based on the before and after crash rates. Table 4-3 contains reduction factors based on estimated and observed post-construction crash rates. The study sites in these tables are arranged in order of increasing ADT. The ADTs shown are a twelve year average. Negative reduction factors indicate an increase in crash rate and are shown in bold.

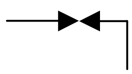
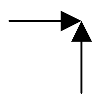
TYPE 1	**TYPE 2A**	**TYPE 2B**	**TYPE 3**	**TYPE 4**
Same	Intersecting-LT	Intersecting-NO LT	Opposite	Other
				

Table 4-1 Crash Type Definitions

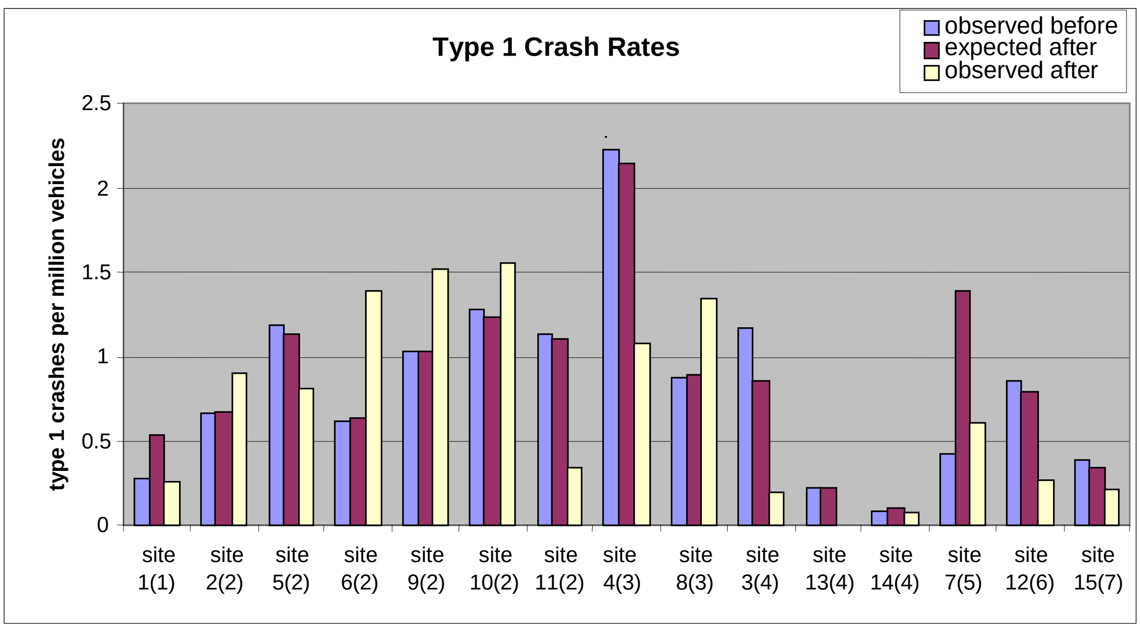


Figure 4-3 Type 1 Crash Rates

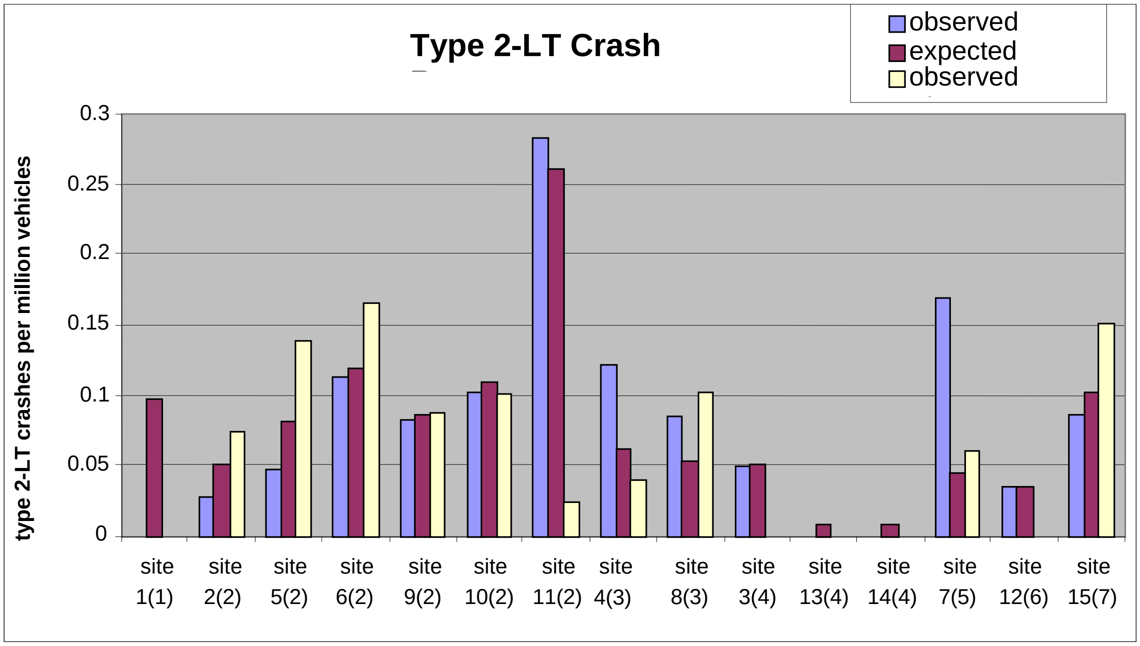


Figure 4-4 Type 2A Crash Rates

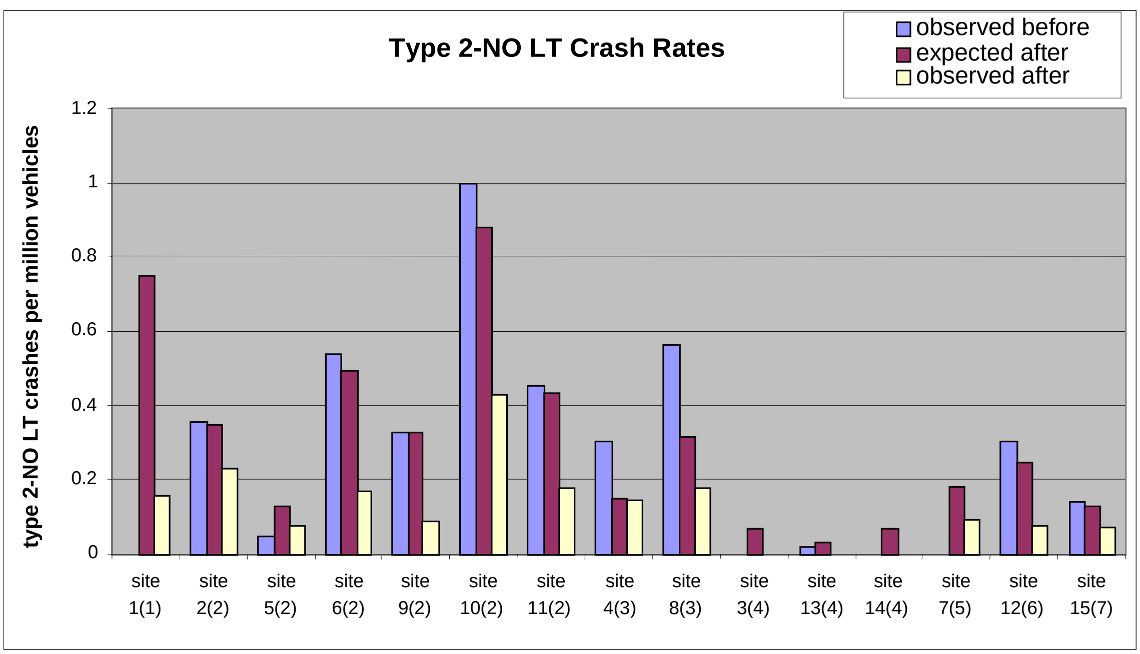


Figure 4-5 Type 2B Crash Rates

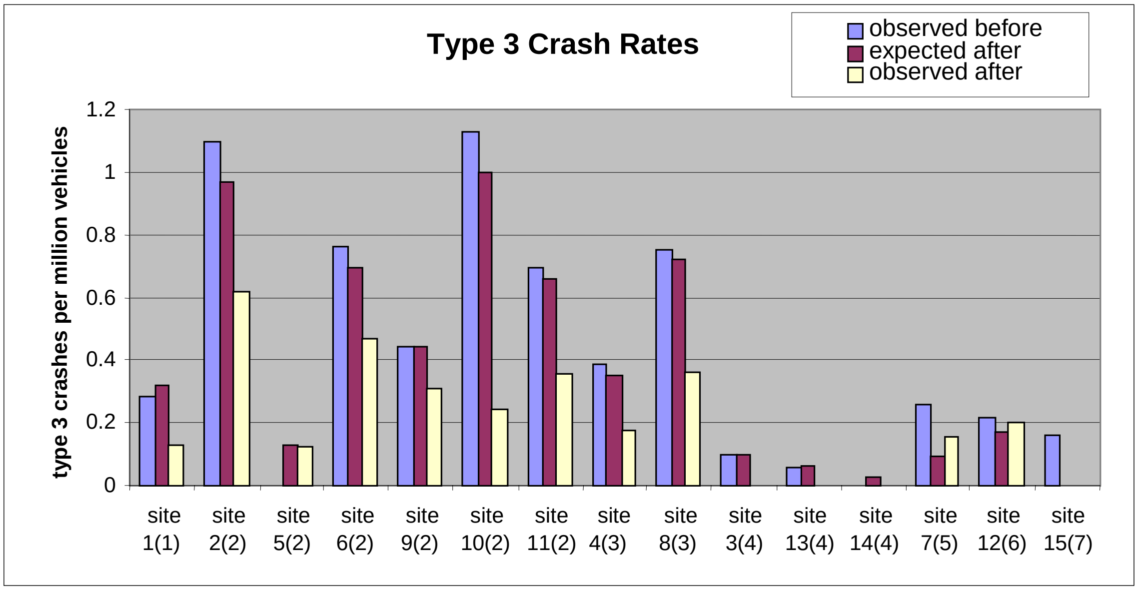


Figure 4-6 Type 3 Crash Rates

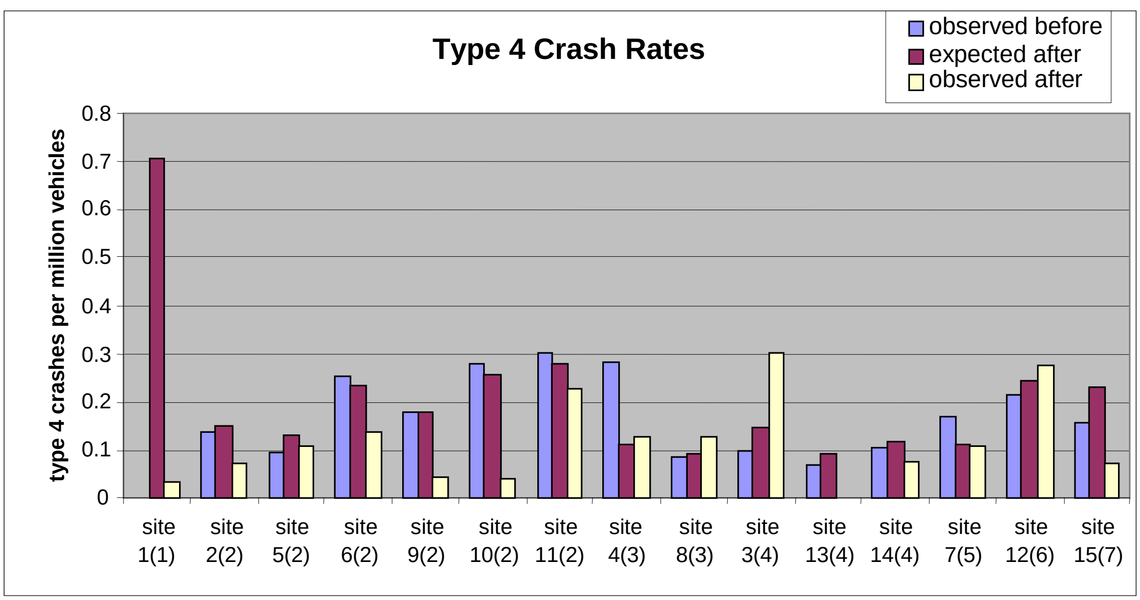


Figure 4-7 Type 4 Crash Rates

Site ID	Intersection Name	AADT	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
1 (1)	Rt.44 & Rt.97	7,500	8.0%	----	----	55.1%	----	**-15.0%**
3 (4)	Rt.195 & Puddin Lane	13,600	83.7%	100.0%	----	100.0%	**-207.3%**	65.8%
