EFFECTIVENESS OF ROADWAY SAFETY IMPROVEMENTS

FINAL REPORT

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EXECUTIVE SUMMARY

Ninety-four traffic safety projects were analyzed to determine crash reduction factors and benefit/cost (B/C) ratios for seven different improvement categories. Confidence intervals for the various crash categories were also determined. New crash reduction factors and B/C ratios are recommended for five of the seven categories analyzed.

Overall analysis showed that the projects had a mean crash reduction rate of 23 percent. Hazard Elimination Safety (HES) projects accounted for a 40 percent decrease in crashes. Transportation Safety Funds (TSF) projects showed a 21 percent decrease in crashes. In all cases, the 90 percent confidence interval (the interval at which we can be 90 percent confident that the true mean lies within) is positive. The following table lists these factors and their confidence intervals.

Summary of Crash Reduction Factors by Funding Source

Category	Mean Crash Reduction	90% Confidence Interval Lower Limit	90% Confidence Interval Upper Limit
All projects	23%	12%	35%
HES projects only	40%	26%	54%
TSF projects only	21%	7%	34%

This research also analyzed benefit/cost ratios of improvement projects. The following table lists the B/C ratios and their confidence intervals by funding source. For all types of projects, a mean B/C ratio of 6.3 was determined. For HES projects, the mean B/C ratio is 2.6. For TSF projects, the mean B/C ratio is 6.9. The lower confidence interval limit for HES projects is a negative number. This is an indication that the true B/C ratio for the HES projects may be as low as –0.8. This is likely due to the small sample size available for analysis. Only nine HES projects had adequate data for this analysis.

Summary of Benefit/Cost Ratios by Funding Source

Category	Mean B/C Ratio	90% Confidence Interval Lower Limit	90% Confidence Interval Upper Limit
All projects	6.3	0.5	12.0
HES projects only	2.6	–0.8	6.0
TSF projects only	6.9	0.3	13.4

Adding turn lanes while modifying the signal phasing (i.e., adding left-turn arrows) had the highest crash reduction factor (58 percent). Replacing pedestal-mounted signals with mast arm mounted signals also had a significant effect (36 percent reduction). Adding turn lanes without signal improvements only reduced total crashes by 12 percent. However, the confidence interval spans from –12 percent to +36 percent, meaning that the true crash reduction factor for adding turn lanes may be negative. Similarly, projects that added a new traffic signal and turn lanes also indicated a lower confidence interval limit that was negative. The following table lists these factors and their confidence intervals.

Summary of Crash Reduction Factors by Project Type

Category	Mean Crash Reduction	90% Confidence Interval Lower Limit	90% Confidence Interval Upper Limit
New traffic signal	27%	7%	47%
New traffic signal + turn lane(s)	20%	–12%	51%
Add turn phasing to existing signal	36%	23%	48%
Add turn phasing + turn lane(s)	58%	46%	70%
Pedestal mount replacement	36%	28%	43%
Add turn lane(s)	12%	–12%	36%
Other geometric improvements	32%	11%	53%

Finally, the following table lists the summary of the benefit/cost ratios by project type. Pedestal mount replacement had the highest B/C ratio of all the project types (11.2). There were only two projects in the category of adding turn phasing to the existing signals; therefore, the ratio and confidence interval are not of much value.

Summary of Benefit/Cost Ratios by Project Type

Category	Mean B/C Ratio	90% Confidence Interval Lower Limit	90% Confidence Interval Upper Limit
New traffic signal	0.8	–6.6	8.2
New traffic signal + turn lane(s)	4.1	1.7	6.6
Add turn phasing to existing signal	1.3	–63.3	66.0
Add turn phasing + turn lane(s)	3.4	–1.0	7.8
Pedestal mount replacement	11.2	3.6	18.8
Add turn lane(s)	0.7	–6.0	7.4
Other geometric improvements	2.5	–2.2	7.2

Analyzing crash data is a very complex task. It has been generally known that making improvements of a certain type (e.g., adding a traffic signal) will oftentimes change the type of crashes rather than simply reduce the number of crashes. Therefore, just because a particular type of improvement shows that crashes may increase, a closer examination should be made into the type of crashes that are increasing and their severity.

In the cases above where the confidence interval included a negative number, the sample sizes are very small. More data should be collected before making any strong conclusions about those two particular types of projects.

More detailed information on each type of project and benefit/cost ratios can be found in the Data Analysis portion of this report.

With a couple of exceptions, it is recommended that the Iowa Department of Transportation use the total crash reduction factors and benefit/cost ratios that are shown in the preceding tables. Factors for categories turn phasing projects and other geometric improvements should not be adopted without further research. The sample size of turn phasing projects was very small. The types of projects included in other geometric improvements were varied and should probably not be lumped into one type of improvement project.

BACKGROUND

The Iowa Department of Transportation (Iowa DOT) maintains a comprehensive list of over 17,000 crash locations and regularly identifies and mitigates problems at the highest crash locations with funding from several sources. The Iowa DOT continuously assesses the likely causes of crashes at high-crash locations throughout the Iowa roadway network and designs solutions to reduce the incidences of crashes.

This research analyzed approximately 100 safety projects constructed in the past 10 years to see what affect they had on highway safety. The projects are grouped into seven categories as defined by their scope of work: (1) install new traffic signal, (2) add turn lane(s), (3) install new signal and turn lane(s), (4) add left-turn phasing, (5) add left-turn phasing and turn lane(s), (6) replace pedestal mount signals with mast arm signals, and (7) other geometric improvements.

The project makes use of an extensive statewide crash database. The results of the project will evaluate the assumed reduction factors and benefit/cost (B/C) analysis, determine the actual cost effectiveness of the Iowa DOT's safety programs, and allow the Iowa DOT to better prioritize future improvements.

LITERATURE REVIEW

The main purpose of a safety improvement is to reduce the number and severity of traffic crashes. It is important to know the effectiveness of these safety improvements. Once the effectiveness is known, proper allocation of future safety dollars can be made. The safety effectiveness can be measured in a number of ways. One such tool for measuring safety improvement effectiveness is a benefit/cost analysis. A benefit/cost analysis uses a benefit to cost ratio. The benefit portion of the ratio comes from the costs saved resulting from a reduction in traffic crashes. The cost portion of the ratio may include construction and maintenance costs. A before-and-after crash study can be used to determine the benefit/cost ratios.

A before-and-after study consists of four steps. The first step is site selection. Study sites with adequate accident data for periods before-and-after construction (i.e., two years before and after) should be selected (*1*). These sites should be selected in a random manner to be consistent with statistical sampling theories and to avoid bias. The second step is data collection and preparation. Geometric features, traffic volumes, and crash history should be gathered for all of the test sites. Also, sites with the same safety improvement can be grouped together. The third step in the before-and-after study process is the crash frequency estimation. In this step, the number of accidents that would be expected had the safety improvement not been implemented needs to be estimated. The use of control groups for this step is also possible. The fourth and final step in the process is the comparison and statistical inferences of the before-and-after data. Here the estimated after accident totals are compared to the actual total of accidents that occurred. Statistical inferences (i.e., confidence intervals) can be made (*1*).

In 1997, the Kansas Department of Transportation Bureau of Traffic Engineering performed a before-and-after crash reduction and benefit/cost analysis to measure safety improvements in the state of Kansas (*2*). In this study, four general types of safety improvements were studied: (1) new traffic signals, (2) upgrades of existing signals, (3) geometric changes with new traffic signals, and (4) geometric changes with an upgrade to existing signals. Three years of before and three years of after accident data were evaluated for each of the 90 projects studied. Data concerning the total number of accidents, accident severity, and type of collision were collected. To perform benefit/cost calculations, dollar values need to be assigned to fatalities and injuries in order to place a total cost on an accident. In the Kansas study, $2,100 was assigned to property damage only (PDO) accidents and a value of $126,300 was assigned to fatal and injury accidents. The percent crash reduction and respective benefit/cost ratio for the four categories of this study can be seen in Table 1 (*2*).

Table 1 Results of Kansas Department of Transportation Study

Category	Crash Reduction	Benefit/Cost Ratio
New traffic signals	45%	26
Upgrade of existing traffic signals	49%	26
Left-turn lanes with new signals	41%	9
Left-turn lanes with signal upgrades	62%	19

The Kansas study simply compared the number of before accidents to the number of after accidents in their analysis. Some researchers believe that this method of analysis does not provide accurate results due to a bias, making the improvements to appear more effective than they really are (*3*, *4*, *5*). Making the assumption that the number of accidents that can be expected to occur without treatment is equal to the number of accidents that occurred prior to the improvement is erroneous and may lead to biased results (*3*). The Kansas study made this assumption by comparing the number of before accidents to the number of after accidents. Another bias occurs when only high accident locations are studied. Sites with above "… average-accident numbers or rates must be expected to decrease in a subsequent period even without treatment, and vice versa" (*3*). In other words, high-accident locations are likely to show a decrease (or increase) in the number of accidents that occur in an "after" period due to natural fluctuations. This is known as the regression-to-mean phenomenon. However, oftentimes the regression-to-mean phenomenon is not accounted for since it is rarely statistically significant and does not greatly affect the results of the analysis (*3*).

