Safety Benefits of Intersection Approach Realignment on Rural Two-Lane Highways

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One task of traffic safety engineers is the identification of high crash locations and selection of appropriate highway treatments to reduce the number of crashes. This process relies on the availability of accurate information on crash reduction factors of various treatments. Currently, most agencies rely on information dating back to the 1960s. It is necessary to update and reassess these factors using new data and new evaluation methods. A before-and-after study is currently being conducted using empirical Bayesian methods to estimate crash reduction factors for modern conditions on two-lane rural highways. The results of the second phase of the study are reported, which aimed to evaluate the safety benefits of intersection approach realignment. Furthermore, an analysis of variance model is used to identify extra benefits of comprehensive treatments. The improvements studied appeared to reduce the total number of crashes, but the effect on type of crashes was different. Also, combining realignment with adding a left-turn lane or traffic signal does not appear to offer significant additional benefits in crash reduction.

An important aspect of traffic engineering is improving the safety of highways. Highway improvements, such as adding left-turn lanes, widening travel lanes, flattening sharp curves, or realigning intersection angles, are regarded as effective methods to reduce the number of crashes. 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 small budget more effectively. But as noted in previous publications by the authors (*1, 2*), currently much of this estimation process is done on the basis of a study using data over 50 years old, and there is a need to update the predictions of crash reduction rates using new observations.

Ongoing research into updating these crash reduction factors is described 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.

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In the Phase I study, four rural, two-lane intersections with varying background conditions were examined, which were 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. Because of the scope of work for the first phase of the project, comparison with groups of similar sites was not applied.

In Phase II, data collection and analysis procedures were refined using greater numbers of analysis sites and larger quantities of data. The focus in this phase was on the collection of 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 baseline crash rates that would be expected if no improvement were implemented. This was done to avoid the common regression-to-the-mean problem.

Furthermore, in the past 40 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. The combined effects of realigning a roadway along with adding a signal or left-turn lane were studied on a preliminary basis to learn if combining these treatments results in extra safety benefits.

STUDY METHODOLOGY

Before-and-After Method

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

One approach is the use of matched-control-group methods that involve a classical experimental design (*3, 4*). 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 the before and after periods of the control group are required. Theoretically, this type of method avoids the regression-to-the-mean effect completely and the problem of bias does not arise, but the method has some practical difficulties because of the extensive data requirements.

The empirical Bayesian (EB) method was introduced by various researchers (*3–8*) 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 a control group consisting of counts from a reference group of sites similar to the treated sites. 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 (*3, 5*) and Hauer and Persaud's (*4*) studies, m is defined as the expected number of crashes at a location, and the actual count of crashes that 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-the-mean effect.

Hauer (*3*) and Hauer and Persaud (*4*) derived the following formula to estimate m for a site at which the observed crash count is x:

$$\epsilon = x + \{E(m)/[\mathrm{VAR}(m) + E(m)]\}\ [E(m) - x] \tag{1}$$

which can also be written as

$$\epsilon = \alpha E(m) + (1 - \alpha)x \tag{2}$$

where

ϵ = estimator of m for intersection that recorded x crashes,
x = crash count,
$E(m)$ = expected value of m,
$\mathrm{VAR}(m)$ = variance of m, and

$$\alpha = [1 + \mathrm{VAR}(m)/E(m)]^{-1} \tag{3}$$

The following equations are provided by Hauer (*5*) to calculate $E(m)$ and $\mathrm{VAR}(m)$ for populations having a gamma distribution:

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

$$\mathrm{VA\hat{R}}(m) = s^2 - \overline{X} \tag{5}$$

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, and 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 (*9*). Al-Masaeid et al. (*7*) 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 EB method were generally comparable with the results obtained from analysis using the before-and-after study with the 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. (*10*) 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 with regard to 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 (*11*). When the improvement sites are considered only on the basis of critical crash count and no other factors, 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 the before-and-after estimation, the EB estimator becomes inconsistent. Therefore, Davis suggested that when estimating effects of traffic safety measures, site selection is included as part of the overall assessing procedure.

Another important part of crash reduction studies 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 (*3*) were given in the Phase 1 report (*1, 2*).

