ESTIMATING BENEFITS FROM SPECIFIC HIGHWAY SAFETY IMPROVEMENTS: PHASE II SAFETY BENEFITS OF INTERSECTION APPROACH REALIGNMENT

Final Report

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16. Abstract

One task of the traffic safety engineer is to identify high crash locations and to select appropriate highway treatments for reducing the number of crashes. This process relies on the availability of accurate information on the crash reduction factor of the various treatments. Currently, most agencies rely for their prediction on the information dating back to 1960's. It is necessary to update and reassessment these factors using the new data and new evaluation methods.

Currently we are conducting a before/after type study and using Empirical Bayes method to estimate crash reduction factors for modern conditions on two-lane rural highways. This paper reports on the results of the second phase of the study, which was aimed at evaluating the safety benefits of intersection approach realignment. Furthermore, Analysis of Variance model is used to identify the extra benefits of the comprehensive treatments. The research shows that the improvements studied appeared to reduce the total number of crashes, but the effect on different type of crashes is different. Also, combining realignment with adding a left-turn lane or traffic signal does not appear to offer significant additional benefits in crash reduction.

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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)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

* 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

°F 32 98.6 212 °F

-40 0 40 80 120 180 200

-40 -20 0 20 40 60 80 100

°C 37 °C

ACKNOWLEDGMENTS

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INTRODUCTION

An important aspect of traffic engineering is improving the safety of highways. Highway improvements are regarded as effective methods to reduce the number of crashes such as adding left turn lanes, widening travel lanes, flattening sharp curves, or realigning intersection angles. Estimating lives saved and property damage avoided through specific highway improvements provides information for selecting the appropriate countermeasure for a specific hazardous location, thus allocating a limited budget more effectively. But as noted in previous publications by the authors (*1*, *2*), currently much of this estimation process is based on a study using data over fifty years old, and there is a need to update the predictions of crash reduction rates using new observations.

This paper describes ongoing research into updating these crash reduction factors in Phase II of a Joint Highway Research Advisory Council project titled "Estimating Benefits from Specific Highway Safety Improvements." The overall objective of this project is to update the prediction procedure. The first phase of the project was a feasibility study that formed and demonstrated a procedure for predicting the crash reduction rates of specific highway safety improvements according to prevailing features of the implementation site. One objective was to determine the availability of data from existing Connecticut Department of Transportation (ConnDOT) record systems for developing statistically reliable estimates of crash reduction factors. As noted in the first phase report (*1*), the feasibility of gathering the needed data has been clearly established.

In the Phase I study, we examined four rural, two-lane intersections with varying background conditions all subject to the same type of improvement: roadway or intersection approach leg realignment. Two methods of before-and-after analysis for calculating crash reduction factors were demonstrated in the application: point estimation with confidence intervals and likelihood function estimation. Due to the scope of work for the first phase of the project, comparing with groups of similar sites was not applied.

In Phase II, we refined our data collection and analysis procedures using greater numbers of analysis sites and larger quantities of data. The focus in this phase was on collecting data at a larger sample of intersections with conditions similar to those studied in the first phase, including some that were improved and some that were not. Study intersections (those treated) involve either a curve on the main road being straightened, or a skewed approach leg being realigned. Intersections and road sections that also have similar problems (*i.e.*, sharp curves or skewed intersection approaches) and similar background conditions (*i.e.*, population density, traffic control type, left turn arrangement, number of legs) without improvements served as control cases to establish the base line crash rates that would be expected if no improvement were implemented. This was done to avoid the common regression-to-mean problem.

Furthermore, in the past forty years, much research has discussed the benefit of various highway treatments. However, few studies have addressed the effects of combining multiple treatments, even though this is a common situation. Here, the combined effects of realigning a roadway along with adding a signal or left-turn lane are studied on a preliminary basis to learn if combining these treatments results in extra safety benefits.

STUDY METHODOLOGY

Before-and-after Method

This project is designed to be a before-and-after study. The safety effect of an improvement is determined by comparing the crash rate expected without implementing the improvement with the crash rate observed after the improvement. As noted in the previous paper (*2*), the problem most frequently associated in the literature with this type of study is the regression-to-mean effect. The key concept here is estimating the number of crashes expected if no improvement had been done at the site. Various researchers have developed different methods to deal with this problem.

One approach is to use matched-control-group methods that involve a classical experimental design (*4, 5*). In this method, the changes in crash rates at the treated sites are compared with those for a carefully matched control group. Crash data for both before and after periods of the control group are required. Theoretically, this type of method avoids the regression-to-mean effect completely and the problem of bias does not arise, but it has some practical difficulties due to the extensive data requirements.

The Empirical Bayesian (EB) method was introduced by various researchers (*4-9*) to compute estimates of after crashes without the improvement. In this method the number of crashes expected without the improvement is estimated using the "before" crash count at the treated sites along with counts from a reference group of sites similar to the treated sites, called a control group. This kind of analysis assumes that the number of crashes at any particular location fits 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. This method does not require crash data in the after periods for the control cases.

In Hauer's study (*4-6*), '*m*' is defined as the expected number of crashes at a location, and the actual count of crashes which is subject to random variation is denoted by '*x*'. The actual crash count should be treated like one observation from a random variable because of natural fluctuations. The distribution of *m*'s in a group of sites can be described by a gamma probability distribution function. With this in mind, one can estimate the expected number of crashes for a treated site, and compare this estimator with the observed after count to get the crash reduction factor, thus mitigating the regression-to-mean effect.

Hauer derived the following formula to estimate *m* for a site at which the observed crash count is *x* (*4, 5*):

$$\varepsilon = x + \left[E\{m\}/\left(VAR\{m\} + E\{m\}\right)\right]\left[E\{m\} - x\right] \qquad (1)$$

which can also be written as

$$\varepsilon = \alpha E\{m\} + (1-\alpha)x \qquad (2)$$

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*,
VAR {m} is the variance of *m*, and
α is defined by the following expression

$$\alpha = (1 + VAR\{m\} / E\{m\})^{-1} \quad (3)$$

The following equations are provided by Hauer (*6*) to calculate *E {m}* and *VAR {m}* for populations having a Gamma distribution.

$$\hat{E}\{m\} = \overline{X} \quad (4)$$

$$V\hat{AR}\{m\} = s^2 - \overline{X} \quad (5)$$

Many previous studies also compared the performances of different methods of conducting the before-and-after study. Kulmala studied the safety effect of road measures at junctions such as road lighting, stop sign, signal control, road widening and concluded that the magnitude of the regression-to-the-mean effect was an average of 20 percent and varied greatly between the different measures (*10*). Al-Masaeid (*11*) examined the performance of different safety evaluation methods and found that the simple before-and-after method overestimated the effectiveness of safety improvements and led to erroneous conclusions at specific locations, as well as at the aggregate level. Their analysis indicated that the results of using the empirical Bayesian method were generally comparable with the results obtained from analysis using the before-and-after study with comparison group method. Therefore, they recommended that the Bayesian method be used in evaluating safety improvements if there is a difficulty in identifying a suitable and large number of comparison locations. Mountain *et al.* (*12*) also concluded that the EB methods did not perform significantly better than other methods in assessing the changes in crash frequencies at intersections, but for link segments, EB methods perform better in terms of all summary measures.

Recently, Davis argued that methods for estimating accident reduction effects could be compromised when not properly accounting for the influence of the site selection mechanism (*13*). When the improvement sites are selected based only on the critical crash count and no other factors are considered, the EB estimator is consistent provided the samples in the control group are Gamma distributed. But when site selection is confounded by an important factor that is neglected in before/after estimation, the EB estimator becomes inconsistent. Therefore, he suggested that when attempting to estimate the causal effect of traffic safety measures, site selection be included as part of the overall assessing procedure.

Another important part of crash reduction study is conducting a conclusive statistical experiment for the analysis. Procedures and examples of inferring the reduction factors by point estimator with confidence interval and likelihood functions taken from Hauer (*4*) were given in the Phase 1 report (*1*). This phase (Phase 2) continued to use these methods.