The best way to debias the results is to use control locations similar to the locations being improved. However, a suitable number of control locations may not always be possible. In these circumstances, there are a couple of analytic methods that can be used to estimate the number of accidents that can be expected to occur had the treatment not been applied. The first method is known as the nonparametric method. This method relies on an assumption that crashes on any system are Poisson distributed. The nonparametric equation uses the following equation (*3*):

$$\alpha_k = [(k+1)N_{k+1}]/N_k$$

where

α_k = number of accidents expected to occur during an equivalent after period on a system that has k before accidents
N_{k+1} = number of systems with (k + 1) accidents in the population of similar systems
N_k = number of systems with k accidents in the population of similar systems

The second method for estimating the number of expected accidents is known as the empirical Bayesian Method. This method relies on two assumptions. The first assumption is that the number of accidents for a system follows a Poisson distribution. The second assumption is that the means for a population of systems can be approximated by a gamma distribution. The sample mean (*m*) and variance (s^2) for the systems in the population are calculated using crash data. The parameters of the gamma distribution (*b* and *c*) are calculated using the following relationships (*3*):

$$b = m^2 / \left(s^2 - m\right) \quad m < s^2$$

$$c = m / \left(s^2 - m\right) \quad m < s^2$$

The equation to estimate the number of expected accidents is

$$\alpha_k = (b + k)/(c + 1) \quad m < s^2$$

If the sample mean of the population is greater than or equal to the variance, α_k is equal to the mean (*m*). When these two methods are compared to actual after accident counts, the Bayesian Method appears to give better estimates while the nonparametric method tends to slightly overestimate the number of accidents (*3*).

The above equations are used when a system of locations is studied. If only one particular project location is considered, the expected number of crashes to occur (*m*) can be found using the following equation (*1*):

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

where

ϵ = the estimator of *m* for an intersection
x = before crash count
α = $(1 + \mathrm{VAR}\{m\}/E\{m\})^{-1}$
$E\{m\}$ = the expected value of *m*
$\mathrm{VAR}\{m\}$ = the variance of *m*

Another analysis method used to estimate the crash reduction is the likelihood function. “The likelihood function identifies the most likely value of crash reduction and presents the uncertainty surrounding it in a intuitively clear function” (*1*). The likelihood function is as follows (*4*):

$$L(\theta) = \prod_{i=1}^{n} \theta^{X_i'} \left[B_i + \alpha_i + \left(\varepsilon'/\varepsilon\right)_i A_i\theta\right]^{-\left(X_i + \beta + x_i'\right)}$$

where

θ = index of safety effect (as a decimal)
X_i' = number of accidents on entity *i* during the after period
X_i = number of accidents on entity *i* during the before period
B_i = number of before years studied
A_i = number of after years studied
(ϵ'/ϵ) = ratio of exposure of the after to the before period
α_i, β = statistical parameters

One of the reasons to use one of the above analysis methods is to eliminate the bias produced by studying high accident locations. This bias may produce crash reduction values that are over estimated. This does not mean however, that safety improvements at high accident locations are not as effective. Persaud evaluated data from studies on one-way stop controlled intersections in Philadelphia and two-way stop controlled intersections in San Francisco that were converted into all-way stop controlled intersections (*5*). Persaud concluded from these studies that "… the belief that the more accidents expected to occur at a site, the larger the safety effect of a measure is likely to be" is supported (*5*). Again, this is due to the fact that the regression-to-mean phenomenon may not greatly impact the estimated crash reduction results.

Once crash reduction values have been calculated, decision makers still may not be able to make a decision on the safety improvements effectiveness and whether these improvements should be used in the future. Another tool to help with the decision making process is the calculation of a critical accident-rate reduction value (*6*). The critical accident-rate reduction is the minimum relative reduction in accidents that can economically justify future implementations of a specific safety improvement. This can be calculated using the following net-present value (NPV) model (*6*):

$$\mathrm{NPV} = \mathrm{PVB} - \mathrm{PVC}$$

The present value of benefits (PVB) is defined as the present dollar value of the future reduction of accidents due to the safety improvement. The present value of the costs (PVC) is defined as the present dollar value of deploying and maintaining the safety improvement. The PVB and PVC can be calculated using the following equations (*6*):

$$\mathrm{PVB} = (\mathrm{AAR})(\Delta)(\mathrm{AC})(N)(\mathrm{SPW}_{i,n})$$

where

AAR = present average annual accident rate
Δ = percentage of reduction in *AAR* due to the safety improvement
AC = average dollar cost of an accident
N = number of sites at which treatment is to be deployed
$\mathrm{SPW}_{i,n}$ = series present worth factor for discount rate of *i* percent and analysis period of *n* years

$$\mathrm{PVC} = 2N\left[(\Delta C + \mathrm{LC} + \mathrm{MC}) + \left(\Delta C/m^2\right)\left(\mathrm{GPW}_{i,m}\right) + (\Delta C/m)\left(\mathrm{SPW}_{i,n-m}\right)\left(\mathrm{PW}_{i,m}\right)\right]$$

where

ΔC = materials cost difference between current and proposed improvement (in dollars)
LC = labor cost for implementing improvement
MC = mileage cost per treatment for installation crew
m = average life of improvement (in years)
$GPW_{i,m}$ = uniform gradient present-worth factor for discount rate of i percent over m years
$PW_{i,m}$ = present worth factor for discount rate of i percent over m years

If an NPV greater than zero is determined, then the safety improvement is economically feasible. Therefore, to find the critical crash reduction factor, set the NPV equal to zero and solve for Δ (*6*). If the crash reduction calculated from the before-and-after study is greater than the critical reduction factor, the safety improvement has been effective enough, from an economic point of view, to warrant its use in the future.

The methods discussed thus far require the use of crash data. In some situations, the crash data may not be accurate or available for the time periods required (i.e., three years before and after). In some cases, the crash data may be "… incomplete, erroneous, unavailable, or non-representative of long-term conditions due to factors other than the improvement at the project site" (*7*). Another problem that may be encountered is a lack of crashes to perform a statistically significant analysis. This is usually not a problem at high accident locations but may be a problem at low-volume or rural locations. If these problems or inconsistencies exist, a nonaccident measure of effectiveness may be required. Nonaccident effectiveness measures can be used for the following types of projects (*7*):

1. safety projects that impact traffic performance
2. need for a quick indication of project impacts
3. projects implemented to reduce hazard potential
4. projects involving staged countermeasure implementation

Examples of non-accident effectiveness evaluation may include travel time, delay, speeds, and driver behavior (*7*).

The first step in developing a non-accident analysis is to develop an evaluation plan that includes evaluation objectives, measures of effectiveness (MOEs), experimental plans, and data requirements. When determining the evaluation objectives, causal factors and contributory factors as well as the safety problem should be considered. Causal factors are the main reason the safety problem exists. Contributory factors are those that "… lead to or increase the probability of a failure in the driver, the vehicle, or the environment." Intermediate evaluation objectives are determined by examining how the casual and contributory factors will be affected by the implementation of the safety project (*7*). The theory behind this procedure is that if the causal and contributory factors are accounted for and minimized, the safety problem will be lessened.

Once the intermediate objectives are defined, MOE(s) should be assigned to each of the objectives. The MOE should "… reflect the quantitative measurements and units to be collected in the field to evaluate each intermediate objective." After the data concerning each of the intermediate objectives are obtained, the effectiveness of the safety project can be evaluated. The effectiveness is measured by the difference between the actual MOEs and the expected MOEs had the safety improvement not been implemented (*7*).

In conclusion, before-and-after studies can be an effective tool used to determine the effectiveness of a safety improvement. However, it has also been shown that before-and-after studies tend to overestimate the crash reduction for a specific safety improvement if care is not taken to avoid bias. There are several analytical methods that have been used to avoid bias from entering a study. Also, depending on the type of safety project and the availability of needed data (i.e., crash data, volumes, etc.), effectiveness can be measured by non-accident evaluations. Nonaccident evaluations require an observer to record various driver behaviors at a particular location. For example, recording the number of quick stops to avoid a rear-end collision would be an example of evaluating nonaccident data. The nature of this project did not allow the researchers to use this methodology.

ANALYSIS METHODOLOGY

Two different analysis methods were used in this study. The first method was a before-and-after benefit/cost analysis. The second analysis method was an estimation of the crash reduction factors for each type of improvement category.

Benefit/Cost Analysis

Benefit/cost analyses were completed for all projects in all of the project categories. Only those projects where cost data were obtained were included in the analysis. There were several projects that cost data were unable to be obtained for various reasons.

Benefits are assumed to be in the form of dollars saved by reducing crashes. For the purpose of this study, the values listed in Table 2 were used.

Table 2 Dollar Value Equivalents for Crash Severities

Severity	Dollar Value Equivalent
Fatality	$800,000
Major injury	$120,000
Minor injury	$8,000
Possible injury	$2,000
Property damage only	Actual Value

Source: Iowa Department of Transportation.

Two separate benefit/cost ratios are calculated for each category. The first uses the dollar values as shown in Table 2 and is referred to as method 1. The second analysis treats the first fatality at an individual intersection as a major injury rather than a fatality. Any additional fatalities were assigned the dollar value of $800,000. This may minimize the affect that a single fatality can have at a given location. This method is referred to as method 2. This method is presented as an alternative to method 1. There is no solid documentation that says this is a better or worse methodology. Anecdotal information obtained from an Institute of Transportation Engineers (ITE) discussion list indicated that some jurisdictions use this method to minimize the effect of a single fatality.

Signal projects and turn-lane projects were assumed to have a service life of 15 years. Geometric improvements were assumed to have a service life of 20 years. A rate of inflation of 3 percent was also assumed for the analysis.