Likelihood measures the possibility of different expected values for crash reduction because of the safety treatment when the outcome of the treatment has been observed. The likelihood function is of the following form:

$$L(\theta) = \prod_{i=1}^{n} \theta^{N_{A_i}} [B_i + \alpha_i + (V_A/V_B)_i A_i \theta]^{-(N_{B_i} + \beta_i + N_{A_i})} \tag{6}$$

$$\alpha_i = \overline{N}_{B_i} \Big/ \left| S^2_{B_i} - \overline{N}_{B_i} \right| \tag{7}$$

The parameters α_i and β_i are estimates given by

$$\alpha_i = \overline{N}_{B_i} \Big/ \left| S^2_{B_i} - \overline{N}_{B_i} \right| \tag{8}$$

$$\beta_i = \overline{N}^2_{B_i} \Big/ \left| S^2_{B_i} - \overline{N}_{B_i} \right| \tag{9}$$

where

$\overline{N}_{B_i}$ = sample mean of the number of before crashes for the group to which site i belongs,
$S^2_{B_i}$ = sample variance of the number of before crashes for the group to which site i belongs,
$(V_A/V_B)_i$ = ratio of exposure in the after to the before period for site i,
N_{B_i} = observed number of before crashes for site i,
N_{A_i} = observed number of after crashes for site i,
B_i = number of years in the before period for site i, and
A_i = number of years in the after period for site i.

The variable θ serves as the index of the safety effect. If a measure reduces the expected number of accidents to 90 percent of its previous value, then $\theta = 0.90$. If a measure causes an increase of 5 percent, then $\theta = 1.05$. In other words, the reduction factor is $1 - \theta$. The $L(\theta)$ value is scaled between 0 and 1: the larger the value of $L(\theta)$, the more likely is the value of $1 - \theta$ to be the true reduction factor.

Analysis of Variance

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. The crash rate reduction is a dependent variable that is regarded as the basic criterion for evaluating the benefit of the improvement. The treatment type is an independent variable. The ANOVA model is as follows:

$$P_{ij} = \mu + \alpha_i + \epsilon_{ij} \quad (10)$$

where

P_{ij} = crash rate reduction of site j with treatment i,
μ = overall effect on the sites (such as weather, traffic volume, and geometric design),
α_i = effect due to treatment i, and
ϵ_{ij} = errors that are identically and independently distributed.

The null hypothesis is that the effects because of treatments are the same. If the hypothesis is not rejected, it must be concluded that there is no significant difference between the two treatments.

STUDY DESIGN

On the basis of the Phase I result, the study was continued 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 from the control group. Intersections that have similar problems and similar background conditions that were not improved served as control cases to establish the baseline crash rates that would be expected if no treatment was implemented.

Site Selection

Locations were restricted to intersections on suburban and rural two-lane highways that had been the subject of roadway realignment projects. As in the previous phase, study sites involve either a curve on the main road being straightened, which is referred to as *curve realignment*, or a skewed intersection approach leg on the side road being realigned, which is referred to as *angle realignment*.

The study sites are selected from a ConnDOT preconstruction management system 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. The 12 study sites are listed in Table 1. Crash data were available from January 1989 to June 1998; all of the study sites selected have a before period of at least 3 years and an after period of at least 7 months.

To select control sites, the study sites were classified into seven groups, as shown in Table 1, according to their population density, presence of a signal, and left-turn arrangement. An "A" in the group name indicates that the treatment approach was angle realignment; a "C" in the name indicates curve realignment. Intersection Route 70 and Route 68 in Group 6C is the only study site with a traffic signal for the before period. For each group, at least five control sites are selected.

Data Collection and Preparation

Geometric and crash data for study sites were collected within 0.16 km (0.1 mi) of each approach of the intersections with the same variables. Crashes occurring during the construction period were excluded from the analysis. The average daily traffic vehicle entering each intersection was used as traffic exposure. Table 1 lists some of the important physical characteristics for the study sites.

Because of the difficulty of retrieving large amounts of data, crash data for the control sites were collected only from 1993 to March 1997. The expected crash frequency and variance for each group were calculated on the basis of these data. This is accomplished using the assumption that there was no time trend in these crash data because the data in this time period (1993 to 1997) were used to represent the general situation in the long run. Table 2 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