Analysis of Variance Test (ANOVA)

Analysis of variance (ANOVA) models are useful for studying the statistical relation between a dependent variable and one or more independent variables. Therefore, ANOVA can be applied in analyzing the different benefit estimates of various highway improvements or treatments. Here, the crash rate reduction is a dependent variable which is regarded as the basic criterion for evaluating the benefit of the improvement. The treatment type is an independent variable. Therefore, the ANOVA model is as follows.

$$P_{ij} = \mu + \alpha_i + \varepsilon_{ij} \qquad (6)$$

where:

P_{ij} is the crash rate reduction of site j with treatment i,

μ is overall effect on the sites (such as weather, traffic volume, geometric etc),

α_i is the effect due to treatment i,

ε_{ij} is errors that are identically and independently distributed.

The null hypothesis is that the effects due to treatments are the same. If the hypothesis is not rejected, we conclude that there is no significant difference between the two treatments.

STUDY DESIGN

Based on Phase I result, we continued the study in Phase II by adding more sites. Other than having more treated sites in the sample, the major difference between these two phases is that the before crash frequency at a treated site will be adjusted by a control group of similar intersections, and the parameters α and β in likelihood functions will also be estimated by the control group. Intersections that have similar problems and similar background conditions which were not improved served as control cases to establish the base line crash rates that would be expected if no treatment were implemented.

Site Selection

To focus the study, locations are restricted to intersections on rural or suburban two-lane highways that had been the subject of roadway realignment projects. As in the previous phase, study sites either involve a curve on the main road being straightened, or a skewed intersection approach leg on the side road being realigned. The first type, we call 'curve realignment', and the second type 'angle realignment'.

The study sites are selected from the ConnDOT Pre-Construction Management System (PCMS) list of projects that have been implemented in recent years. The main standard for selection of the sites was the availability of a sufficient number of years of crash data before and after construction. Eight new study sites are selected in this phase, in addition to the four sites studied in Phase 1, for a total of 12 study sites listed in Table 1. Crash data were available from January 1989 to June 1998 (in Phase I, data were available from 1989 to 1996), thus all of the study sites selected have a before period of at least three years and an after period of least seven months.

Table 1. Study Intersections and Crash Counts

Control group ID	Intersection ID	Intersection	Town	Before period (year)		Before crash count	After period (year)		After crash count
1A	2016	Rt. 6 & Rt. 316	Andover	01/89 - 09/92	3.7	29	09/93 - 03/98	4.6	23
2A	1002	Rt. 79 & Sr.450	Madison	01/89 - 10/93	4.8	40	07/94 - 06/98	4.0	19
2C	1003	Rt.163 & Maple St.	Montville	01/89 - 04/93	4.3	19	07/94 - 06/98	4.0	3
	1005	Rt.7 & Candlewood Lake Rd.	New Milford	01/89 - 05/93	4.3	40	10/94 - 06/98	3.8	18
3A	2019	Rt. 123 & Old Norwalk Dr.	New Canaan	01/89 - 03/94	5.2	34	09/94 - 03/98	3.6	14
	1004	Rt.106 & Weed St.	New Canaan	01/89 - 04/94	5.3	53	04/95 - 06/98	3.3	5
4A	2011	Rt. 5 & 150	Wallingford	01/89 - 02/92	3.1	53	07/92 - 03/98	5.8	81
	2022	Rt.71 & 150	Wallingford	01/89 - 10/93	4.8	69	12/93 - 03/98	4.3	53
5A	2023	Rt. 69 & Wolcott St	Bristol	01/89 - 06/97	8.4	86	11/97 - 06/98	0.7	6
	2013	Rt.44 & Tolland St	East Hartford	01/89 - 07/96	7.5	156	05/97 - 06/98	1.2	13
	2020	Rt.174 & Carr Ave	Newington	01/89 - 06/92	3.4	16	10/93 - 03/98	4.5	8
6C	2012	Rt. 70 & Rt.68	Cheshire	01/89 - 11/92	3.8	66	08/94 - 03/98	3.7	36

In Table 1, a site ID beginning with '1' indicates sites selected in Phase I and kept in the study for this phase, too. A site ID beginning with '2' indicates new sites added in Phase II. In this table, we also list the construction period, population density of the towns in which study sites are located, and before and after crash counts for each site.

To select control sites, we classified the study sites into 7 groups as shown in Table 1 according to their population density, presence of a signal, and left-turn arrangement. We did not control for number of approach legs because we only have one four-leg study site (RT.174 & Carr Ave.), and all the others are three-leg intersections. It was hard to find enough control sites for the four-leg intersection, so we mixed it with the others. Capital letter 'A' in the group ID indicates that the treatment was approach angle realignment; 'C' indicates curve realignment. Group 6 C contains one site – intersection of Rt.70 and Rt.68, the only study site with a traffic signal for the before period, all other sites were without signal control. For each group, at least five control sites are selected. A detailed list of the control sites is in Appendix A.

Data collection and preparation

As in the previous phase, geometric and crash data for study sites are collected within 0.1 mile (0.16 km) of each approach of the intersections with the same variables. Crashes occurring during the construction period were excluded from the analysis. The average daily vehicle count entering each intersection is again used as traffic exposure. Table 2 lists some of the important physical characteristics for the study sites.

Table 2. Important Before Site Characteristics

Control group ID	ID	Area type	Number of legs	Treatment	Population density**	Signal	Left turn lane	Median island	Speed limit	Number of driveways							
										Res	Gas	Ret	Off	Ind	Other	Int.	Total
1A	2016	rural	3	1,3,4	170	no*	no*	no	40	3	0	3	0	0	0	1	7
2A	1002	rural	3	1,4	440	no	no*	no	45	3	0	0	0	0	0	1	4
2C	1003	rural	3	2	400	no	no	no	30	3	0	0	0	2	0	0	5
	1005	rural	3	2	400	no	no	no	40	2	0	0	0	0	2	0	4
3A	2019	rural	3	1,4	820	no	no*	no	45	4	0	0	0	0	0	0	4
	1004	rural	3	1,5	820	no	no	yes	30	9	0	1	0	0	0	0	10
4A	2011	suburban	3	1,3	1100	no*	no	no	40	0	2	8	0	0	0	1	11
	2022	suburban	3	1,5	1100	no	no	yes	40	0	2	2	0	0	2	0	6
5A	2023	suburban	3	1,3,4	2300	no*	no*	no	40	5	0	1	0	0	0	1	7
	2013	suburban	3	1	2700	no	no	no	35	3	0	14	3	0	0	4	24
	2020	suburban	4	1	2200	no	no	no	35	1	0	0	0	1	0	0	2
6C	2012	rural	3	2	840	yes	yes	no	35	3	1	2	0	0	2	1	9

Treatment:
1. Approach angle realignment
2. Horizontal curve realignment
3. Add signal
4. Add left turn lane
5. Remove island

Driveway Type:
Res: Residential
Gas: Gas Station
Ret: Retail
Off: Office
Ind: Industry
Int: Intersection

* means feature was added with improvement
** In person per square mile

Due to the difficulty of retrieving large amounts of data, crash data for the control sites are only collected from 1993 to March of 1997. The expected crash frequency and variance for each group are calculated based on these data. To do this we must assume there was no time trend in these crash data because we use the data in this time period (1993-1997) to represent the general situation in a long run. Table 3 shows the results of expected crash estimation for study sites using control sites by EB methods. In Phase II, instead of using the observed crash rate for the before period, we estimate the expected crash frequency for the study sites (ε) from their control group statistics and their actual crash counts (x), and calculate the expected crash rate (λ_ε) for the before period using ε. λ_ε is compared with the after crash rates to obtain the crash reduction factors.