12 (6)	Rt.110 & Long Hill Ave	16,400	68.0%	**-74.5%**	75.1%	1.5%	**-28.0%**	38.9%
14 (4)	Rt.44-Silver St	17,500	10.8%	----	----	----	25.7%	25.6%
13 (4)	Rt.44-Mark Dr	17,500	100.0%	----	100.0%	100.0%	100.0%	100.0%
15 (7)	Rt.44-Cedar Swamp Rd	17,700	44.7%	100.0%	49.4%	100.0%	55.0%	60.3%
7 (5)	Rt.1 & Rt.81	18,700	**-44.3%**	63.9%	----	39.9%	36.9%	**-8.2%**
10 (2)	Rt.99 & Parsonage St.	21,000	**-21.4%**	1.1%	57.4%	78.4%	85.6%	47.4%
5 (2)	Rt.104 & Buckingham	21,800	30.8%	**-193.9%**	**-3.0%**	----	**-14.2%**	5.4%
11 (2)	Rt.99 & Rt.160	22,400	68.7%	91.1%	60.9%	49.3%	24.6%	62.1%
4 (3)	Rt.175 & Mountain Rd.	24,000	51.6%	65.8%	15.7%	54.0%	55.4%	59.4%
6 (2)	U.S.1 & Sound Beach	24,400	**-123.2%**	**-47.3%**	69.0%	38.2%	45.5%	**-10.2%**
8 (3)	Rt.529 & Shield St.	24,900	**-52.5%**	**-19.7%**	68.3%	52.4%	**-47.9%**	19.7%
9 (2)	Rt.22 & Rt.5	39,900	**-47.3%**	**-8.2%**	73.0%	30.4%	75.6%	**-2.7%**
2 (2)	Rt.229 & Pine St	42,800	**-33.7%**	**-164.4%**	35.1%	44.0%	47.1%	16.2%

*numbers in parenthesis indicate comparison group id

Table 4-2 Reduction Factors Based on Before and After Crash Rates

Site ID	Intersection Name	AADT	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