TABLE 1 Important Before Site Characteristics

Control group	Site ID	Intersection	Town	Before crash	After crash	Treatment	Population density**	Signal	Left turn	Number of driveways
1A	2016	Rt. 6 & Rt. 316	Andover	29	23	1,3,4	170	no*	no*	7
2A	1002	Rt. 79 & Sr.450	Madison	40	19	1,4	440	no	no*	4
2C	1003	Rt.163 & Maple St	Montville	19	3	2	400	no	no	5
	1005	Rt.7 & Candlewood Lake Rd	New Milford	40	18	2	400	no	no	4
3A	2019	Rt. 123 & Old Norwalk Dr	New Canaan	34	14	1,4	820	no	no*	4
	1004	Rt.106 & Weed St	New Canaan	53	5	1,5	820	no	no	10
4A	2011	Rt. 5 & 150	Wallingford	53	81	1,3	1100	no*	no	11
	2022	Rt.71 & 150	Wallingford	69	53	1,5	1100	no	no	6
5A	2023	Rt. 69 & Wolcott St	Bristol	86	6	1,3,4	2300	no*	no*	7
	2013	Rt.44 & Tolland St	East Hartford	156	13	1	2700	no	no	24
	2020	Rt.174 & Carr Ave	Newington	16	8	1	2200	no	no	2
6C	2012	Rt. 70 & Rt.68	Cheshire	66	36	2	840	yes	yes	9

Treatment: 1. Approach angle realignment; 2. Horizontal curve realignment; 3. Add signal; 4. Add left turn lane; 5. Remove island.
* feature was added with improvement. ** people per square mile.

TABLE 2 Control Group Statistics and Crash 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; $\varepsilon = x + \{E(m)/[\text{VAR}(m) + E(m)]\}\,[E(m) - x]$; $\lambda = x$ /average daily traffic (ADT); ADT $\lambda_\varepsilon = \varepsilon / ADT$.

before period, the expected crash frequency was estimated for the study sites (ϵ) from their control group statistics and their actual crash counts (x); the expected crash rate (λ_ϵ) was calculated for the before period using ϵ. λ_ϵ was used for comparison with the after crash rates and to obtain the crash reduction factors.

ANALYSIS

Crashes were classified into different categories in order to study the safety effect of the improvement on different crash types. One type is the multivehicle nonintersection crash; these crashes occur within 0.16 km (0.1 mi) 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 into the category of other in order to study the effect of driveways on the crash reduction factor. Another category is the multivehicle intersection crash; these are the crashes that occur directly at the intersecting point and because of 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 separated out because there was a large number of this crash type for the before period at one of the study sites in this group. The study aimed to analyze the occurrence of these crashes after the treatment. The other large 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 intersection, run-off-road, and hit-animal crashes were considered to be the target crashes (crashes the treatment was expected to reduce). Multivehicle 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 to get better ideas of how they distributed around the most likely values of the crash reduction. The effect of other factors such as traffic volume and driveways on the crash reduction factor was also studied. Some of the sites received other treatment such as the addition of a left-turn lane and addition of traffic signals at the time of the realignment treatment; the comprehensive effect of these treatments on reducing crashes was also examined.

RESULTS

Tables 3 and 4 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

TABLE 3 Crash Rate Reduction Factors for Curve Realignment

Crash Category		1003 (2C)	1005 (2C)	2012 (6C)	Mean	Std. Dev.	90% upper	90% lower
Multivehicle nonintersection	Driveway	100%	-584%	56%	-143%	383%	100%	-773%
	Other	43%	2%	16%	20%	20%	54%	-13%
	Subtotal	52%	-71%	50%	10%	71%	100%	-106%
Multivehicle 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%

Bold means target crashes; NA denotes no crashes during the before or total study period. Note that reduction factor cannot be greater than 100%; negative reduction factors indicate an increased crash rate.

TABLE 4 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
Multiveh nonint		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 cannot be greater than 100%; negative reduction factors indicate an increased crash rate.

confidence intervals, and the values are presented as percentages. Since the reduction factor cannot be greater than 100 percent, the upper limit was set to be 100 percent. There were three study sites in the curve realignment group. 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 3, what can also be seen is that the nontarget crashes such as intersection multivehicle crashes other than head-on and rear-end and multivehicle nonintersection crashes have a negative lower bound of crash reduction, which implies these crashes are not necessarily reduced by the treatment.

The observation of the increase of multivehicle nonintersection crashes at Site 1005 is consistent with what was observed in Phase I (*1, 2*). This is because of 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, thereby making the driveways become more dangerous. Also, it was observed that multivehicle intersection crashes other than head-on and rear-end crashes increased at Site 2012. This was 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 may reduce the effectiveness of the treatment for crash reduction.