The equation for calculating annualized costs and benefits is

$$\mathrm{EUAW} = \mathrm{NPV}\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right]$$

where

EUAW = equivalent uniform annual worth
NPV = net present value
i = interest rate
N = service life/number of years

The benefit/cost value is calculated by the following equation:

$$B/C = \frac{\mathrm{EUAW}_{\mathrm{Benefits}}}{\mathrm{EUAW}_{\mathrm{Costs}}}$$

where

$\mathrm{EUAW}_{\mathrm{Benefits}}$ = equivalent uniform annual benefits
$\mathrm{EUAW}_{\mathrm{Benefits}}$ = equivalent uniform annual costs

A benefit/cost ratio was calculated for each project. These B/C ratios were then statistically analyzed using confidence intervals.

Ninety percent confidence intervals were determined for the B/C ratio of each category using both methods (1 and 2) of cost calculations. Since the population variance is unknown in the analysis, confidence intervals were based on the *t*-statistic. The *t*-statistic is calculated from the following equation:

$$t = \frac{\overline{X} - \mu}{S / \sqrt{n}}$$

where

$\overline{X}$ = sample mean
μ = population mean
S = sample standard deviation
n = sample size

Therefore, a 100(1 – α) percent, two-tailed, confidence interval is given by the following equation:

$$\overline{X} - t_{\alpha/2,n-1}\, S\big/\sqrt{n} \;\le \mu \le \overline{X} - t_{\alpha/2,n-1}\, S\big/\sqrt{n}$$

This analysis assumes that the population of the sample data is normally distributed.

Crash Reduction Factor Analysis

After the crash data were collected and the projects grouped, the projects were evaluated for improved safety. First, the number of before-and-after crashes were compared and the percent reduction was calculated by the following equation:

$$\text{Percent Reduction} = \frac{\text{Before Crashes} - \text{After Crashes}}{\text{Before Crashes}} \times 100$$

This procedure was followed for all projects in each of the seven improvement categories.

For each project, the crash reduction factor was calculated for total crashes, each level of severity (fatalities, major injuries, minor injuries, possible injuries, and property damage only crashes), and each type of collision (right angle, left turn, rear end, and other).

Confidence intervals were determined for total crashes, each severity type, and each collision type. Intervals were calculated using the same *t*-statistic method described in the B/C ratio methodology.

PROJECT SELECTION AND DATA COLLECTION

The Iowa DOT provided the list of potential safety improvement projects. General information on these projects was obtained from the Iowa DOT project files. The general information gathered included: project number, type of improvement, location of the improvement (city and county), beginning and ending construction dates, construction costs, and intersection node numbers.

Table 3 lists all of the projects that are included in this analysis.

Table 3 Project List

Jurisdiction	Project No.	Location
Ames	CS-TSF-0155(2)	Old 30 (Lincoln Way) @ Dayton
Ames	CS-TSF-0155(3)	Old 30 (Lincoln Way) @ Hyland Ave
Ames	HES-30-5(57)	US-30 @ Dayton Rd
Ames	STP-69-5(46)	US-69 (Grand) @ 24th St
Ankeny	CS-TSF-0187(1)	E 1st St @ Delaware Ave
Ankeny	CS-TSF-0187(4)	E 1st @ N and S Trilein Dr
Ankeny	TSF-160-1(5)	IA-160 @ S entrance to DMACC
Cascade	CS-TSF-1147(1)	US-151 @ IA-136
Clinton	CS-TSF-1415(1)	2nd Ave S @ Bluff Blvd

Table 3 Project List *continued*

Jurisdiction	Project No.	Location
Clive	CS-TSF-1425(1a)	US-6 @ 92nd
Clive	CS-TSF-1425(1b)	US-6 @ 104th
Clive	CS-TSF-1425(1c)	US-6 @ 111th
Clive	TSF-6-4(103)	I-35/80 @ US-6 ramps
Coralville	(HES)STP-6-7(41)	US-6 from 1st Ave to Rocky Shore
Council Bluffs	CS-TSF-1642(6)	IA-192 (South Expressway) @ 32nd & 7th
Council Bluffs	FM-TSF-0078(1)	IA-92 @ Valley View Dr
Council Bluffs	HES-192-0(14)	IA-192 @ 23rd Ave
Council Bluffs	HES-192-0(16a)	IA-192 (N 16th St) @ Ave B
Council Bluffs	HES-192-0(16b)	IA-192 (N 16th St) @ Ave G
Davenport	CS-TSF-1827(3a)	US-61 (Brady St.) @ 3rd St
Davenport	CS-TSF-1827(3b)	US-6 (Brady St) @ 4th St
Davenport	CS-TSF-1827(3c)	US-61 (Harrison St) @ 2nd St
Davenport	CS-TSF-1827(3d)	US-61 (Harrison St) @ 3rd St
Davenport	CS-TSF-1827(3e)	US-6 (Harrison St) @ 4th St
Davenport	CS-TSF-1827(5)	Gaines St @ W 3rd
Davenport	CS-TSF-1827(6)	Gaines St @ W 4th
Decorah	CS-TSF-1867(1)	IA-9 @ Short St
Des Moines	CS-TSF-1945(1)	University Ave @ Penn
Des Moines	CS-TSF-1945(1)a	University @ 9th
Des Moines	CS-TSF-1945(2)	Harding/19th St @ University
Des Moines	CS-TSF-1945(2)a	Harding/19th @ Clark
Des Moines	CS-TSF-1945(3a)	US-6 (Hickman) @ Merle Hay Rd
Des Moines	CS-TSF-1945(3b)	US-6 (Merle Hay) @ Urbandale Ave
Des Moines	CS-TSF-1945(4)	I-235 (WB on-ramp) @ E 6th St
Des Moines	CS-TSF-1945(5a)	University @ 9th
Des Moines	CS-TSF-1945(5b)	University @ 13th
Des Moines	CS-TSF-1945(5c)	Grand Ave @ E 1st St
Des Moines	CS-TSF-1945(5d)	Grand Ave @ E 6th St
Des Moines	CS-TSF-1945(5e)	Grand Ave @ E 9th St
Des Moines	CS-TSF-1945(5f)	Grand Ave @ E 12th St
Des Moines	CS-TSF-1945(5g)	2nd Ave @ Holcomb
Des Moines	CS-TSF-1945(5h)	2nd Ave @ New York St
Des Moines	CS-TSF-1945(5i)	6th Ave @ Holcomb
Des Moines	CS-TSF-1945(5j)	6th Ave @ College Ave
Des Moines	CS-TSF-1945(5k)	6th Ave @ Forest Ave
Des Moines	CS-TSF-1945(5l)	Court Ave @ E 6th St
Des Moines	CS-TSF-1945(6)	2nd @ University
Des Moines	CS-TSF-1945(7a)	Locust @ 10th
Des Moines	CS-TSF-1945(7b)	Locust @ 12th
Des Moines	CS-TSF-1945(7c)	Locust @ 13th
Des Moines	CS-TSF-1945(7d)	Locust @ 15th
Des Moines	CS-TSF-1945(7e)	Locust @ 17th
Des Moines	CS-TSF-1945(7f)	Grand @ 10th

Table 3 Project List *continued*

Jurisdiction	Project No.	Location
Des Moines	CS-TSF-1945(7g)	Grand @ 12th
Des Moines	CS-TSF-1945(7h)	Grand @ 13th
Des Moines	CS-TSF-1945(7i)	Grand @ 15th
Des Moines	CS-TSF-1945(7j)	Grand @ 17th
Des Moines	HES-28-2(22)-2H-77	IA-28(63rd St) @ University Ave
Des Moines	HES-5-5(20)	IA-5 (Army Post Rd) @ SE 5th St
Des Moines	HES-5-5(32)--2H-77	Army Post Rd @ Chaffee/SE Union
Des Moines	HES-6-4(99)--2H-77	Delaware (NE 22nd) @ Euclid (US-65/69)
Des Moines	HES-65-4(55)	US-69 @ Maple
Fort Dodge	HES-169-6(32)	US-169 @ O Ave
Fort Dodge	HES-20-3(63)	US-20 @ E 29th St
Grimes	CS-TSF-3125(2)	IA-141 @ NW 54th
Grinnell	CS-TSF-3127(1)	IA-146 (West St) @ 1st Ave
Holy Cross	TSF-52-2(58)	US-52 @ County Road Y-13
Mason City	HES-18-5(52)	US-18 @ Pierce Ave
Mount Pleasant	FM-TSF-0044(1)	US-218 @ Winfield Ave (H-38)
Nevada	HES-30-5(71)	US-30 @ 11th St
Oelwein	CS-TSF-5657(1a)	IA-150 @ 2nd St SE
Oelwein	CS-TSF-5657(1b)	IA-150 @ 7th St SE
Perry	TSF-141-6(39)	IA-141 @ IA-144
Pleasant Hill	CS-TSF-6102(1)	IA-163 @ N Hickory Blvd
Sioux City	CS-TSF-7057(3)	IA-12 (Gordon Dr) @ Westcott St
Sioux City	CS-TSF-7057(5)	US-75 (Lewis Blvd) @ 41st St
West Burlington	TSF-34-9(64)	US-34 @ IA 406/Co. Road X-40
West Des Moines	CS-TSF-8260(1a)	8th St @ Grand
West Des Moines	CS-TSF-8260(1a)a	8th St @ Ashworth
West Des Moines	CS-TSF-8260(1b)	31st St @ Westown Pkwy
West Des Moines	CS-TSF-8260(4)	IA-28 (1st St) @ Ashworth
Clinton County	HES-67-2(23)	US-67 Follets N to Commanche
Lee County	TSF-61-1(60)	US-61 @ IA-2
Plymouth County	TSF-3-1(38)	IA-3 @ County Road K-22/C-26
Polk County	CS-TSF-0077(9)	IA-28(Merle Hay Rd) @ Meredith w/ front. rds.
Polk County	FM-TSF-0077(1a)	IA-415 @ NW Broadway Ave
Polk County	FM-TSF-0077(1b)	NE Broadway Ave @ NE 3rd St
Polk County	FM-TSF-0077(1c)	NE Broadway Ave @ NE 22nd St
Polk County	FM-TSF-0077(3)	NW 6th Dr @ Aurora Ave
Polk County	FM-TSF-0077(8)	R-56 (NW 6th) S of Saylor Creek to R6F
Polk County	L-TSF-0077(2)	IA-415 @ NW Aurora Ave
Polk County	SN-TSF-3403(5)	US-69 @ NE 66th Ave
Scott County	HES-65-4(52)	US-67 @ Princeton Curve
Sioux County	HES-75-3(14)	US-75 @ IA 110

Those projects whose files could not be located or for which the general data were not sufficient were dropped from the study. These projects are listed in Table 4.