1 (1)	Rt.44 & Rt.97	7,500	51.2%	100.0%	78.8%	60.1%	95.4%	76.0%
3 (4)	Rt.195 & Puddin Lane	13,600	77.6%	100.0%	100.0%	100.0%	**-106.4%**	62.2%
12 (6)	Rt.110 & Long Hill Ave	16,400	65.0%	**-35.0%**	69.3%	**-18.5%**	**-12.5%**	37.2%
14 (4)	Rt.44-Silver St	17,500	29.9%	100.0%	100.0%	100.0%	35.7%	77.2%
13 (4)	Rt.44-Mark Dr	17,500	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
15 (7)	Rt.44-Cedar Swamp Rd	17,700	39.4%	100.0%	44.9%	100.0%	69.0%	57.6%
7 (5)	Rt.1 & Rt.81	18,700	56.3%	**-35.0%**	49.6%	**-68.2%**	3.1%	6.2%
10 (2)	Rt.99 & Parsonage St	21,000	**-25.1%**	7.5%	51.5%	75.7%	84.2%	45.9%
5 (2)	Rt.104 & Buckingham	21,800	27.6%	**-66.2%**	40.4%	2.8%	17.9%	8.3%
11 (2)	Rt.99 & Rt.160	22,400	68.2%	90.2%	59.1%	46.4%	18.7%	61.6%
4 (3)	Rt.175 & Mountain Rd	24,000	49.4%	33.4%	3.3%	49.6%	**-13.9%**	59.0%
6 (2)	U.S.1 & Sound Beach	24,400	**-115.4%**	**-40.4%**	66.2%	32.1%	41.1%	**-17.7%**
8 (3)	Rt.529 & Shield St.	24,900	**-51.3%**	**-91.7%**	43.6%	50.3%	**-36.1%**	19.7%
9 (2)	Rt.22 & Rt.5	39,900	**-48.1%**	**-2.9%**	72.8%	30.0%	75.6%	**-2.8%**
2 (2)	Rt.229 & Pine St	42,800	**-33.9%**	**-36.3%**	33.2%	36.5%	50.9%	15.6%

*numbers in parenthesis indicate comparison group id

Table 4-3 Reduction Factors Based on EB Crash Rates

Both sets of reduction factors seem to show a relationship between Type 1 (same direction) crash reduction and ADT. The number of same direction crashes tends to increase at the intersections with higher ADTs. Study sites 2 and 9 have much higher ADTs than the other sites, and both experienced an increase in same direction crash rates. All intersections with ADTs greater than 24,000 experienced at least a 48.1% increase in Type 1 crash rate. Study site 10, which had an ADT of 21,000, also saw an increase in same direction collisions. Study site 7 had a Type 1 reduction factor of 56.3% using the data obtained with the EB method. However, the simple before and after comparison resulted in a reduction factor of –44.3%. This may be due to a similar situation as encountered with study site 1. Figure 4-8 shows the type 1 crash rates for the comparison sites were slightly higher than that of the study site. However, the low before and after reduction factor can probably be attributed to the short before period, which was only 1.8 years in duration. Therefore, the EB method may be more appropriate here. All other study sites saw Type 1 crash rates drop.