In the angle realignment group, the target crashes had a 90 percent confidence interval of 0 to 94 percent, suggesting that the treatment can have a positive effect on reducing target crashes. The total number of crashes was reduced at eight of the study sites but increased at Site 2023. The lower bound for 90 percent confidence interval was −35 percent, which showed some uncertainty in the overall safety benefits. Head-on crashes at the intersection were reduced 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 1 presents the likelihood curves of total crash reduction for the curve realignment group. The most likely value for the crash reduction factor is about .5 on the plot. This is consistent with the value obtained using the point estimation method in Table 3 (.51). The curve located at the positive part of the axis indicates that the improvement was effective at reducing total crashes.

Figure 2 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 .30, which is also close to the group mean of .27 in Table 4. Almost all points on the curve are located between .1 and .5, indicating the effect of the improvement on total crash is undeniably positive.

There is variance among the reduction factors, which may be because of some different site characteristics at different locations. In this phase, some of the variance was explained by examining site characteristics such as area type, traffic volume, and driveway numbers in the vicinity.

Some of the study sites are located in clearly rural areas, whereas some are in suburban areas. From a study of the site characteristics, the suburban sites were found to tend to have lower crash reduction factors than did the rural sites. Suburban sites usually have more driveways and higher traffic volumes, which may be the factors that reduce the effectiveness of the safety improvement. From the scatter plots of the relationship among traffic volume, number of driveways, and crash reduction factors, it is clear that (*a*) the higher the traffic volume, the lower the crash reduction factor, and (*b*) the greater the number of driveways in the vicinity of the intersection, the lower the crash reduction factor (see Figures 3 and 4).

Also, some of the sites were treated with improvements such as adding a left-turn lane or adding a traffic signal at the time of the realignment. In these situations, it is difficult to separate the effects of a single type of improvement. These factors might contribute to the variance among the crash reduction factors as well.

Consequently, an ANOVA was carried out to determine whether or not combining these treatments resulted in additional safety benefits. Table 5 presents the analysis data. 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. The ANOVA results are shown in Table 6. In this case, the two treatments were regarded as independent from each other; the residual of the crash reduction factor is normally distributed. The results suggest that we fail to reject the null hypothesis that all the means are the same at the 90 percent significant level. This is because the f-value is smaller than $f(1,5 \mid 90 \text{ percent}) = 4.06$ or the p-value is larger than .10 (*12*).

In the Phase II study, crash data of control group sites were used to adjust the observed crash data at study sites in an attempt to mitigate the regression-to-the-mean effect. Figure 5 compares the results of the simple before-and-after study data for all the sites. The regression-to-the-mean effect exists in almost all the cases, and the magnitudes of this effect vary. In Site 2023, the regression-to-the-mean effect appears to be negative, and this might imply