Table 4 Projects Not Included in Study due to Lack of Project Data

Jurisdiction	Project No.	Location
Altoona	HES/FN-6-4(86)	IA-926/old 6 @ IA-950 (NE 56th)
Clear Lake	HES-18-5(48)	US-18 @ IA 107/Co Rd S-28
Crawford County	HES-141-3(17)	IA-45 @ IA-141 and Co Rd M-55
Des Moines	HES-65-4(52)	US-65/E15th @ Grand Avenue
Des Moines	HES-65-4(49)	US-65/E14th @ Grand Avenue
Des Moines	HES-65-4(51 & 52)	US-65/69 @ E15th and Grand Avenue
Cedar Rapids	TSF-30-7-(91)	US-30 near ADM plant
Fort Dodge	HES-169-6(32)	US-169 @ O Ave
Fort Madison	HES???	US-61 @ 48th St
Polk County	FM-TSF-0077(7)	NW 6th from NW 16th - NW 69th
Waterloo	HES-20-6(47)/STp-U-8155(11)	Broadway @ Donald/Longfellow

In some cases, six years of crash data (three before and three after) were not available. Three years of before crash data were available for all of the projects. However, depending on the ending construction date, three years of after crash data may not have been available. Projects that did not have three years of after crash data were not included in the analysis. These projects are listed in Table 5.

Table 5 Projects with Less Than Three Years of After Crash Data Available

Jurisdiction	Project No.	Location
Ankeny	HES-160-1(8)	IA-160 @ Delaware Ave
Ankeny	STPN-69-4(60)	US-69 @ IA-160 (Oralabor Rd)
Clear Lake	CS-TSF-1372(1)	US-18 @ N 20th
Coralville	(HES)STP-6-7(49)	US-6 @ 22nd Ave
Council Bluffs	HES--6-1(71)	US-6 (Kanesville Blvd) from viaduct to 7th St
Des Moines	CS-TSF-1945(11)	IA-5 (Army Post Rd) @ E Indianola Ave
Des Moines	CS-TSF-1945(12c)	E 4th St @ Locust
Des Moines	CS-TSF-1945(10)	US-65/69 (SE 14th) @ Park
Des Moines	(HES)STP-69-4(57)-2H-77	US-69 (E 14th) @ Aurora Ave
Des Moines	CS-TSF-1945(12b)	E 6th St @ Walnut
Des Moines	CS-TSF-1945(12a)	E 6th St @ Locust
Des Moines	(HES)NHS-163-1(52)-2H-77	IA-163 (University) @ Williams St
Hiawatha	CS-TSF-3432(01)	Boyson Rd from Center Point to Hawkeye
Ottumwa	HES-63-2(55)	US-63 (N Court) @ Bryan Rd
Waterloo	CS-TSF-8155 (27)	Old 412 (W San Marnan) @ Ansborough

In total, 94 locations throughout Iowa were evaluated. All were located on primary, secondary, or city roads.

Once the general information was obtained, crash data were collected for each of the projects. The goal was to obtain six years of crash data (three years before and three years after) for each project. The crash data were obtained from the Iowa Department of Transportation. Crash data were only available through 1998 and were queried from the geographic information systems (GIS) Accident Location and Analysis System (ALAS) database by county and node number with the use of ESRI's ArcView GIS software and the crash record keys for the "A," "B," and "C" records. The "A" record contains the total number of accidents, collision type, and total property damage dollar value. The collision types were divided into four groups: (1) right angle, (2) left turn, (3) rear end, and (4) other collisions. All collisions that were not rear-end, left-turn, or right-angle collisions were grouped into the other collisions category. The road environment at the time of the collision was obtained from the "B" records. These data were collected to assure that crashes that occurred during the construction period of the project were not included in the study. The "C" record contains the severity of the injuries. The number of fatalities, major injuries, minor injuries, and possible injuries were obtained for each project. The crash data from the "A," "B," and "C" records were collected for all of the remaining projects.

The general data and the before-and-after crash data for each project were entered into a Microsoft Access database. Once the data were entered, the projects were divided into categories by improvement type. In total, seven improvement categories were identified. Each project was placed in only one category. The seven categories used were

1. new traffic signals
2. new traffic signals and turn-lane(s) addition
3. add turn phasing to existing signal
4. add turn phasing to existing signal and turn lane(s)
5. replace pedestal mount signals with mast arm mount signals
6. add turn lane(s) only
7. other geometric improvements

The analysis was performed for all projects combined and for each of the seven categories.

Traffic volume maps for the jurisdictions of each project were obtained from the Iowa DOT. Since many of the projects in this study are not primary roadways, before-and-after volumes were not available without making numerous traffic related assumptions. It was determined that the volume data obtained were insufficient and were therefore not taken into account in the analysis.

DATA ANALYSIS

Overall Analysis

An initial analysis was performed on all projects and broken down by funding source (Hazard Elimination Safety [HES] projects and Transportation Safety Funds [TSF] projects). Table 6 shows the results of this analysis. Using data from 91 of the projects, a mean crash reduction of 23 percent was obtained (with a 90 percent confidence interval of 11.7 percent to 34.5 percent). HES and TSF projects had a mean crash reduction of 40 percent and 21 percent, respectively.

B/C ratios for all projects were 6.3 (method 1) and 6.0 (method 2). HES and TSF projects had mean B/C ratios of 2.6 and 6.9 (for method 1) and 2.5 and 6.5 (for method 2). Due to the small sample size for HES projects, these values should be used with caution.

Table 6 Overall Crash Reduction Factors and Benefit/Cost Ratios

Category	Mean	Count	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
Crash Reduction					
All projects	23%	91	66%	11.7%	34.5%
HES projects only	40%	15	31%	26.4%	54.2%
TSF projects only	21%	75	70%	7.1%	34.1%
B/C Ratio–Method 1					
All projects only	6.3	78	30.5	0.5	12.0
HES projects only	2.6	9	5.4	–0.8	6.0
TSF projects only	6.9	68	32.6	0.3	13.4
B/C Ratio–Method 2					
All projects	6.0	78	21.3	1.9	10.0
HES projects only	2.5	9	3.7	0.3	4.8
TSF projects only	6.5	68	22.7	1.9	11.1

New Traffic Signals

There were a total of 16 new traffic signal construction projects examined in the research. Table 7 shows the summary of three years of before and three years of after crash data by injury severity. In each case, the table lists the number of fatalities, major injuries, minor injuries, possible injuries, and the value of the property damage for all crashes.

Table 7 Three-Year Crash Data by Severity—New Traffic Signals

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	75,000	0	3	1	8	64,653	0	0	2	14	58,800
2	52,550	0	0	1	0	49,300	0	0	0	0	12,012
3	67,423	0	0	2	6	27,751	0	0	5	14	35,600
4	73,700	0	2	9	9	77,275	0	0	3	12	75,778
5	23,000	0	0	6	2	71,256	0	0	3	4	51,506
6	138,107	0	1	14	16	156,648	1	2	13	24	213,624
7	66,160	0	0	4	4	56,703	0	2	4	14	67,150
8	52,500	0	0	1	0	4,400	0	0	4	4	48,910
9	52,500	0	3	4	9	24,815	0	0	0	0	2,186
10	153,900	0	0	8	10	166,885	0	1	1	1	40,001
11	73,265	0	0	7	14	99,479	0	0	2	10	76,409
12	60,000	0	0	1	0	32,524	0	1	2	8	65,450
13	60,000	0	1	15	9	107,500	0	0	0	0	17,403
14	93,917	0	1	6	2	65,206	0	2	2	5	72,300
15	60,000	0	4	10	15	122,050	1	0	6	6	58,056
16	90,982	0	0	5	7	85,356	0	2	1	18	102,300

The total cost of the 16 projects was $1,193,004. This is an annualized cost of $99,934 (assuming a 15-year service life and inflation rate of 3 percent). The total benefit realized from the projects is –$163,926. The negative number is due to the fact that there were two more fatalities in the after period than the before period. The B/C ratio is therefore –1.64. If the first fatal injury at an individual intersection is considered to be a major injury, the annualized benefit is $316,875 and the B/C ratio is 3.17.

Table 8 shows the summary of the new traffic signal projects by type of collision. The projects showed a reduction in right-angle collisions (–71 percent) and other collisions (–32 percent) but an increase in rear-end (+44 percent) and left-turn (+41 percent) collisions. It has been a generally accepted notion that the addition of a traffic signal will likely increase the incidents of rear-end and left-turn collisions. The data show that nearly every intersection experienced this phenomenon. Therefore, it is not attributable to any unusual intersections.