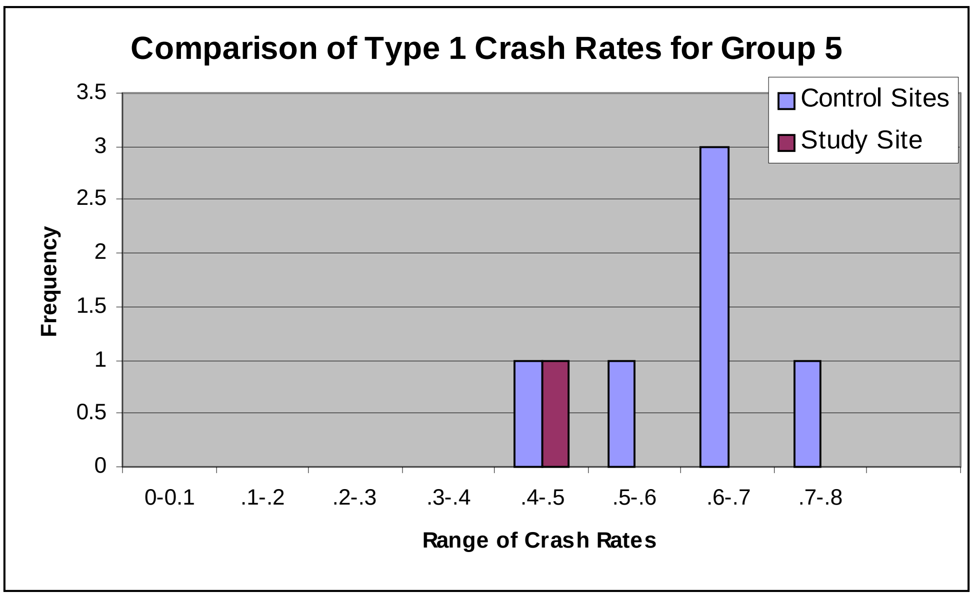


Figure 4-8 Comparison of Type 1 Crash Rates for Group 5

Type 2A crashes also appear to be related to ADT. These are intersecting-direction crashes in which a left turn is made. One would expect this crash type to be reduced by left turn lanes, however crash rates increase for the four intersections with the heaviest volumes. Study sites 5 and 12 also experienced negative reduction factors based on both sets of data. Study site 7 observed an increase in Type 2A crashes based on the EB method data only. Table 4-3 also indicates that five of the six intersections with ADTs below 18,000 experienced a 100% decrease in Type 2A crashes. No Type 2A crashes were observed during the after period.

4.3 Analysis of Geometry and Control Type

The next step was to examine the effects of control type, number of legs, and number of lanes on the safety of these intersections. Control type was expected to impact the safety benefits of left turn lanes because the presence of a signal alters which types of conflicts may exist. Likewise, the number of legs and number of lanes at an intersection will have an affect on the possibility of various crash types. Table 4-4 shows the mean reduction factors for intersections with and without signal control. Table 4-5 contains mean reduction factors for intersections with three and four legs. Table 4-6 shows the reduction factors for sites with two and four lanes on the main approach. These reduction factors in three tables are based on the observed before and after data. Tables 4-7 through 4-9 contain reduction factors for the same features based on the expected after and observed after data. Reduction factors for all crash types, as well as overall reduction factors are shown. F-statistics were used to compare the population variance of each pair of samples. The statistical significance of the observed differences among each pair of samples is also given.