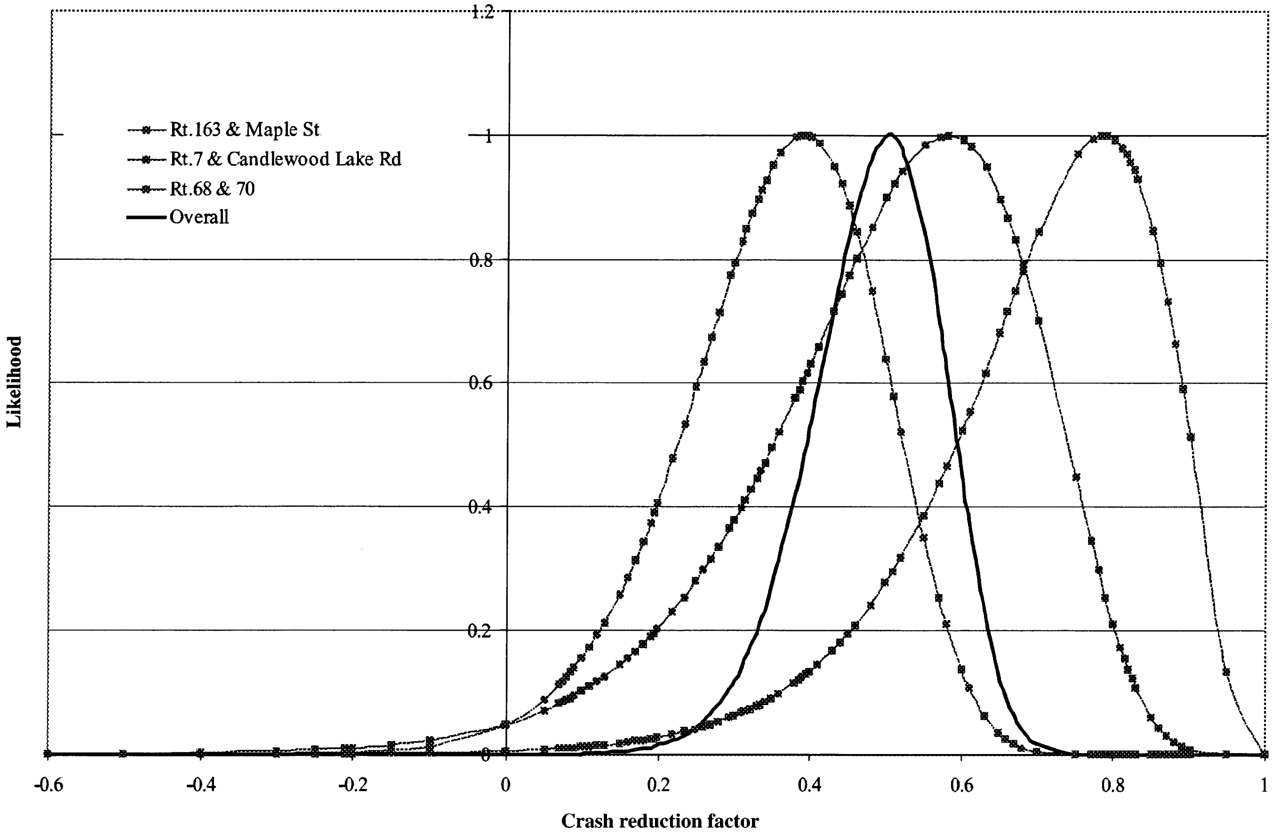

FIGURE 1 Total crash reduction likelihood functions for curve realignment.