Table 8 Number of Crashes by Crash Type—New Traffic Signals

	Right Angle		Rear End		Left Turn		Other	
#	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
1	4	1	8	10	0	5	4	5
2	6	2	5	1	3	2	13	3
3	12	4	7	6	2	7	10	4
4	17	4	3	4	3	8	5	4
5	26	13	2	3	0	0	5	4
6	8	5	7	23	2	1	27	16
7	4	1	0	4	5	11	4	8
8	2	5	0	0	0	5	1	7
9	4	0	2	1	1	0	6	2
10	29	5	2	0	8	5	8	3
11	3	0	4	7	8	2	18	20
12	8	2	2	6	0	7	6	2
13	19	2	2	2	1	2	11	1
14	5	3	3	2	1	1	8	4
15	13	2	4	4	9	7	13	9
16	10	0	8	12	6	6	6	6
Total	170	49	59	85	49	69	145	98
Reduction	71%		(44%)		(41%)		32%	

The overall reduction in crashes for new traffic signal projects was 29 percent (423 before, 301 after).

The final step determines the confidence intervals for crash reduction factors. For each type of crash category, the summary table lists the mean reduction factor, the count of studies included in the calculation, the standard deviation of the crash reduction factors, and the lower and upper 90 percent confidence interval. Table 9 summarizes these data for new traffic signal projects.

As shown, the mean crash reduction factor is a four percent increase in total crashes. The 90 percent confidence interval for total crashes is from a 53.2 percent reduction up to a 61.2 percent increase. From this analysis, it cannot be concluded that the installation of a signal is likely to result in a decrease in total crashes. The only confidence interval that is entirely on the reduction side is right-angle crashes (from 34.6 percent reduction to 86.7 percent reduction). No statistically significant conclusions can be drawn about fatalities. This is because fatal crashes are such a rare occurrence.

The confidence intervals for the B/C ratios also showed similar results. For both methods, the 90 percent confidence interval spans from negative to positive. The mean B/C ratio for method 2 is slightly higher as is the confidence interval.

Table 9 Confidence Intervals—New Traffic Signals

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval	
					Lower	Upper
Total		–4%	16	131%	–61.2%	53.2%
Severity	Fatal	N/A	0	N/A	N/A	N/A
	Major	43%	7	98%	–28.8%	114.5%
	Minor	8%	16	114%	–42.3%	57.3%
	Possible	–44%	13	113%	–99.8%	12.3%
	PDO	0%	16	137%	–60.0%	60.5%
Type	RA	61%	16	59%	34.6%	86.7%
	RE	–28%	14	94%	–71.9%	16.9%
	LT	–27%	12	108%	–82.4%	29.2%
	Other	–9%	16	165%	–81.4%	62.8%
B/C Ratio	Method 1	0.8	16	16.9	–6.6	8.2
	Method 2	5.1	16	16.3	–2.1	12.2

Five of the categories had one or two outliers that severely skewed the data. Outliers were determined using box plots for each data element. An outlier is an observation in a data set that is far removed in value from the others in the data set. It is an unusually large or an unusually small value compared to the others. Oftentimes outliers are attributed to an incorrect measurement. In the case of this study, an outlier may be the result of incorrect crash data. Or it may be possible that the data are correct and that the particular location simply had an unusually large number of crashes due to randomness.

All of the statistical analysis was performed using the program Minitab. Table 10 shows the results of the analysis if these outliers are removed. The mean total crash reduction factor is 27 percent. The confidence interval for total crashes is 7.0 percent to 46.7 percent. Outliers also affected data in property damage only crashes and in right-angle, rear-end, and other crash types. All other categories had no outliers.

Table 10 Confidence Intervals—New Traffic Signals—Outliers Removed

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval	
					Lower	Upper
Total		27%	15	44%	7.0%	46.7%
Severity	PDO	40%	14	24%	28.6%	51.6%
Type	RA	75%	15	20%	65.6%	83.8%
	RE	4%	12	54%	–24.5%	31.8%
	Other	30%	15	49%	7.7%	52.4%

New Traffic Signals and Turn Lane(s) Addition

There were a total of 11 projects that involved new traffic signal construction along with the addition of one or more turn lanes. Table 11 shows the summary of three years of before and three years of after crash data.

Table 11 Three-Year Crash Data by Severity—New Traffic Signals and Turn Lane(s)

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	430,184	0	2	5	6	110,812	0	0	0	1	9,279
2	78,791	0	0	3	5	54,311	0	0	3	7	83,275
3	134,900	0	1	6	11	109,045	0	0	3	2	40,633
4	132,100	0	2	2	5	69,350	0	0	1	9	65,456
5	535,893	0	2	3	8	33,909	0	0	4	17	78,237
6	50,104	1	2	5	11	80,776	0	0	2	5	51,912
7	389,263	0	2	12	24	146,855	0	0	3	9	74,456
8	155,757	2	3	9	17	130,632	0	0	3	1	70,400
9	246,088	0	4	0	5	122,600	0	0	2	4	15,600
10	181,278	0	3	9	14	68,469	0	4	4	7	43,200
11	881,485	1	1	6	10	172,257	0	0	2	2	31,800

The total cost of the 11 projects was $3,215,843. This is an annualized cost of $269,380 (assuming a 15-year service life and inflation rate of 3 percent). The total benefit realized from the projects is $2,214,079. In this case, much of the benefits were gained from the reduction of fatal injuries (from four to zero). The B/C ratio is 8.22. If the first fatal injury at each intersection is considered to be a major injury, the annualized benefit is $1,492,877 and the B/C ratio is 5.54.

Table 12 shows the summary of the projects in this category by type of collision. The projects showed a reduction in right-angle collisions (–71 percent), left-turn collisions (–31 percent), and other collisions (–27 percent) but an increase in rear-end (+24 percent) collisions. Again, it is not unusual to see an increase in rear-end collisions after the installation of a new signal. The data indicates that the increase is not as severe in this category as it was for new traffic signal alone. Seven of the 11 sites saw an increase in rear-end collisions. This is likely attributable to the fact that this category included the addition of one or more turning lanes to improve the intersection. The decrease in left-turn crashes may also be attributed to the turn lane additions.

Table 12 Number of Crashes by Crash Type—New Traffic Signals and Turn Lane(s)

	Right Angle		Rear End		Left Turn		Other	
#	Before	After	Before	After	Before	After	Before	After
1	12	0	5	0	4	2	11	4
2	5	4	4	5	9	16	10	12
3	13	2	4	6	2	1	15	3
4	4	3	2	7	2	3	5	10
5	5	1	8	23	4	6	8	14
6	7	3	5	7	8	1	11	8
7	9	3	17	9	6	0	18	12
8	12	3	2	1	6	3	11	5
9	9	2	3	6	2	0	8	2
10	4	3	6	10	2	1	10	9
11	6	1	7	4	4	1	8	5
Total	86	25	63	78	49	34	115	84
Reduction	71%		(24%)		31%		27%	

The overall reduction in crashes for new traffic signals and turn lane(s) was 29 percent (313 before, 221 after).

Table 13 summarizes the data for this category. The mean crash reduction factor is a 20 percent decrease in total crashes. However, the 90 percent confidence interval for total crashes is from a 51.0 percent reduction up to a 12.0 percent increase. From this analysis, it cannot be concluded that the installation of a signal and turn lane(s) is likely to result in a decrease in total crashes. Both right-angle and left-turn crash types have positive confidence intervals. As did major and minor injuries. No statistically significant conclusions can be drawn about fatalities.

Table 13 Confidence Intervals—New Traffic Signals and Turn Lane(s)

Crash Category		Mean	Count	Std Dev	90% Confidence Interval	
					Lower	Upper
Total		20%	11	57%	–12.0%	51.0%
Severity	Fatal	100%	3	0%	N/A	N/A
	Major	87%	10	42%	62.3%	111.0%
	Minor	49%	10	38%	27.0%	71.4%
	Possible	27%	11	72%	–13.0%	66.0%
	PDO	6%	11	69%	–32.0%	43.1%
Type	RA	63%	11	28%	48.0%	78.4%
	RE	–44%	11	106%	–102.0%	14.4%
	LT	35%	11	64%	0.0%	70.0%
	Other	17%	11	59%	–16.0%	49.5%
B/C Ratio	Method 1	17.0	11	9.0	0.6	33.4
	Method 2	9.8	11	4.2	2.2	17.5

For both B/C calculation methods, the 90 percent confidence intervals were on the positive side. The mean B/C ratio for method 1 is higher than the method 2 B/C ratio (as is the confidence interval).

Table 14 shows the results of removing outliers in those categories where specific projects tended to skew the data. Only two categories (major and minor injuries) had outliers. The small sample size makes it difficult to reach any strong conclusions about these particular data items.

Table 14 Confidence Intervals—New Traffic Signals and Turn Lane(s)—Outliers Removed

Crash Category		Mean	Count	Std Dev	90% Confidence Interval	
					Lower	Upper
Severity	Major	100%	9	0%	100.0%	100.0%
	Minor	66%	8	16%	54.6%	76.6%
B/C Ratio	Method 1	4.1	9	4.0	1.7	6.6
	Method 2	3.8	9	4.0	1.3	6.2

Add Turn Phasing to Existing Signal

There were a total of four projects that involved changing the left-turn phasing at an existing traffic signal. Costs were available for only two of the four projects in this category. Therefore, the B/C analysis is only done on those two projects. Table 15 shows the summary of three years of before and three years of after crash data.