Control	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
No Signal	16500	5	61%	25%	45%	60%	-11%	58%
Signal	24700	10	-16%	-21.20%	18%	34%	21%	17%
F			1.34	0.091	0.669	1.182	0.002	4.847
signif.			0.271	0.77	0.428	0.305	0.969	0.05

Table 4-4 Mean Reduction Factors by Signal Type (Before/After method)

# Legs	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
3	19000	6	44%	12%	43%	51%	-17%	52%
4	24000	9	-13%	-18%	16%	37%	28%	17%
F			0.325	0.133	0.026	0.143	1.081	0.422
signif.			0.58	0.724	0.876	0.714	0.323	0.529

Table 4-5 Mean Reduction Factors by Number of Legs (Before/After method)

# Lanes	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
2	15600	7	39%	27%	32%	57%	-17%	38%
4	27700	8	-16%	-34%	47%	31%	34%	25%
F			0.004	0.855	2.933	1.182	0.016	2.205
signif.			0.949	0.382	0.115	0.305	0.903	0.166

Table 4-6 Mean Reduction Factors by Number of Lanes (Before/After method)

Control	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
No Signal	16500	5	62%	73%	83%	76%	17%	67%
Signal	24700	10	-2%	-4%	50%	32%	34%	27%
F			0.039	0.910	0.816	0.034	0.209	0.155
signif.			0.846	0.361	0.386	0.094	0.656	0.701

Table 4-7 Mean Reduction Factors by Signal Type (EB method)

# Legs	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
3	19000	6	45%	34%	69%	64%	-22%	59%
4	24000	9	2%	13%	55%	35%	51%	28%
F			0.487	0.360	0.045	0.005	4.006	0.800
signif.			0.500	0.561	0.836	0.947	0.071	0.390

Table 4-8 Mean Reduction Factors by Number of Legs (EB method)

# Lanes	Avg AADT	# of sites	Type 1	Type 2A	Type 2B	Type 3	Type 4	Overall
2	15600	7	60%	61%	78%	53%	26%	60%
4	27700	8	-16%	-13%	46%	40%	30%	24%
F			0.487	0.572	0.788	1.515	0.002	0.816
signif.			0.500	0.465	0.394	3.354	0.965	0.386

Table 4-9 Mean Reduction Factors by Number of Lanes (EB method)

In nearly all cases, a larger reduction factor is obtained for the feature associated with lower intensity. Intersections with no signal experienced greater crash reduction than those with signals. Three-legged intersections tended to benefit from the turn lanes more than four-legged intersections. Sites with two lanes on the main road have larger reduction factors than those with four lanes. This held true for all same-direction crashes, intersecting direction left-turn crashes, opposite direction crashes, and for the overall crash rates. Left turn lanes tended to have a negative effect on same direction and intersecting direction crashes with left turns at intersections with the higher intensity features. For intersecting-direction crashes without a left turn involved, unsignalized and three-legged intersections experienced greater crash reduction. For the EB method, three-legged intersections had higher reduction factors than four-legged intersections. However, for the before and after method, the opposite was true. Both methods indicated superior reduction at signalized intersections, 4-legged intersections, and four lane roads for Type 4 (Other) crashes.

Average ADTs are included in Tables 4-4 through 4-9 to show the relationship between the studied features and volume. The unsignalized intersections had much lower traffic volumes than signalized intersections, the three-legged intersections had lower volumes than the four-legged intersections, and the two lane roadways had significantly lower volumes than the four lane roadways. Therefore, it is difficult to determine whether the differences in reduction factors are caused by the specific site feature or by the entering volumes. It seems that both may have an impact. The differences in reduction factors reflect the differences in the levels of vehicle conflicts and interaction. Naturally, there will be less potential for vehicles to conflict at intersections with lower ADTs because more space will be available on the roadway, and headways will increase. Queues and platoons are also likely to be shorter. However, headway and queue and platoon length are also likely to be affected by the geometric features and signalization.

4.4 Analysis of Severity Levels

All crashes occurring at these intersections cannot be weighed equally. A collision resulting in a fatality is much more costly than one resulting only in a dented bumper. An analysis of injury levels has been performed in order to examine the effects of left turn lane construction crash severity . One factor which plays a large role in determining the severity of a collision is the vehicle's speed prior to impact. Therefore, severities at an intersection at which vehicles enter at 45 miles per hour cannot be compared to severities at intersections at which vehicles enter at 35 miles per hour. Speed was not controlled for during the selection of the comparison sites. At most intersection, travel speeds were not even available. Speed limits can be used as an indicator of the observed speeds, but do not always reflect the actual travel behavior accurately. Although most comparison sites have speed limits within five miles per hour of the study site they were selected for, a few do not. Therefore, an estimate based on the comparison sites for a given severity level could inaccurately reflect the actual safety of the study site. Due to these factors, the results obtained using the EB method are not used for this portion of the study. Instead, all analysis is based on before and after data only.