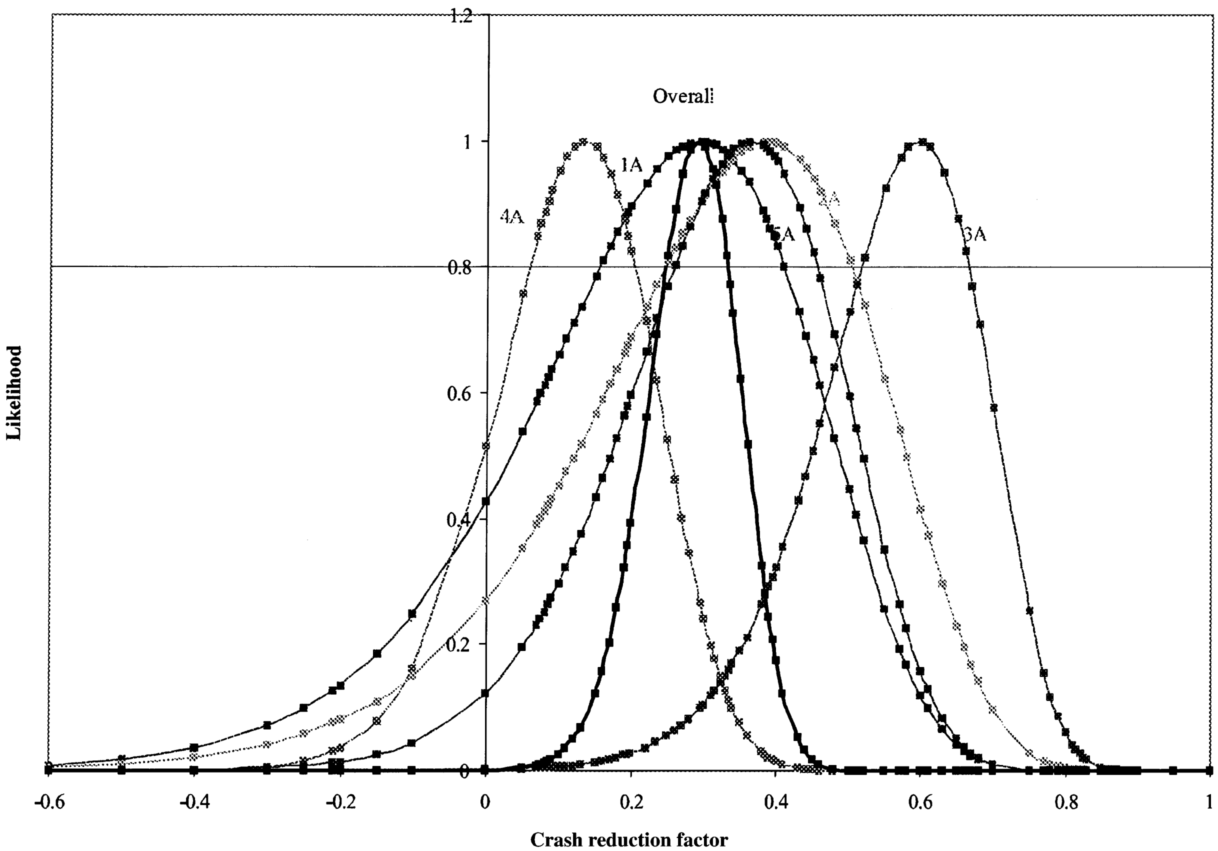

FIGURE 2 Total crash reduction likelihood functions for angle realignment.

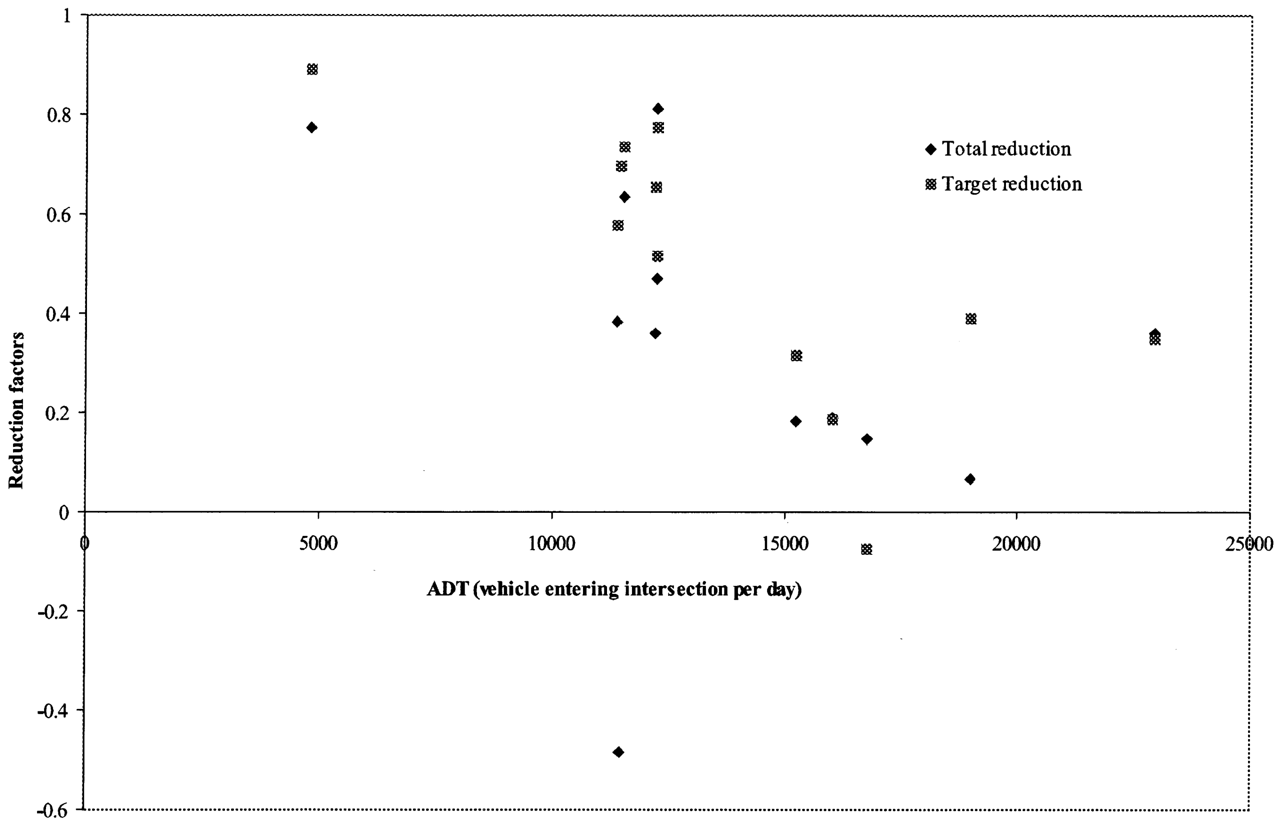

FIGURE 3 Traffic volume and crash reduction factors.