Table 15 Three-Year Crash Data by Severity—Add Turn Phasing to Existing Signal

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	45,459	0	1	9	19	132,932	0	2	6	7	156,906
2	61,917	0	1	2	5	35,600	0	0	0	0	11,856

The projects had a total cost of $107,376 and an annualized cost of $8,995 (assuming a 15-year service life and inflation rate of 3 percent). The total annualized benefit realized from the projects is $26,080. The B/C ratio is 2.90. Since there were no fatal injuries in either the before or after period, the alternate analysis produces the same results.

Table 16 shows the summary of the projects in this category by type of collision. The analysis shows a reduction in right-angle collisions (–43 percent), left-turn collisions (–24 percent), and left-turn collisions (–62 percent) but an increase in other (+12 percent) collisions. The decrease in left-turn accidents is likely attributed to the fact that projects in this category simply included the addition of a left-turn phase.

Table 16 Number of Crashes by Crash Type—Add Turn Phasing to Existing Signal

	Right Angle		Rear End		Left Turn		Other	
#	Before	After	Before	After	Before	After	Before	After
1	3	3	12	9	20	6	11	12
2	11	8	4	3	14	4	10	8
3	14	5	1	2	5	6	4	6
4	0	0	4	2	6	1	1	3
Total	28	16	21	16	45	17	26	29
Reduction	43%		24%		62%		(12%)	

The overall reduction in crashes for this category was 35 percent (120 before, 78 after).

Table 17 summarizes the data for projects that added turn phasing to existing signals. The mean crash reduction factor is a 36 percent decrease in total crashes. The 90 percent confidence interval for total crashes is from a 23.1 percent reduction up to a 47.9 percent reduction. From this analysis, it may be concluded that the modification of signal phasing is likely to result in a decrease in total crashes. Both right-angle and left-turn crash types have positive confidence intervals. No statistically significant conclusions can be drawn about fatalities.

Because of the small sample size, no significant conclusions can be made regarding the B/C ratios. As shown in Table 17, the confidence intervals span from –63.3 to +66.0.

Additional data are required for projects in this category in order to make any stronger conclusions. Due to the extremely small sample size, an analysis with outliers removed was not performed.

Table 17 Confidence Intervals—Add Turn Phasing to Existing Signal

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval	
					Lower	Upper
Total		36%	4	11%	23.1%	47.9%
Severity	Fatal	N/A	0	N/A	N/A	N/A
	Major	22%	3	107%	–158.4%	203.1%
	Minor	50%	4	43%	–0.9%	99.9%
	Possible	37%	4	61%	–35.1%	109.1%
	PDO	29%	4	41%	–18.9%	76.4%
Type	RA	30%	3	32%	–23.8%	84.5%
	RE	0%	4	68%	–79.7%	79.7%
	LT	51%	4	48%	–5.1%	107.1%
	Other	–60%	4	98%	–174.8%	55.3%
B/C Ratio	Method 1	1.3	2	10.2	–63.3	66.0
	Method 2	1.3	2	10.2	–63.3	66.0

Add Turn Phasing to Existing Signal and Turn Lane(s)

There were a total of seven projects that involved changing the left-turn phasing at an existing traffic signal and adding one or more separate turn lanes. Six of these projects had cost data available. Table 18 shows the summary of three years of before and three years of after crash data.

Table 18 Three-Year Crash Data by Severity—Add Turn Phasing and Turn Lane(s)

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	1,154,302	0	2	12	25	168,843	0	0	11	15	84,350
2	440,300	1	1	8	19	154,727	0	0	2	7	45,511
3	416,000	0	0	12	20	114,472	0	0	2	11	34,406
4	416,000	0	3	18	33	224,415	1	1	8	5	88,749
5	606,054	1	2	28	24	270,969	0	0	7	17	138,946
6	2,933,593	0	0	6	31	232,638	0	1	1	8	26,000

The total cost of the six projects was $5,966,249. This is an annualized cost of $499,772 (assuming a 15-year service life and inflation rate of 3 percent). The total annualized benefit realized from the projects is $1,014,668. The B/C ratio is 2.03. If the first fatal injury at each intersection is considered to be a major injury, the annualized benefit is $774,268 and the B/C ratio is 1.55.

Table 19 shows the summary of the projects in this category by type of collision. The analysis shows a reduction in all four categories of collisions: right angle (–62 percent), rear end (–37 percent), left turn (–71 percent), and other (–42 percent).

The overall reduction in crashes for this category was 55 percent (555 before, 251 after).

Table 19 Number of Crashes by Crash Type—Add Turn Phasing and Turn Lane(s)

	Right Angle		Rear End		Left Turn		Other	
#	Before	After	Before	After	Before	After	Before	After
1	20	3	10	3	26	12	19	8
2	6	5	6	8	29	2	8	5
3	19	8	6	2	11	2	7	5
4	6	6	8	3	38	18	25	9
5	22	6	12	14	33	8	37	30
6	16	2	17	2	15	3	28	4
7	20	11	32	25	32	9	47	38
Total	109	41	91	57	184	54	171	99
Reduction	62%		37%		71%		42%	

Table 20 summarizes the data for projects that involved adding turn phasing and turn lane(s) to existing signalized intersections. The mean crash reduction factor is a 58 percent decrease in total crashes. The 90 percent confidence interval for total crashes is from a 46.2 percent reduction up to a 69.5 percent reduction. From this analysis, it may be concluded that the modification of signal phasing and addition of turn lane(s) is likely to result in a decrease in total crashes. All types of severities (except fatal) and crash types have positive confidence intervals. No statistically significant conclusions can be drawn about fatalities.

Table 20 Confidence Intervals—Add Turn Phasing and Turn Lane(s)

					90% Confidence Interval	
Crash Category		Mean	Count	Std Dev	Lower	Upper
Total		58%	7	16%	46.2%	69.5%
Severity	Fatal	100%	2	0%	N/A	N/A
	Major	85%	5	20%	66.2%	104.6%
	Minor	65%	7	27%	45.4%	84.6%
	Possible	51%	7	23%	33.9%	68.4%
	PDO	57%	7	21%	41.8%	72.2%
Type	RA	52%	7	34%	27.5%	77.1%
	RE	37%	7	47%	2.6%	71.7%
	LT	73%	7	15%	62.0%	83.7%
	Other	45%	7	25%	26.1%	63.4%
B/C Ratio	Method 1	3.4	6	2.2	-1.0	7.8
	Method 2	2.7	6	1.8	1.2	4.2

In general, the B/C ratios for this category were primarily positive. Method 1 indicates a lower confidence limit of –1.0. Again, the small sample size limits the conclusions that can be made. Outliers occurred only in the minor injury category (see Table 21).

Table 21 Confidence Intervals—Add Turn Phasing and Turn Lane(s)—Outliers Removed

					90% Confidence Interval	
Crash Category		Mean	Count	Std Dev	Lower	Upper
Severity	Minor	75%	6	10%	66.4%	82.6%

Replace Pedestal Mount Signals with Mast Arm Mount Signals

There were a total of 33 projects that involved replacing pedestal mounted traffic signal hardware with mast arm mounted signals. Thirty-one of the 33 projects had cost data available. Table 22 shows the summary of three years of before and three years of after crash data.

Table 22 Three-Year Crash Data by Severity—Pedestal Mount Replacement

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	53,700	0	0	1	2	90,342	0	0	1	6	36,768
2	53,700	0	4	8	12	106,589	0	0	2	4	33,812
3	53,700	0	3	3	11	99,124	0	2	1	6	61,856
4	53,700	0	0	18	28	258,649	0	0	1	9	77,337
5	53,700	0	0	13	23	208,861	0	0	6	11	73,822
6	40,400	0	0	6	19	104,532	0	0	5	10	81,227
7	39,696	0	0	3	27	133,591	0	0	0	2	34,318
8	265,000	0	2	18	13	177,800	0	3	20	32	192,802
9	40,000	0	1	14	19	174,190	1	7	16	28	233,615
10	31,000	0	1	6	10	62,032	0	0	4	18	65,957
11	31,000	0	1	4	12	66,109	0	2	11	17	81,350
12	31,000	0	2	2	8	64,400	0	0	0	2	24,542
13	31,000	0	5	6	17	125,162	0	2	5	11	83,668
14	31,000	0	0	2	3	46,506	0	2	4	8	29,928
15	31,000	0	2	2	2	59,615	0	0	3	7	58,256
16	31,000	0	4	11	14	180,055	0	1	16	14	130,771
17	31,000	0	0	4	10	44,743	0	0	3	6	74,951
18	31,000	0	1	9	12	75,589	0	0	3	4	37,904
19	31,000	0	0	1	6	32,853	0	0	9	16	71,385
20	31,000	0	0	4	12	40,814	0	1	9	15	55,702
21	31,000	0	1	10	14	128,506	0	1	1	4	61,723
22	37,500	0	0	1	4	44,876	0	0	2	8	43,054
23	37,500	0	0	0	9	58,921	0	1	5	10	72,466
24	37,500	0	1	6	7	114,521	0	1	4	3	60,837
25	37,500	0	2	2	14	57,856	0	0	2	2	31,961
26	37,500	0	1	0	0	37,734	0	0	1	1	18,109
27	37,500	0	1	5	4	105,341	0	0	6	9	41,281
28	37,500	0	0	4	8	61,712	0	2	2	9	38,990
29	37,500	1	0	2	11	94,203	0	1	0	0	7,506
30	37,500	0	0	3	9	67,259	0	0	0	4	19,407
31	37,500	0	0	6	6	64,013	0	0	1	2	22,856

The total cost of the 31 projects was $1,400,596. This is an annualized cost of $117,323 (assuming a 15-year service life and inflation rate of 3 percent). The total annualized benefit realized from the projects is $753,846. The B/C ratio is 6.43.