Table 3. Control Group Statistics and Crash Count Estimation

Control group ID	Control sample size	Intersection ID	$E\{m\}$	$VAR\{m\}$	x	ε	ADT	λ	λ_{ε}
1A	5	2016	8	13	29	21	15250	1.4	1.0
2A	6	1002	12	101	40	37	12250	1.9	1.7
2C	5	1003	8	10	19	14	4850	2.5	1.9
		1005	18	77	40	36	11400	2.2	2.0
3A	6	2019	21	146	34	32	12220	1.5	1.4
		1004	21	149	53	49	12240	2.2	2.1
4A	5	2011	31	662	53	52	19000	2.4	2.4
		2022	40	1099	69	68	16040	2.5	2.4
5A	5	2023	42	734	86	84	11450	2.4	2.4
		2013	55	1251	156	152	16790	3.4	3.3
		2020	17	113	16	16	11540	1.1	1.1
6C	5	2012	21	72	66	60	22950	2.0	1.9

m : expected number of crashes at a location

$E\{m\}$: expected value of m

$VAR\{m\}$: variance of m

x : crash count

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

$$\lambda = x / ADT$$

$$\lambda_{\varepsilon} = \varepsilon / ADT$$

ANALYSIS

Crashes were classified into different categories in order to study the safety effect of the improvement on different crash types. One is multi-vehicle non-intersection crashes, or crashes that occurred within 0.1 mile of the intersection but not directly related to the intersecting point. For the curve realignment group, this category was further divided into "driveway-related" and "other" in order to study the effect of driveways on the crash reduction factor. Another category is multi-vehicle intersection crash, which are the crashes that occurred at the intersecting point and due to the existence of the intersection. They are further classified into head-on, rear-end, and other crashes. For the angle realignment group, head-on turn crashes were classified separately because there was a large number of this crash type for the before period at one of the study sites in this group, and we wanted to know what happened to these crashes after the treatment. The other crash categories were run-off road crashes and hit animal crashes. Generally, these were single vehicle crashes.

In the curve realignment group, head-on and rear-end crashes at intersecting points, run-off road, and hit animal crashes were considered to be the target crashes, or the crashes the treatment was expected to mitigate. Multi-vehicle crashes at intersections were considered the target crash for the angle realignment treatment.

The crash reductions for the two treatments along with their 90 percent confidence intervals for all type of crashes were calculated. The likelihood functions of total crashes for the seven groups were also studied in order to get better ideas of how they distributed around the most likely values of the crash reduction. We also studied the effect of other factors such as traffic volume and driveways on the crash reduction factor. Some of the sites received other treatment like adding left turn lane, adding traffic signals at the time of the realignment treatment; we also checked their combined effect of reducing crashes. The rest of this chapter will discuss the results that we obtained.

RESULTS

Figures 1 through 12 present comparisons of observed before, estimated and after crash rates for each site by crash type. In most of the sites, the expected crash rate without treatment was lower than the observed crash rate except site 2020 (Rt.174 and Carr Ave.). The improvement seems to have a different effect at different sites, and also have different effect on different types of crashes. Overall crash rates were reduced at all sites but one (site 2023, Rt.69 and Wolcott Street).

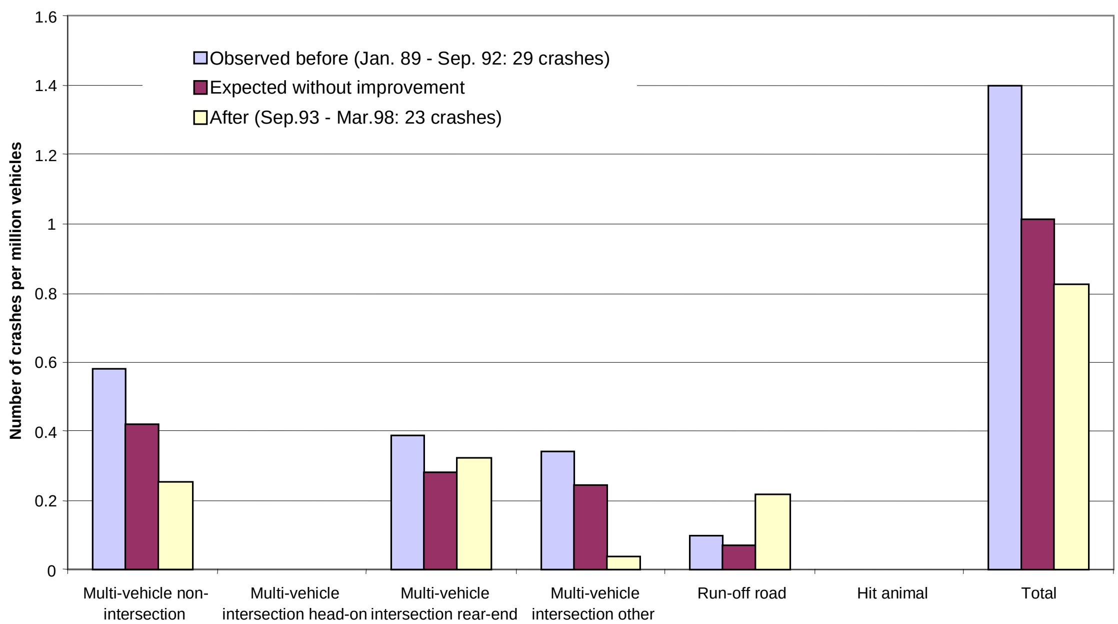

Figure 1. Site 2016 - Rt.6 & Rt.316 Crashes by Type (Group 1A)

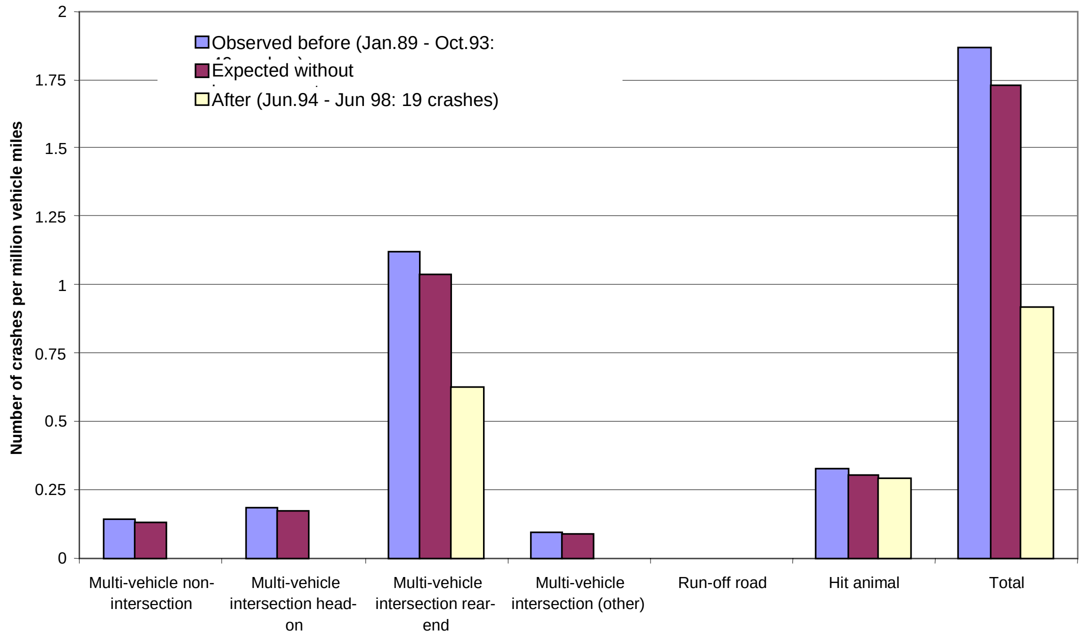

Figure 2. Site 1002 - Rt.79 & Sr.450 Crashes by Type (Group 2A)

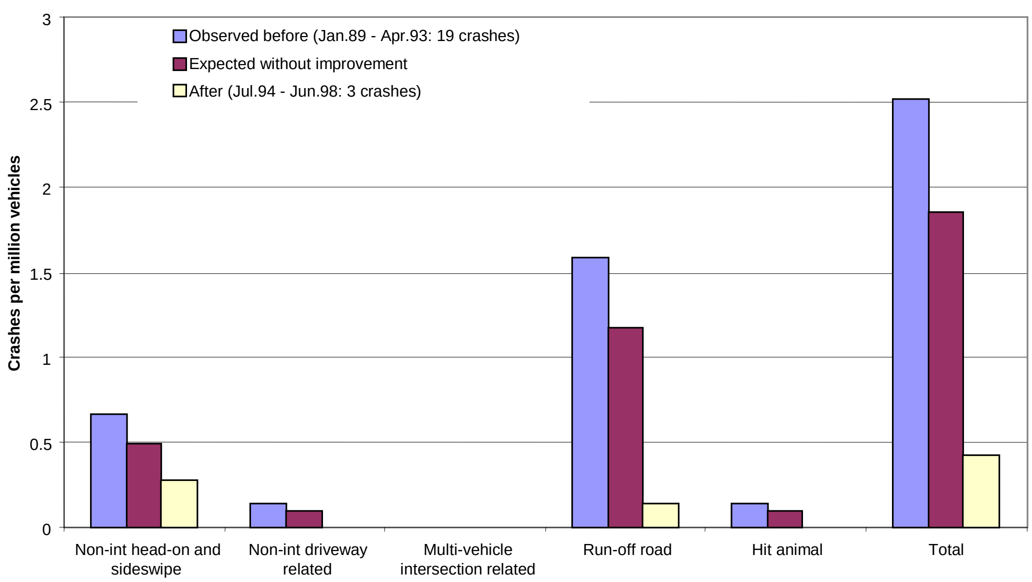

Figure 3. Site 1003 - Rt.163 and Maple St. Crashes by Type (Group 2C)