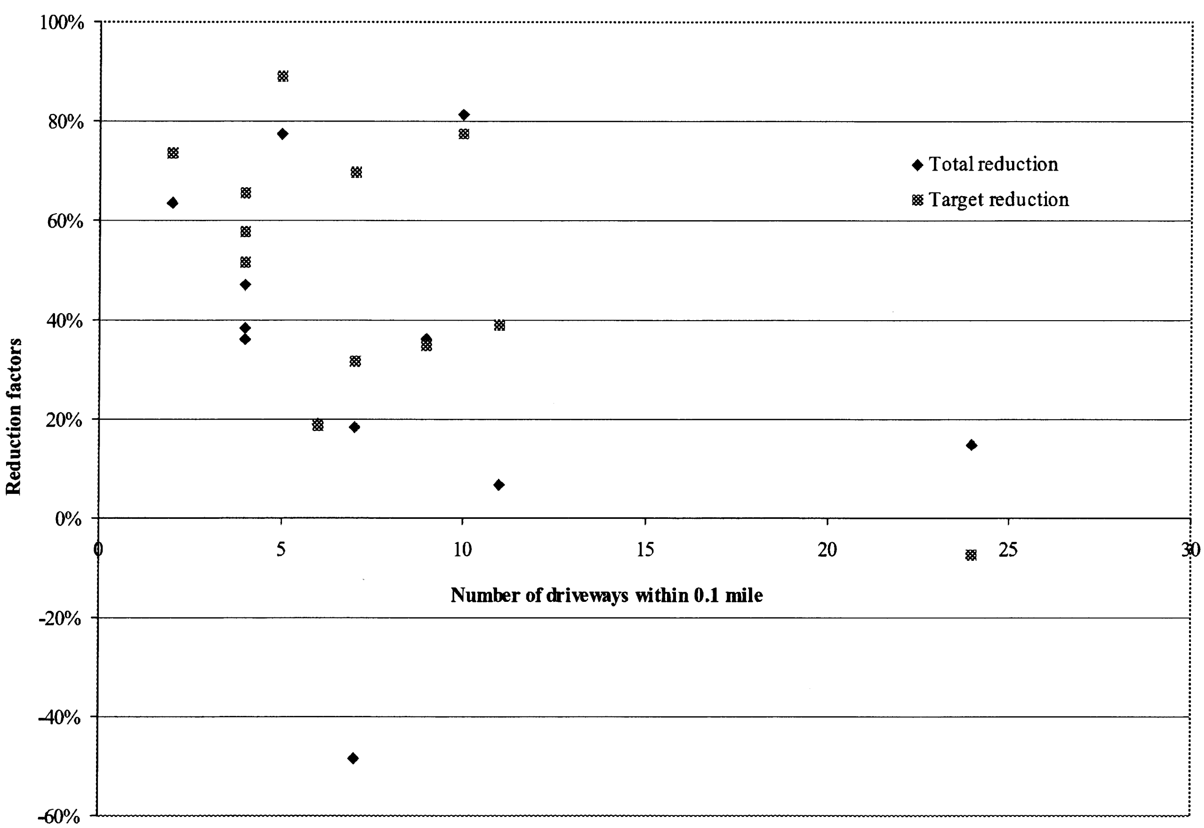

FIGURE 4 Number of driveways and crash reduction factors.

TABLE 5 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 6 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			