If the first fatal injury is considered to be a major injury, the annualized benefit is $753,846 and the B/C ratio is 6.43. The results are the same because there was only 1 fatality in both the before-and-after cases.

Table 23 shows the summary of the projects in this category by type of collision. The analysis shows a reduction in right-angle collisions (–66 percent), rear-end collisions (–1 percent), and other collisions (–27 percent) but an increase in left-turn (+34 percent) collisions.

Table 23 Number of Crashes by Crash Type—Pedestal Mount Replacement

	Right Angle		Rear End		Left Turn		Other	
#	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
1	8	1	1	2	4	1	38	20
2	22	4	12	0	0	1	12	7
3	16	10	1	1	2	1	20	9
4	40	5	7	2	5	6	56	31
5	35	9	1	2	0	0	34	15
6	13	6	4	2	2	1	27	15
7	13	4	3	1	1	4	36	11
8	18	9	6	12	11	21	22	21
9	38	34	3	10	4	5	23	21
10	13	8	2	2	3	5	10	8
11	8	4	24	27	8	6	29	41
12	6	4	5	5	7	9	16	14
13	13	5	6	3	5	6	9	7
14	6	0	3	4	0	2	8	6
15	27	7	3	9	5	4	22	13
16	5	1	2	3	5	6	10	6
17	6	0	2	7	6	7	7	3
18	23	8	1	6	9	17	18	16
19	8	0	4	5	1	11	7	14
20	11	0	10	2	2	0	15	12
21	3	4	6	17	1	4	13	25
22	3	1	4	9	1	7	21	13
23	23	6	5	0	4	8	13	8
24	11	4	7	6	4	0	7	10
25	10	11	7	3	0	3	14	8
26	17	4	6	7	3	5	12	11
27	13	2	2	1	4	4	6	4
28	4	1	3	1	1	1	7	8
29	25	3	3	0	2	3	9	9
30	10	5	2	5	0	2	13	4
31	13	0	6	2	4	4	7	2
32	4	0	10	4	7	2	11	13
33	11	1	1	1	8	3	10	6
Total	476	161	162	161	119	159	562	411
Reduction	66%		1%		(34%)		27%	

The overall reduction in crashes for this category was 32 percent (1,319 before, 892 after).

Table 24 summarizes the data for projects that replace pedestal mounted signals with mast arm mounted signals. The mean crash reduction factor is a 29 percent decrease in total crashes. The 90 percent confidence interval for total crashes is from a 17.2 percent reduction up to a 40.0 percent reduction. From this analysis, it may be concluded that the replacement of pedestal mounted traffic signals with mast arm mounted signals is likely to result in a decrease in total crashes. No statistically significant conclusions can be drawn about fatalities.

B/C ratio confidence intervals spanned positive and negative for this category (although mostly on the positive side). Removing the outliers in several of the categories yielded the results shown in Table 25. The total crash reduction factor increased to 36 percent and the confidence interval was narrowed. The B/C ratios increased by 3.3 and 3.6 for methods 1 and 2, respectively.

Table 24 Confidence Intervals—Pedestal Mount Replacement

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval	
					Lower	Upper
Total		29%	33	39%	17.2%	40.0%
Severity	Fatal	100%	1	N/A	N/A	N/A
	Major	11%	18	167%	–57.9%	79.4%
	Minor	–13%	31	165%	–63.3%	37.5%
	Possible	–12%	32	96%	–41.0%	16.4%
	PDO	36%	33	35%	25.7%	46.4%
Type	RA	66%	33	32%	56.8%	75.5%
	RE	–35%	33	130%	–73.1%	3.7%
	LT	–80%	28	231%	–94.3%	2.4%
	Other	20%	33	41%	7.6%	32.0%
B/C Ratio	Method 1	7.9	31	7.7	–5.2	21.0
	Method 2	7.7	31	5.5	–1.5	17.0

Table 25 Confidence Intervals—Pedestal Mount Replacement—Outliers Removed

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval	
					Lower	Upper
Total		36%	31	25%	28.2%	43.4%
Severity	Major	47%	17	71%	16.4%	76.9%
	Minor	13%	30	79%	–11.1%	37.8%
	PDO	40%	32	27%	31.9%	48.1%
Type	RA	72%	31	23%	64.8%	78.8%
	RE	–20%	32	102%	–50.6%	10.2%
	LT	–2%	24	59%	–22.5%	19.1%
	Other	27%	31	29%	18.3%	36.2%
B/C Ratio	Method 1	11.2	29	24.0	3.6	18.8
	Method 2	11.3	30	23.6	4.0	18.6

Add Turn Lane(s) Only

There were a total of eight projects that involved only the addition of one or more separate turning lanes. Seven of the eight projects had cost data available. Table 26 shows the summary of three years of before and three years of after crash data.

Table 26 Three-Year Crash Data by Severity—Add Turn Lane(s) Only

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	993,116	0	0	4	22	173,338	0	1	9	25	208,340
2	260,000	0	2	5	21	195,044	0	1	15	33	236,680
3	421,593	0	1	8	46	243,444	1	6	20	37	311,004
4	413,901	0	6	9	15	110,353	0	0	0	11	35,303
5	599,955	0	2	10	20	129,400	0	1	10	17	185,626
6	832,187	0	0	1	11	62,062	0	1	5	10	140,459
7	357,555	1	2	5	6	86,304	0	0	0	8	38,769

The total cost of the seven projects was $3,878,307. This is an annualized cost of $324,873 (assuming a 15-year service life and inflation rate of 3 percent). The total benefit realized from the projects is $23,957. The B/C ratio is 0.07.

If the first fatal injury is considered to be a major injury, the annualized benefit is $23,957 and the B/C ratio is 0.07. The results are the same because there was only one fatality in both the before-and-after cases.

Table 27 shows the summary of the projects in this category by type of collision. The analysis shows a reduction in right-angle collisions (–8 percent), rear-end collisions (–21 percent), and other collisions (–31 percent) but an increase in left-turn (+64 percent) collisions. This seems to be contradictory to the purpose of installing exclusive turn lanes. The data show that left-turn crashes increased at six of the eight sites. It is unclear in this analysis why this is the case.

Table 27 Number of Crashes by Crash Type—Add Turn Lane(s) Only

	Right Angle		Rear End		Left Turn		Other	
#	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
1	15	3	23	27	5	20	24	19
2	7	2	21	23	28	26	28	28
3	6	11	42	25	17	32	51	28
4	2	2	10	2	2	3	15	7
5	1	3	12	9	9	20	50	30
6	0	1	0	0	0	1	0	4
7	4	10	6	7	3	16	17	11
8	3	3	9	4	8	0	15	12
Total	38	35	123	97	72	118	200	139
Reduction	8%		21%		(64%)		31%	

The overall reduction in crashes for this category was 10 percent (433 before, 389 after).

Table 28 summarizes the data for turn-lane only projects. The mean crash reduction factor is a 12 percent decrease in total crashes. The 90 percent confidence interval for total crashes is from a 36.4 percent reduction up to a 12.1 percent increase. From this analysis, it cannot be concluded that the addition of left-turn lane(s) is likely to result in a decrease in total crashes. No statistically significant conclusions can be drawn about fatalities.

The mean B/C ratios for this category were close to zero. Subsequently, the confidence intervals spanned both negative and positive numbers. Outliers occurred only in the PDO-crash category. Results are shown in Table 29.

Table 28 Confidence Intervals—Add Turn Lane(s) Only

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
Total		12%	7	33%	–12.1%	36.4%
Severity	Fatal	100%	1	N/A	N/A	N/A
	Major	–40%	5	258%	–286.0%	206.0%
	Minor	–96%	7	179%	–228.2%	35.3%
	Possible	–5%	7	31%	–27.6%	18.1%
	PDO	11%	7	36%	–15.5%	37.5%
Type	RA	–40%	7	108%	–119.3%	38.7%
	RE	22%	7	39%	–5.9%	50.7%
	LT	–127%	7	183%	–260.8%	7.7%
	Other	31%	7	18%	13.4%	40.1%
B/C Ratio	Method 1	0.7	7	3.4	–6.0	7.4
	Method 2	0.5	7	2.1	–3.5	4.6

Table 29 Confidence Intervals—Add Turn Lane(s) Only—Outliers Removed

Crash Category		Mean	Count	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
Severity	PDO	23%	6	18%	8.6%	37.7%

Other Geometric Improvements

There were a total of 14 projects that involved some other type of geometric improvement such as the addition of a median or the relocation of a driveway. Only 5 of the 14 projects had cost data available. Table 30 shows the summary of three years of before and three years of after crash data.

Table 30 Three-Year Crash Data by Severity—Other Geometric Improvements

		Before					After				
#	Cost ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)	Fatal	Major Injury	Minor Injury	Poss.	PDO Value ($)
1	2,254,000	0	1	10	23	131,436	0	1	4	25	68,781
2	1,049,352	0	1	6	5	94,285	0	0	1	3	30,873
3	735,132	0	0	0	2	23,300	0	1	2	3	44,049
4	1,200,000	2	10	17	23	244,165	0	0	0	2	40,000
5	602,000	0	1	2	3	28,600	0	0	0	4	18,065

The total cost of the five projects was $5,840,484. This is an annualized cost of $489,237 (assuming a 20 year service life and inflation rate of 3 percent). The total benefit realized from the projects is $1,238,070. The B/C ratio is 2.53. If the first fatal injury is considered to be a major injury, the annualized benefit is $997,669 and the B/C ratio is 2.04.