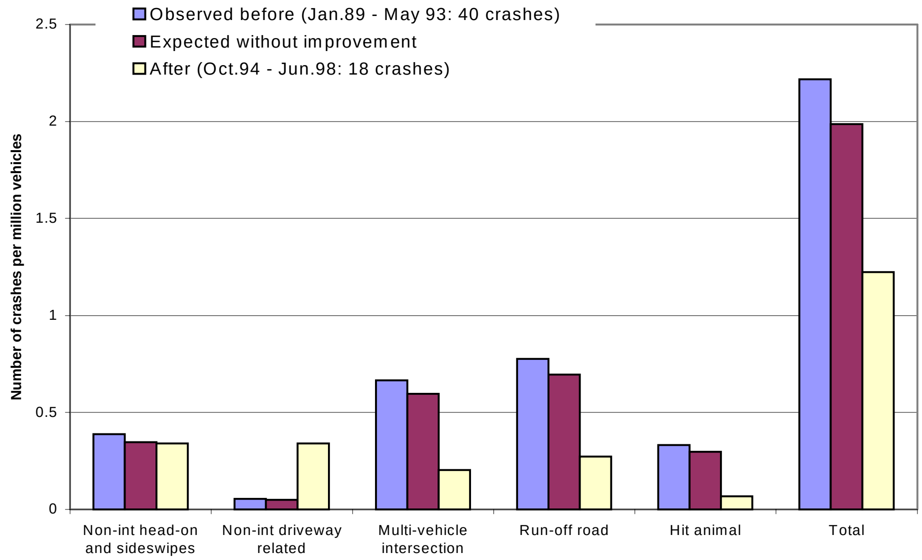

Figure 4. Site 1005 Rt.7 & Candlewood Lake Rd. Crashes by Type (Group 2C)

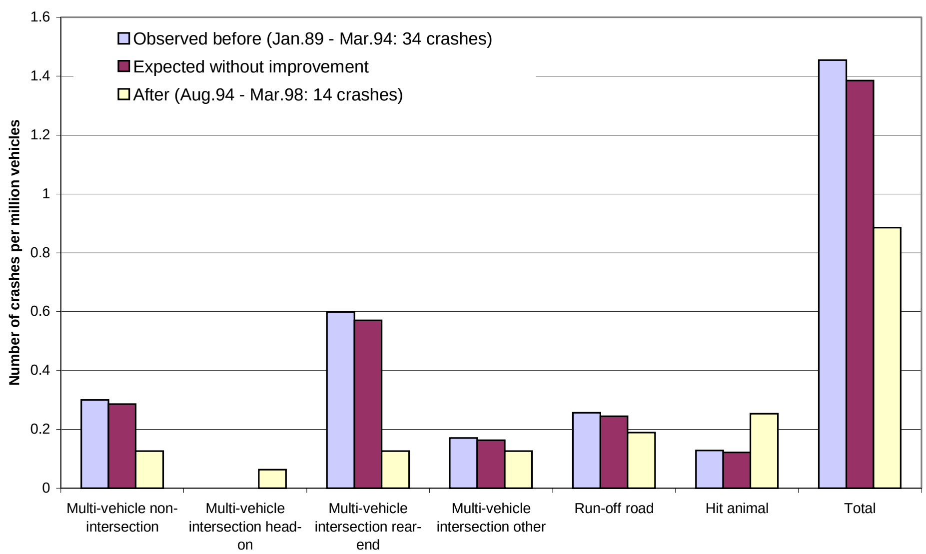

Figure 5. Site 2019 - Rt.123 & Old Norwalk Dr. (Group 3A)

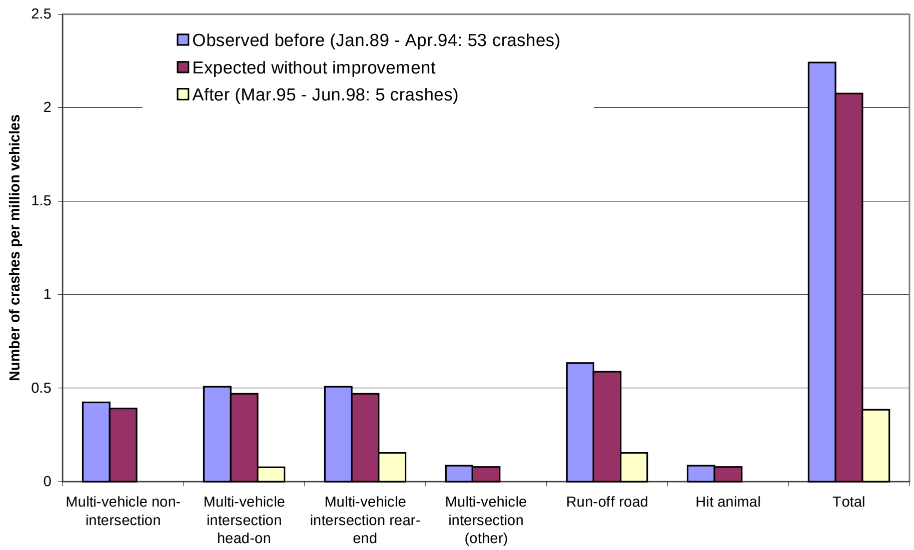

Figure 6. Site 1004 - Rt.106 & Weed St. Crashes by Type (Group 3A)

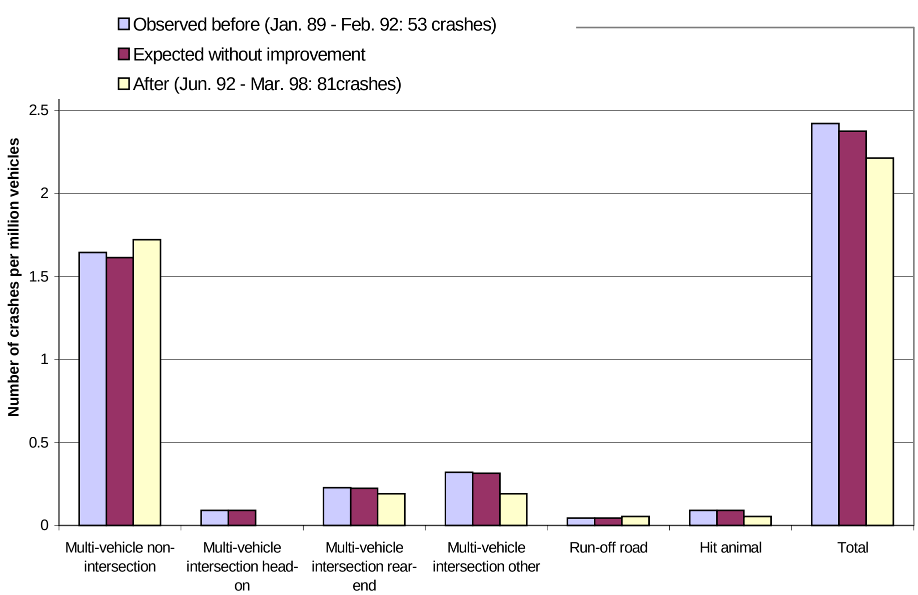

Figure 7. Site 2011 - Rt.5 & Rt.150 Crashes by Type (Group 4A)