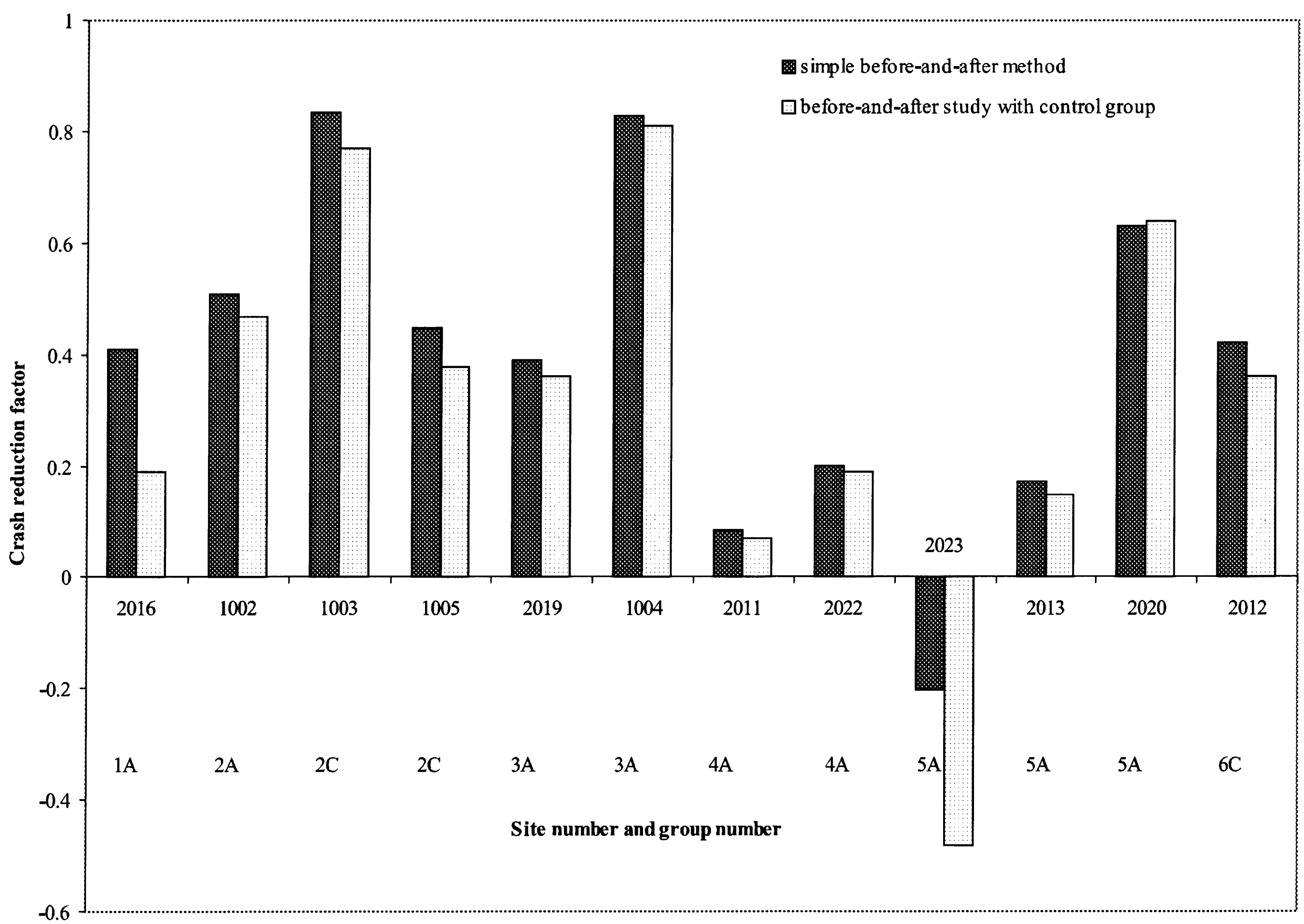

FIGURE 5 Comparison of before-and-after study data.

that the improvement was implemented for reasons other than a high rate of crashes.

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. Data collection and analysis procedures were refined by the greater numbers of 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. Study intersections involve either a curve on the main road being straightened or a skewed approach being realigned. Intersections and road sections that have similar problems and similar background conditions that were not improved served as control cases. The controls established the baseline 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. The observed crash count at each study site was adjusted by group mean and variance to estimate the expected crash frequency.

Both of the improvements studied appeared to reduce the total number of crashes within 0.16 km (0.1 mi) of intersections. The effect on different types of crashes was different. The treatment did not necessarily reduce all types of crashes but instead might have increased some. For the curve realignment improvement, run-off-road crashes and head-on and rear-end crashes at the intersection were more greatly reduced than other types of crashes. The crash reduction for angle realignment differed noticeably by location. Run-off-road crashes increased at some sites.

Crash reduction factors were also classified to site characteristics such as area type, traffic volume, and number of driveways in the 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 was large. For instance, the reduction factor for curve realignment treatment changes from Site 1003 (77 percent) to Site 1005 (38 percent) varied considerably. Therefore, it is alarming to note that the sample mean was not sufficient to represent the population mean because the sample size was too small or the samples were not selected randomly. For instance, the average reduction factor was 44 percent after the curve realignment treatment. But it is highly likely that the average reduction factor for the small number of sites treated with realignment was not a fitted or precise estimate of the population mean for all the sites with realignment treatment.

On the basis of the data in the exploratory study, intersection realignment combined with the addition of a left-turn lane does not appear to have extra benefits in reducing the total number of crashes. However, the conclusion provides traffic engineers with some indication that the benefits of comprehensive treatments are not always greater than those of separate treatments not used in conjunction with others.

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

In Phase II, the EB method was used to estimate the crash rate for a study site from its control group sites. Time trend in data was not considered. Also, the 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.

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