This analysis involves a comparison of percentages of crashes in each severity category before and after improvement. The percentage of crashes in each severity level for all intersections combined has also been calculated. These results are shown in Table 4-10. Pairs of before and after percentages are shown in bold to indicate a decrease after treatment.

	Fatal		**Severity A**		**Severity B**		**Severity C**		**PDO**	
Site	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
2	0.0%	0.0%	**5.1%**	**3.3%**	6.3%	9.0%	21.5%	34.2%	**67.0%**	**53.5%**
1	0.0%	5.0%	0.0%	0.0%	0.0%	0.0%	**50.0%**	**40.0%**	50.0%	55.0%
9	0.0%	0.0%	**8.7%**	**1.1%**	5.7%	8.5%	**37.4%**	**30.0%**	48.3%	60.6%
3	0.0%	0.0%	**3.2%**	**0.0%**	**6.5%**	**5.3%**	**32.3%**	**31.6%**	58.1%	63.2%
12	0.0%	0.0%	**17.5%**	**7.1%**	**7.5%**	**7.1%**	20.0%	31.0%	**55.0%**	**54.8%**
7	0.0%	0.0%	0.0%	0.0%	4.3%	29.4%	4.3%	55.9%	**91.5%**	**14.7%**
4	0.0%	1.6%	**8.4%**	**7.9%**	6.0%	7.8%	**36.5%**	**21.9%**	49.1%	60.9%
5	**3.2%**	**2.2%**	**3.2%**	**2.2%**	**9.7%**	**5.6%**	**41.9%**	**28.1%**	41.9%	61.8%
6	0.0%	0.0%	**2.1%**	**1.2%**	3.2%	8.3%	**28.4%**	**11.9%**	66.3%	78.6%
10	0.0%	1.0%	6.6%	7.3%	6.6%	11.5%	23.0%	59.4%	**63.8%**	**20.8%**
8	0.0%	0.0%	**9.8%**	**0.0%**	**6.8%**	**3.5%**	**40.2%**	**36.0%**	43.2%	60.5%
11	**0.7%**	**0.0%**	**8.6%**	**7.0%**	**14.5%**	**11.6%**	**41.4%**	**25.6%**	34.9%	55.8%
13	**5.3%**	**0.0%**	0.0%	0.0%	**15.8%**	**0.0%**	**26.3%**	**0.0%**	**52.6%**	**0.0%**
14	0.0%	0.0%	0.0%	0.0%	**8.3%**	**0.0%**	**8.3%**	**0.0%**	83.3%	100.0%
15	0.0%	0.0%	**2.0%**	**0.0%**	**7.8%**	**0.0%**	**5.9%**	**0.0%**	84.3%	100.0%
Total	0.2%	0.5%	**6.9%**	**3.3%**	7.3%	8.7%	31.0%	33.2%	**54.5%**	**54.4%**

Table 4-10 Distribution of Crash Severity Levels Before and After Treatment

These results indicate the benefit of the left turn lanes is actually greater when severity is taken into consideration. A greater proportion of fatal crashes was observed during the after period. However, this may not accurately reflect the left turn lanes' success in reducing fatal crashes. The occurrence of such crashes was very rare. Amongst all the intersections only three fatalities were observed during the before period, and five during the after period. For other severity levels, many more crashes were observed. Therefore, the results may reflect actual safety benefits more so than chance. It appears that life-threatening crashes (Severity A) benefited the most from treatment. Before treatment, 6.9% of all collisions involved life-threatening injuries. After treatment, only 3.3% of the crashes were considered life threatening.   The percentage of crashes involving visible injury (Severity B) and non-visible injury (Severity C) increase for the after period. The proportion of property damage only crashes remains about the same. These results seem to indicate that collisions that would have resulted in life threatening injury prior to left turn lane installation, were somewhat less severe as a result of the treatment. This would explain the increase in non life-threatening injuries.

The improvements in injury severity may reflect a decrease in speeds after the construction of left turn lanes. The presence of an additional lane changes the path of the turning vehicle. It also impacts the behavior or traffic traveling straight through the intersection, because those drivers may now avoid vehicles slowing to turn. While it would have been useful to study the affect of left turn lanes on speed, it was not possible for this study. The majority of the study sites had no speed data available in the immediate vicinity of the intersection prior to treatment.