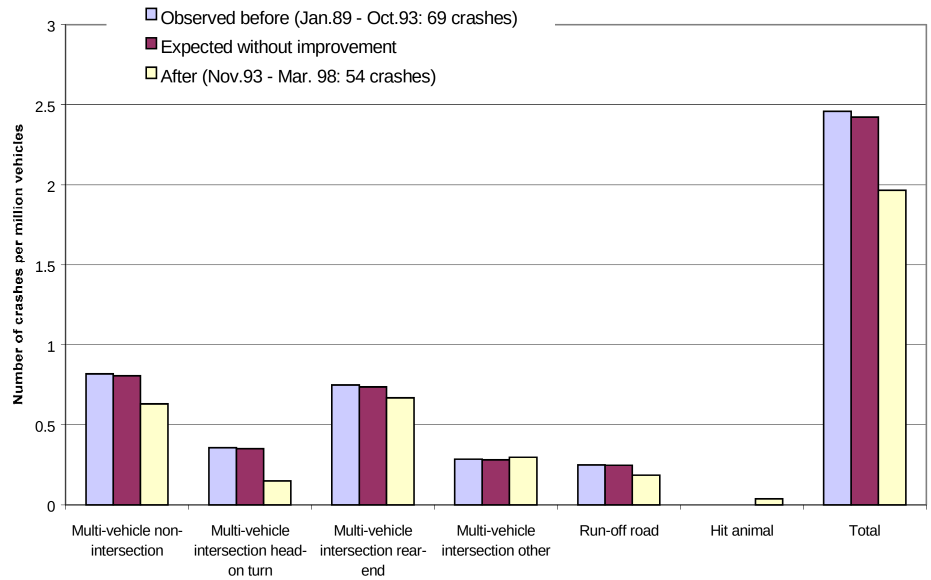

Figure 8. Site 2022 - Rt.150 & Rt.71 Crashes by Type (Group 4A)

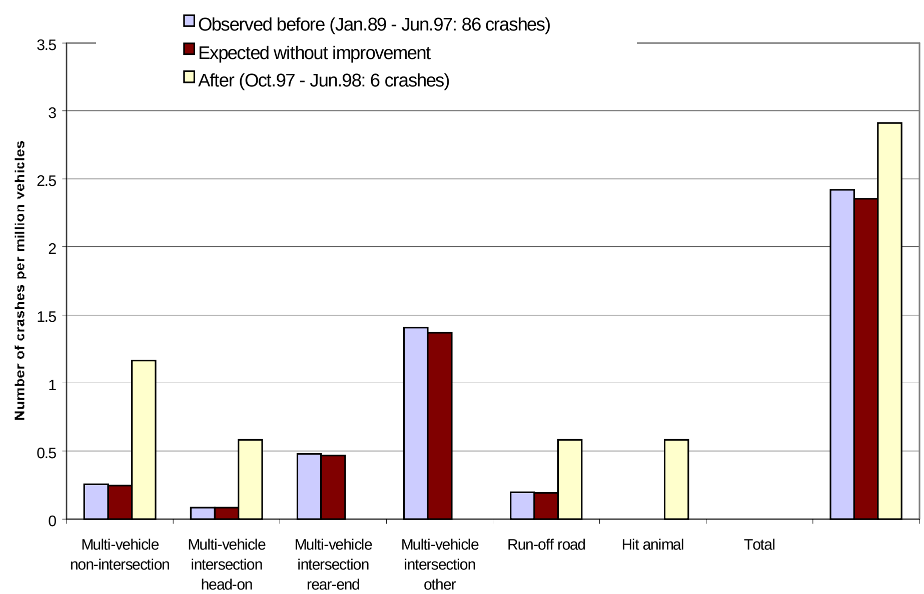

Figure 9. Site 2023 - Rt.69 & Wolcott St. Crashes by Type (Group 5A)

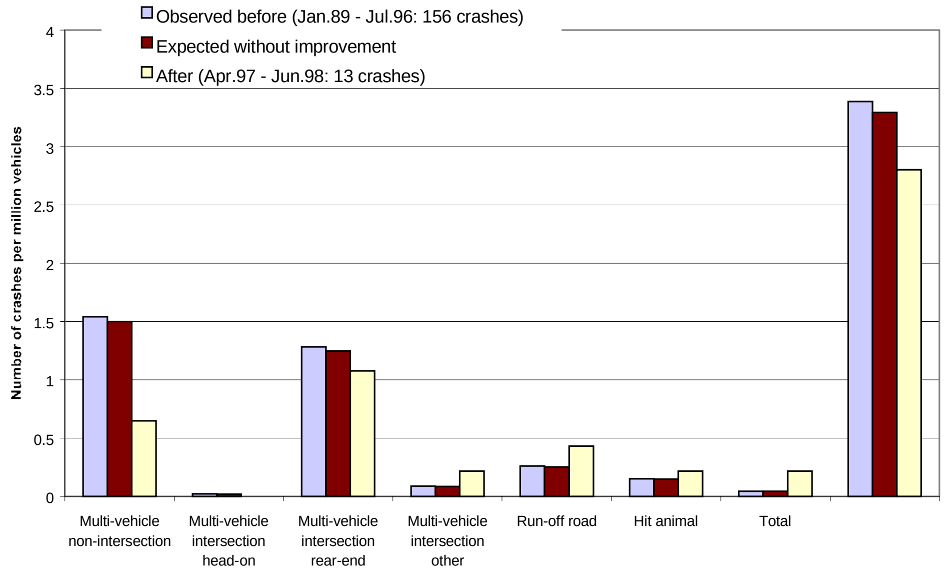

Figure 10. Site 2013 - Rt.44 & Tolland St. Crashes by Type (Group 5A)

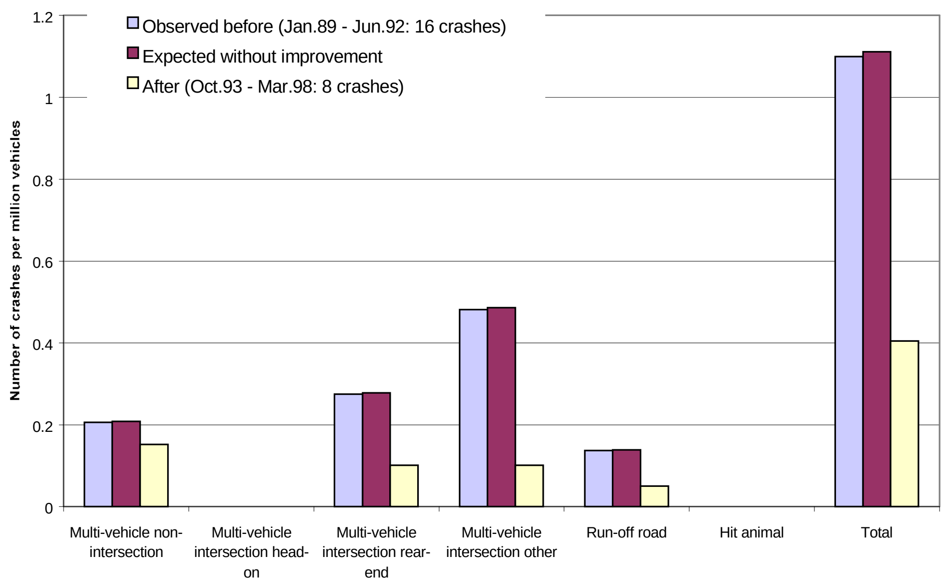

Figure 11. Site 2020 Rt.174 & Carr Ave. Crashes by Type (Group 5A)

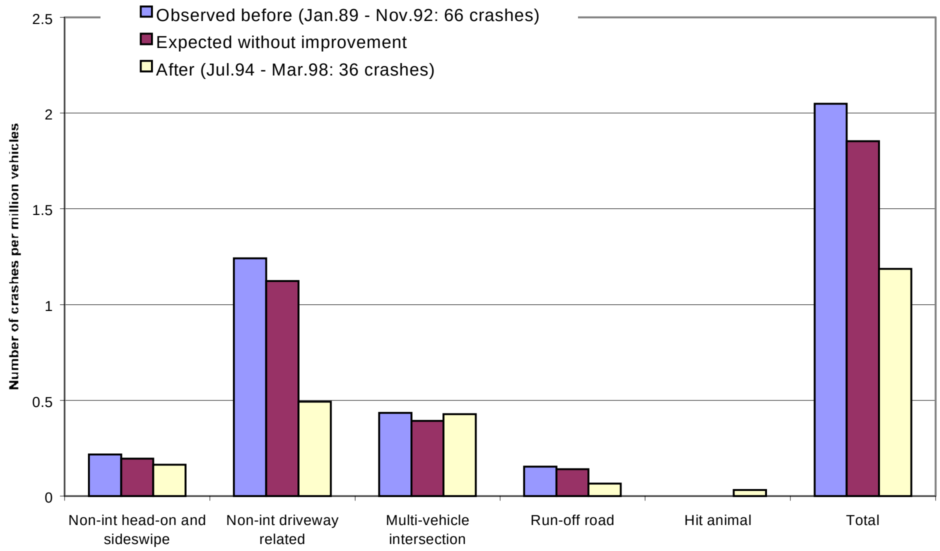

Figure 12. Site 2012 - Rt.68 & 70 Crashes by Type (Group 6C)

Tables 4 and 5 further quantify the reduction in crash rates for curve realignment and angle realignment, respectively. In the tables, the expected reduction factors were calculated with their 90 percent confidence interval, and the values are presented as percent reductions. Since reduction factor cannot be greater than 100%, the upper limit for these intervals is by definition 100%. Negative numbers indicate an increased crash rate, and 'NA' denotes there were no crashes during the before or total study period. Target crashes are presented with bold fonts.

Table 4. Crash Rate Reduction Factors for Curve Realignment

Crash Category		1003 (2C)	1005 (2C)	2012 (6C)	Mean	Std. Dev.	90% upper	90% lower
Multi-vehicle non-intersection	Driveway	100%	-584%	56%	-143%	383%	100%	-773%
	Other	43%	2%	16%	20%	20%	54%	-13%
	Subtotal	52%	-71%	50%	10%	71%	100%	-106%
Multi-vehicle intersection	**Head-on**	**NA**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Rear-end	**NA**	**18%**	**22%**	**20%**	**3%**	**24%**	**15%**
	Other	NA	100%	-486%	-193%	415%	100%	-875%
	Subtotal	NA	66%	-11%	28%	54%	100%	-61%
Run-off road		**88%**	**61%**	**53%**	**67%**	**18%**	**98%**	**37%**
Hit animal		**100%**	**77%**	**NA**	**89%**	**16%**	**100%**	**62%**
Target		89%	58%	35%	61%	27%	100%	16%
Total		77%	38%	36%	51%	23%	89%	12%

^ Add left turn lane
* Add signal
Bold means target crashes
NA denotes no crashes during the before or total study period
Note that reduction factor can not be greater than 100%
Negative reduction factors indicate an increased crash rate

Table 5. Crash Rate Reduction Factors for Angle Realignment

Crash Category		1002^ (2A)	1004 (3A)	2011* (4A)	2013* (5A)	2016*^ (1A)	2019^ (3A)	2020 (5A)	2022 (4A)	2023*^ (5A)	Mean	Std. Dev.	90% upper	90% lower
Multi-veh non-int		100%	100%	-7%	57%	40%	56%	27%	22%	-373%	2%	145%	100%	-236%
Multi-vehicle int	Head-on	100%	84%	100%	100%	NA	NA	NA	NA	NA	96%	8%	100%	82%
	Rear-end	40%	67%	15%	14%	-16%	78%	64%	10%	100%	41%	38%	100%	-22%
	Head-on turn	NA	NA	NA	-155%	NA	NA	NA	58%	-609%	-235%	341%	100%	-796%
	Other	100%	100%	39%	-70%	85%	22%	79%	-6%	100%	50%	59%	100%	-47%
	Subtotal	**52%**	**77%**	**39%**	**-7%**	**32%**	**66%**	**74%**	**19%**	**70%**	**47%**	**29%**	**94%**	**0%**
Run-off road		NA	74%	-22%	-46%	-208%	22%	64%	25%	-204%	-37%	112%	100%	-220%
Hit animal		3%	100%	39%	-410%	NA	-107%	NA	NA	NA	-75%	202%	100%	-407%
Target		52%	77%	39%	-7%	32%	66%	74%	19%	70%	47%	29%	94%	0%
Total		47%	81%	7%	15%	19%	36%	64%	19%	-48%	27%	37%	88%	-35%

^ Add left turn lane
* Add signal
Bold means target crashes
NA denotes no crashes during the before or total study period
Note that reduction factor can not be greater than 100%
Negative reduction factors indicate an increased crash rate

There were three study sites in the curve realignment group. Site 1003 and 1005 were studied in Phase I, and were updated by adding new data. The 90 percent confidence interval was 16 to 100 percent for target crashes, and 12 to 89 percent for total crashes, both showing significant reductions. From Table 4, we can also see that the lower bound of the crash reduction interval for non-target crashes such as intersection multi-vehicle crashes other than head-on and rear-end, multi-vehicle non-intersection crashes is negative, which implies these crashes are not necessarily reduced.

The observation of the increase of multi-vehicle non-intersection crashes at site 1005 is consistent with what we observed in Phase I. This is due to the three crashes occurring at driveways near the intersection in the after period, which might imply that straightening the curve increased the vehicle speed in the vicinity of the intersection and these driveways, so the driveways became more dangerous. We also observed that multi-vehicle intersection crashes other than head-on and rear-end crashes were increased at site 2012. This is the only site with traffic signal control for the before period, with an average daily traffic of more than 20,000 vehicles entering the intersection, suggesting that these factors reduce the effectiveness of the treatment for crash reduction.

Among the nine sites in the angle realignment group, Site 1002 and 1004 were studied in Phase I, and crash data for them was updated in this Phase. The target crashes have a 90 percent confidence interval of 0 to 94 percent, suggesting that the treatment has a positive effect on reducing target crashes. The total number of crashes decreased at eight of the study sites, but increased at site 2023. The lower bound for the 90 percent confidence interval was –35%, which showed some uncertainty in the overall safety benefits. Head-on crashes at the intersection decreased substantially at all sites. Run-off road crashes increased at four out of the eight sites that were applicable, and hit animal crashes also had great variance among the study sites.

Figure 13 presents the likelihood curves of total crash reduction for the curve realignment group. The most likely value for the crash reduction factor is approximately 0.5 on the plot. This is consistent with the value obtained using the point estimation method in Table 4 (0.51). The likelihood curves also provide a clear picture of the uncertainty surrounding the most likely value. It is clear that the shape of the likelihood function obtained in this Phase is narrower than that in Phase I (*c.f.* Figure 4-17). The curve is located at the positive part of the axis indicating that the improvement is effective in reducing total crashes.

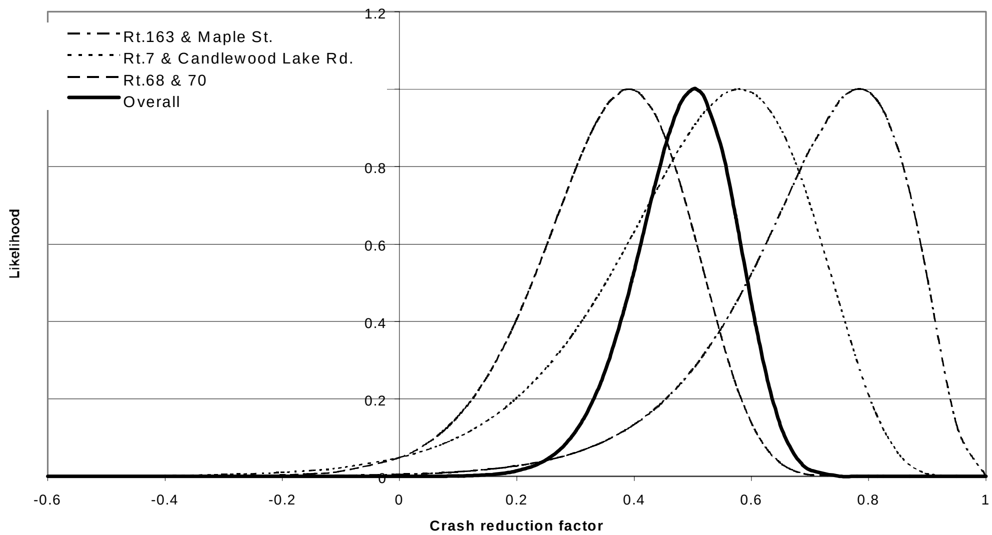

Figure 13. Total Crash Reduction Likelihood Functions for Curve Realignment

Figure 14 gives the same information for angle realignment by group. Each curve on the plot summarizes the total crash reduction in a group, and the 'overall' curve summarizes likelihood function for all sites that experienced angle realignment treatment. The most likely value is 0.30, also close to the group mean of 0.27 in Table 5, and the shape of the curve is also narrower than that of Phase I (c.f. Figure 4-13). Almost all points on the curve are located between 0.1 and 0.5 indicating the effect of the improvement on total crash is positive.