5. Conclusions

Previous studies by Hauer, Al-Masaeid, Kulmala, and others indicate that the regression to mean effect creates a significant bias in the evaluation of safety-related highway improvements. The Empirical Bayesian method mitigates the regression to mean effect by estimating the crash rate during the post-treatment period had no intervention taken place. This estimate can be compared to the actual post-treatment crash rate, providing a more accurate indication of the safety measure's effectiveness. Little work has been done pertaining to the effect of regression to mean on highway treatments that are not strictly safety related. This study examines the effect or regression to mean in the evaluation of left turn lane installation, a treatment which is more often intended to increase an intersection's capacity.

Empirical Bayesian and simple before and after analyses were conducted for fifteen Connecticut intersections that have recently had left turn lanes constructed on at least one approach. The EB results appear to be unreliable for one study site, due to a lack of similar comparison sites. For the remaining fourteen study sites, the average "observed before" crash rate was 1.818 crashes per million entering vehicles. The average "expected after" crash rate, calculated using the EB method, was 1.805 crashes per million entering vehicles. Therefore, reduction factors based on the "observed before" rate would very slightly overestimate the benefit of implementing left turn lanes. In comparison, the benefits of treatments mainly intended to improve safety, such as speed bumps, medians, lighting, stop signs, and larger signal heads, are overestimated by 20% to 33% according to the research of Al-Masaeid, Kulmala, Mountain, and others.

The regression to mean effect is minimal for a simple before and analysis of left turn lanes because the treatments were aimed to increase capacity. The sites were not treated because of high crash rates during the before period, but because of inefficient flow. However, it appears that some bias may be present, as the "observed before" rate was slightly higher than the EB estimate. This may be the result of time trends. Over the course of twelve years, significant engineering improvements have been made to vehicles. Technologies such as antilock brakes allow crashes to be avoided. The benefits of these technologies should not be attributed to highway improvements. Therefore, the EB method may offer some advantage over the simple before and after method. The "expected after" estimate is based on data collected for the entire duration of the study, thus reducing the effect of time trends. Still, in the case of left turn lanes, the time trend effect appears to be minimal. Since the EB method is more time consuming, expensive, and complex, the simple before and after method may be preferable. It does not seem to introduce any type of significant bias and is more straightforward than the EB method.

In addition to comparing these statistical methods, this study also focused on the actual safety benefits of the left turn lanes. Crash rates were computed for several crash types based on the vehicles' pre-collision travel direction. These crash types are: same direction, intersecting direction with left turn, intersecting direction without left turn, opposite direction, and "other" type crashes. The results show that at intersections with higher entering volumes, the same direction crash rate tended to increase after left turn lanes were installed. Left turn lanes also experienced less success, in terms of reducing intersecting direction crashes involving left turns, at sites with greater entering ADTs. Although one would expect left turn lanes to reduce these types of crashes, the four intersections with the heaviest volumes actually saw the number of these crashes increase after treatment.

Other factors that affect the safety benefits of left turn lanes, such as control type, number of lanes, and number of legs, were also studied. In most cases, larger reduction factors were observed for sites with features associated with lower traffic intensity. Intersections with no signal experienced greater crash reduction than those with signals. Three-legged intersections experienced greater safety benefits than four-legged intersections. Left turn lanes also performed better at sites with two lanes rather than four lanes on the main road. However, it is unclear whether these differences should be explained by the specific site features or by the entering volumes.

Finally, this study examined the effects of left turn lane installation on crash severity. When injury severity is taken into consideration the safety benefits seem to be greater. The greatest reduction observed was for life threatening crashes. Although fatalities experienced a slight increase this may not be an accurate representation of the safety benefits. The increases in percentages of non life-threatening injuries may be a result of the downgrading of life threatening injuries.

The results of this study may be useful for predicting the safety benefits of proposed left turn lane installations. The research may help determine under which circumstances left turn lane installation should be considered. It appears that the safety benefits of left turn lanes are maximized at intersections with lower volumes and at intersections with three legs, two lanes, and no signal. Because such features are associated with lower entering volumes it is unclear which causes the superior safety performance. It may be the low volumes, the varying features, or a combination of these factors. This topic requires further study. It is also recommended that similar research be done for highway interventions such as adding a lane and altering signal phasing. Although these changes affect safety, they may also primarily be aimed at improving capacity. Further research would determine whether a regression to mean bias would exist for simple before and after analyses of these changes.

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