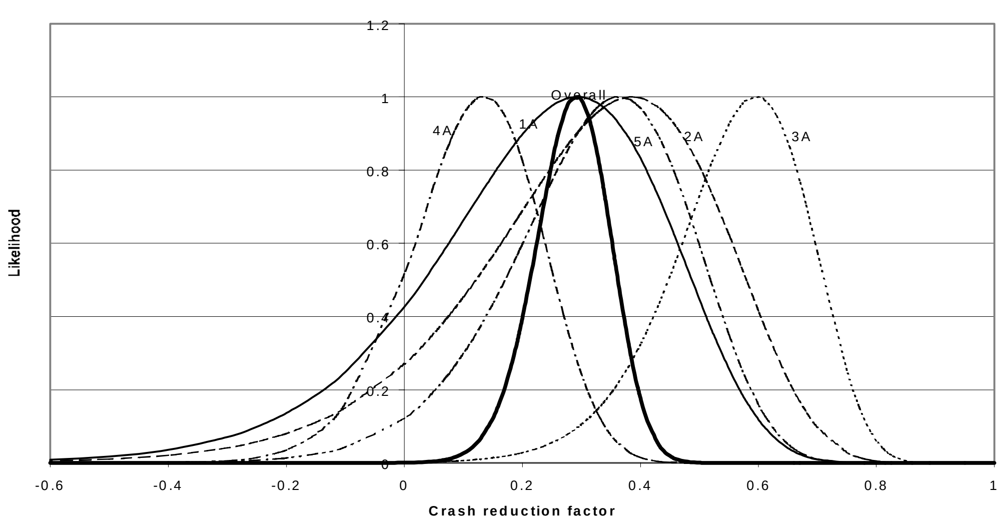

Figure 14. Total Crash Reduction Lieklihood Functions for Angle Realignment

There is variance among the reduction factors, which may be due to some differences in the site characteristics at each location. In this Phase, we tried to explain some of the variance by looking at these site characteristics such as area type, traffic volume, and driveway numbers in vicinity.

Some of the study sites are located in a rural area and some are in a more suburban area. After studying some of the site characteristics we found that the suburban sites tend to have lower crash reduction factors than rural sites. Suburban sites usually have more driveways in the vicinity of the intersection and higher traffic volumes. These factors likely complicate the effectiveness of the safety improvement. Figure 15 shows the relationship between traffic volume and crash reduction factors. The tendency on the plot is that the higher the traffic volume, the lower the crash reduction factor. Figure 16 gives some idea of how the number of driveways relates to the crash reduction factors. Here the tendency on this plot is also negative: the more driveways in the vicinity of the intersection, the lower the crash reduction factor tends to be.

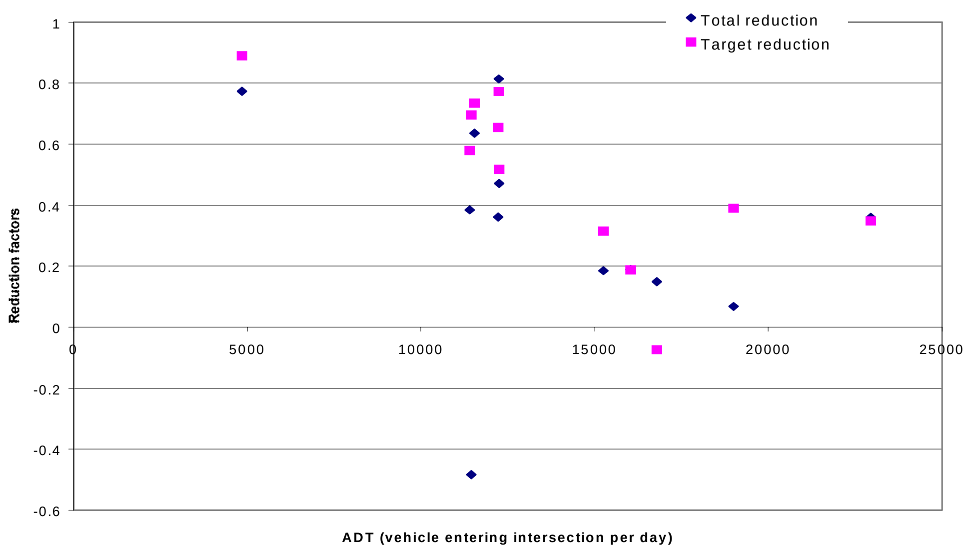

Figure 15. Traffic Volume and Crash Reduction Factor

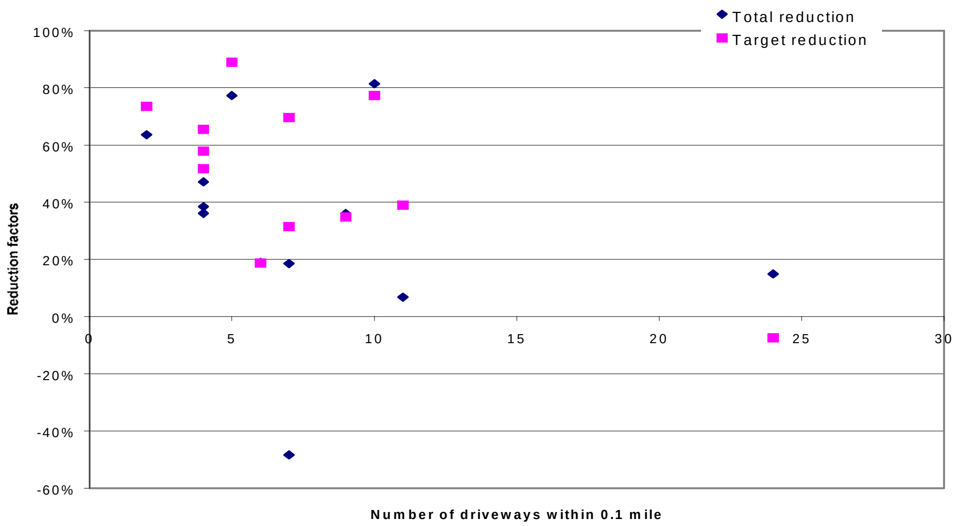

Figure 16. Number of Driveways and Crash Reduction Factor

Also, some of the sites were treated with other improvements such as adding a left turn lane or adding a traffic signal at the time of the realignment. In this kind of situation, it is hard to separate the effect of a single type of improvement. These other factors might contribute to the variance among the crash reduction factors, too.

Consequently, an analysis of variance was carried out to determine whether or not combining treatments results in additional safety benefits compared with one treatment alone. Table 6 presents the analysis data for the relevant sites. The null hypothesis is that the mean value is the same for each combination of treatment and the alternative hypothesis is that the mean value is different for each. The ANOVA results are shown in Table 7. In this case, we regard the two treatments as independent from each other and the residual of the crash reduction factor to be normally distributed. The results direct us to fail to reject the null hypothesis that all the means are the same at the 90 percentage significant level, because F-value is smaller than $F(1,5 \mid 90\%)=4.06$ or P-value is larger than 0.10. Thus, there is no significant difference between the crash rate reduction factor of the two treatments. Table 8 summarizes the effect of these factors for total and target crashes by area type. Intersection realignment combined with adding left turn lane, or adding traffic signal, or adding both treatments do not appear from this table to have extra benefits in reducing the total number of crashes. One reason for this may be that sites treated with the other two types of improvement normally also have higher traffic volumes, so these two factors are highly correlated. And as we observed, high traffic volume sites tend to have lower crash reduction. Another possible reason is some improvement types may be designed to reduce a certain type of crash (adding left turn lane to reduce rear-end crashes) or may be designed to reduce the overall crash severity (adding traffic signal may actually increase rear-end crashes but the crashes would be less severe than angle collisions). Thus they do not necessarily reduce the total crash rate.

TABLE 6. Crash Rate Reduction for Various Treatments

ID	Site name	Town name	Treatment type*	Crash rate before treatment	Crash rate after treatment	Crash reduction factor P_{ij} (%)
1003	Rt.163~Maple St	Montville	1	2.522	0.580	77%
1005	Rt.7~Candlewood lake Rd	New Milford	1	2.217	1.375	38%
2012	Rt.70~Rt.68	Cheshire	1	1.854	1.186	36%
2013	Rt.44~Tolland St	East Hartford	1	3.295	2.802	15%
2020	Rt.174~Carr Ave	Newington	1	1.111	0.404	64%
1002	Rt.79~Sr.540	Madison	2	1.385	0.885	47%
2019	Rt.123~Old Norwalk Dr	New Canaan	2	1.867	0.989	36%

*: 1: Realignment only
2: Realignment + left-turn lane added

TABLE 7. ANOVA Model for Comparison of Crash Rates

Source	DF	Sum of Squares	Mean Square	F-value	P-value>F
Model	1	0.00089286	0.00089286	0.02	0.9029
Error	5	0.27105000	0.05421000		
Corrected Total	6	0.27194286			

Table 8. Average Most Likely Value

Crash type	Area type	realign only	realign + signal	realign + left turn	realign + both	**overall**
Total crashes	Rural	58%	NA	42%	19%	**48%**
	Suburban	41%	11%	NA	-48%	**11%**
	Overall	53%	11%	42%	-15%	**33%**
Target crashes	Rural	65%	NA	59%	32%	**58%**
	Suburban	46%	16%	NA	70%	**39%**
	Overall	59%	16%	59%	51%	**50%**

In Phase II study, we used crash data of control group sites to adjust the observed crash data at study sites and mitigate the regression-to-mean effect. But how much of this effect has been reduced? Figure 17 provides the comparison of our results with that of a simple before-and-after study for all the sites. We can see that the regression-to-mean effect exists in almost all the cases, and the magnitudes of this effect vary. In site 2020, the regression-to-mean effect appeared to be negative, and this might imply that the improvement was implemented for reasons other than a high crash frequency.

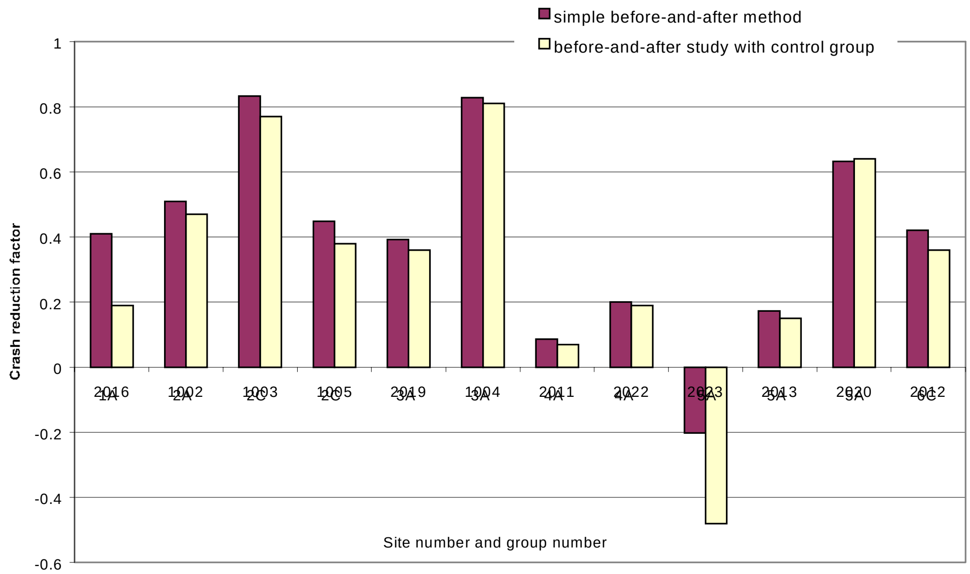

Figure 17. Comparison of Simple and Enhanced methods

CONCLUSIONS

The purpose of Phase II was to apply the procedure developed in Phase I and obtain a crash reduction factor with statistical validity for intersection realignment. We refined our data collection and analysis procedures by greater numbers of analysis sites and larger quantities of data. This includes both additional sites that received the treatment (study sites) and similar sites that were not treated (control sites). Intersection realignment improvement was distinguished between main road curve and side road approach realignment. Study intersections involve either a curve on the main road being straightened, or a skewed approach leg being realigned. Intersections and road sections that also have similar problems and similar background conditions which were not improved served as control cases to establish the base line crash rates that would be expected if no improvement were implemented. The crash data of control sites were used to estimate group mean and variance of crash frequency for the intersections, and the observed crash count at study sites were adjusted by group mean and variance to estimate the expected crash frequency. By doing this, the regression-to-mean effect was mitigated and more statistically robust results were obtained.

Both of the improvements studied appeared to reduce the total number of crashes within 0.1 mile of an intersection, and the effect varies for different types of crashes. The treatment does not necessarily reduce all types of crashes, but instead might increase some. For the curve realignment improvement, run-off road crashes, head-on and rear-end crashes at the intersection have greater reduction than other types of crashes. The crash reduction for angle realignment differs noticeably by location, and run-off road crashes increased at some sites.

Crash reduction factors were also classified according to site characteristics such as area type, traffic volume, and number of driveways in vicinity. All of these factors appeared to help explain the crash reduction factor's magnitude.

In addition, over all the treatments, the variance from case to case is large. For instance, the reduction factor for realignment treatment changes from site 1003 (77%) to site 1005 (38%). Therefore, it is alarming to note that the sample mean is not sufficient enough to represent the population mean because the sample size is too small or the samples are not selected randomly. For instance, the average reduction factor is 44% after the realignment treatment. But it is highly likely that the average reduction factor for the limited number of sites treated with realignment is not a fitted or precise estimate of the population mean for all the sites with realignment treatment.

Based on the limited data in the exploratory study, intersection realignment combined with adding left turn lane do not appear to have extra benefits in reducing total number of crashes from this table. However, the conclusion gives traffic engineers some ideas that the benefits of comprehensive treatments are not always greater than they are separately.

In Phase II study, some site characteristics such as area type, number of driveways in vicinity, traffic volume did appear to have some effect on the crash reduction factor, but their statistical significance wasn't tested, and they also need to be quantified in future study. Also the effect of one improvement combined with other improvements deserve to be further studied.

In Phase II, we used the Empirical Bayesian method to estimate crash rate for a study site from its control group sites. Time trend in data wasn't considered, and also effect of exposure was assumed to be linear over the number of crashes. In the next phase, the effect of these factors will need to be considered and used to calibrate the EB method.

Given these findings, we recommend that engineers charged with highway design (for new construction and reconstruction as well as safety retrofitting) consider the following:

- If a road section being considered for curve re-alignment does not experience a high rate of run-off-road or head-on crashes, straightening the curve is likely to have little benefit. In fact, such a reconstruction is likely to increase the rate of intersecting-vehicle crashes, particularly if there are a lot of driveways and local road intersections along the section.

- If a skewed intersection approach being considered for re-alignment does not experience a high rate of head-on crashes, re-aligning the approach is likely to have little benefit. This is particularly true in more densely developed areas, where run-off-road and rear-end crashes are likely to increase with such an intersection re-alignment.

- Both roadway improvements (curve re-alignment and intersection approach re-alignment) tend to reduce one or more types of crash, but increase other types of crash. Fortunately, the crash types each tends to reduce tend to be more severe than the types that they increase; for example, curve realignment tends to reduce run-off-road and head-on crashes and increase intersecting-vehicle crashes. Consequently, if a candidate road section or intersection does not experience the types of crash expected to be reduced by a proposed realignment, there will be little benefit to performing the improvement, and in fact, there may be a negative impact.

- The phenomena described in the above bullet items relate directly to the traffic calming issue being given a great deal of attention in traffic engineering circles lately. In particular, widening and straightening roads reduces run-off road and head-on crashes, but also facilitates higher vehicle speeds. This is not appropriate in built-up areas where higher speeds would be dangerous in the context of frequent local road intersections and driveways or presence of pedestrians. Instead, curve straightening should be considered only on roadways where speed limits of 45 mph or greater are appropriate; in other cases lower design speed curves are appropriate and in fact an important part of design consistency.

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