Table 31 shows the summary of the projects in the other geometric improvement category by type of collision. The analysis shows a reduction in all four categories of collisions: right angle (–73 percent), rear end (–53 percent), left turn (–53 percent), and other (–21 percent).

Table 31 Number of Crashes by Crash Type—Other Geometric Improvements

	Right Angle		**Rear End**		**Left Turn**		**Other**	
#	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
1	3	0	29	18	7	1	13	9
2	7	2	6	4	5	4	12	9
3	1	3	3	0	4	1	11	7
4	1	1	1	0	0	1	9	15
5	21	0	8	3	5	0	16	6
6	16	0	7	0	0	0	11	7
7	7	5	32	20	45	26	39	29
8	9	5	37	11	48	24	37	27
9	0	0	0	0	0	0	3	3
10	4	0	5	5	6	1	9	10
11	0	0	0	0	0	0	0	3
12	0	0	0	0	0	0	0	0
13	4	3	0	0	2	0	2	7
14	1	1	7	2	2	0	12	6
Total	74	20	135	63	124	58	174	138
Reduction	73%		53%		53%		21%	

The overall reduction in crashes for this category was 45 percent (507 before, 279 after).

Table 32 summarizes the data for geometric improvement projects. The mean crash reduction factor is a 32 percent decrease in total crashes. The 90 percent confidence interval for total crashes is from a 10.9 percent reduction up to a 52.7 percent decrease. From this analysis, it may be concluded that other geometric improvements are likely to result in a decrease in total crashes. No statistically significant conclusions can be drawn about fatalities.

Table 32 Confidence Intervals—Other Geometric Improvements

					90% Confidence Interval	
Crash Category		**Mean**	**Count**	**Std Dev**	**Lower**	**Upper**
Total		32%	12	40%	10.9%	52.7%
Severity	Fatal	100%	2	0%	N/A	N/A
	Major	61%	10	57%	27.9%	94.1%
	Minor	–8%	10	245%	–150.2%	133.6%
	Possible	39%	11	50%	11.1%	66.0%
	PDO	28%	12	37%	9.0%	47.7%
Type	RA	34%	11	87%	–14.1%	81.2%
	RE	61%	10	34%	41.7%	80.9%
	LT	73%	9	29%	54.9%	90.9%
	Other	–3%	12	85%	–39.3%	34.5%
B/C Ratio	Method 1	2.5	5	2.2	–2.2	7.2
	Method 2	2.0	5	1.7	–1.7	5.7

Similar to other categories, the mean B/C ratios were very low and hence, confidence intervals that ranged from negative numbers to positive numbers. Results of removing the outliers are shown in Table 33.

Table 33 Confidence Intervals—Other Geometric Improvements—Outliers Removed

Crash Category		Mean	Count	Std Dev	90% Confidence Interval Lower	90% Confidence Interval Upper
Severity	Minor	69%	9	31%	49.6%	87.5%
	PDO	37%	11	23%	24.2%	49.8%
Type	RA	57%	10	42%	32.4%	81.4%
	Other	24%	12	22%	12.0%	35.2%

CURRENT CRASH REDUCTION FACTORS

The Iowa DOT currently uses the crash reduction factors found in Table 34. Only three of the factors were in categories that were similar to those identified in this research project.

Table 34 Current Iowa DOT Factors

Improvement	Reduction Factor
New signal	20%
Upgrade signal	15%
Add turn lane(s)	25%

Source: Iowa Department of Transportation.

SUMMARY AND RECOMMENDATIONS

Table 35 summarizes the mean B/C ratios and crash reduction factors for all seven improvement categories. When all data are considered, the highest B/C ratios are for new traffic signal with turn lane(s) projects and pedestal mount signal replacement projects for both methods of calculating crash costs. When the outliers are removed from the analysis, pedestal replacement projects remain much higher than the other categories. The highest crash reduction factor is for projects that added turn phasing with turn lane(s) when all data are included in the analysis. New traffic signal projects actually shows an increase in the crashes. However, if outliers are eliminated, the crash reduction factors are remarkably similar.

Table 35 Summary of Benefit/Cost Ratios and Crash Reduction Factors

	B/C Ratio				Total Crash Reduction	
	Method 1		Method 2			
Category	All Data	No Outliers	All Data	No Outliers	All Data	No Outliers
New traffic signal	0.8	0.8	5.1	5.1	-4	27
New signal + turn lane(s)	17.0	4.1	9.8	3.8	20	20
Add phasing to existing signal	1.3	—	1.3	—	36	—
Add phasing + turn lane(s)	3.4	3.4	2.7	2.7	58	58
Replace pedestal w/ mast arms	7.9	11.2	7.7	11.3	29	36
Add turn lane(s)	0.7	0.7	0.5	0.5	12	12
Other geometric improvements	2.5	2.5	2.0	2.0	32	32

When compared to current crash reduction factors, the results of this research show some differences. It is recommended that the Iowa DOT use the total crash reduction factors that are shown in Table 35 with the outliers removed. The B/C ratio that should be assigned to projects should also be adopted from Table 35. With the exception of new traffic signal projects, the B/C ratios between methods 1 and 2 are very similar. Current Iowa DOT policy indicates that method 1 should be used. However, further research may want to be done to determine if method 2 is a more applicable method in order to reduce the affect that one fatality has on a particular improvement site.

Factors for categories turn phasing projects and other geometric improvements should not be adopted without further research. The sample size of turn phasing projects was very small. The types of projects included in other geometric improvements were varied and should probably not be lumped into one type of improvement project.

It must be reiterated, that this analysis did not take into account traffic volumes. Reliable traffic volumes were not available for all project locations. A more detailed analysis was not possible without making numerous assumptions about traffic volumes. This analysis also did not account for the regression to the mean phenomenon described in the literature review.

REFERENCES

1. Yuan, F., J. Ivan, N. Garrick, and C. Davis. *Estimating the Benefits from Specific Highway Safety Improvements: Phase I-Feasibility Study*. University of Connecticut and Connecticut Department of Transportation, May 1999.

2. Voss, L. G. *Accident Reduction Factors*. Kansas Department of Transportation Bureau of Traffic Engineering, May 1997.

3. Persaud, B. N., and E. Hauer. “Comparison of Two Methods for Debiasing Before-and-After Accident Studies.” *Transportation Research Record,* No. 975, Jan. 1984.

4. Hauer, E., and J. Lovell. “New Directions for Learning About the Safety Effect of Measures.” *Transportation Research Record,* No. 1068, Jan. 1986.

5. Persaud, B. N. “Safety Migration, the Influence of Traffic Volumes, and Other Issues in Evaluating Safety Effectiveness—Some Findings on Conversion of Intersections to Multiway Stop Control.” *Transportation Research Record,* No. 1068, Jan. 1986.

6. Berg, W. D., and C. Fuchs. “Evaluating Need for Accident-Reduction Experiments.” *Transportation Research Record*, No. 905, Jan. 1983.

7. Perkins, D. D., and B. L. Bowman. “Effectiveness Evaluation by Using Nonaccident Measures of Effectiveness.” *Transportation Research Record,* No. 905, Jan. 1983.

APPENDIX

Benefit/Cost Ratios by Project Type - Method 1

Category	Before					After								
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C

1. Add New Signal(s)

Category / Project Cost	Before Fatal	Before Major	Before Minor	Before Poss	Before PDO $	After Fatal	After Major	After Minor	After Poss	After PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-8260(4)															
$73,265	0	0	7	14	$99,479	0	0	2	10	$76,409	$183,479	$112,409	($6,137)	($25,125)	4.09
CS-TSF-0187(4)															
$75,000	0	3	1	8	$64,653	0	0	2	14	$58,800	$448,653	$102,800	($6,282)	($122,270)	19.46
TSF-6-4(103)															
$90,982	0	0	5	7	$85,356	0	2	1	18	$102,300	$139,356	$386,300	($7,621)	$87,302	-11.46
L-TSF-0077(2)															
$60,000	0	4	10	15	$122,050	1	0	6	6	$58,056	$712,050	$918,056	($5,026)	$72,829	-14.49
FM-TSF-0078(1)															
$93,917	0	1	6	2	$65,206	0	2	2	5	$72,300	$237,206	$338,300	($7,867)	$35,740	-4.54
FM-TSF-0077(1a)															
$60,000	0	0	1	0	$32,524	0	1	2	8	$65,450	$40,524	$217,450	($5,026)	$62,549	-12.45
CS-TSF-8260(1b)															
$153,900	0	0	8	10	$166,885	0	1	1	1	$40,001	$250,885	$170,001	($12,892)	($28,595)	2.22
CS-TSF-5657(1b)															
$52,500	0	3	4	9	$24,815	0	0	0	0	$2,186	$434,815	$2,186	($4,398)	($152,947)	34.78
CS-TSF-5657(1a)															
$52,500	0	0	1	0	$4,400	0	0	4	4	$48,910	$12,400	$88,910	($4,398)	$27,049	-6.15
CS-TSF-3127(1)															
$66,160	0	0	4	4	$56,703	0	2	4	14	$67,150	$96,703	$367,150	($5,542)	$95,611	-17.25
CS-TSF-3125(2)															
$138,107	0	1	14	16	$156,648	1	2	13	24	$213,624	$420,648	1,405,624	($11,569)	$348,219	-30.10
CS-TSF-1945(4)															
$23,000	0	0	6	2	$71,256	0	0	3	4	$51,506	$123,256	$83,506	($1,927)	($14,053)	7.29
CS-TSF-1425(1a)															
$73,700	0	2	9	9	$77,275	0	0	3	12	$75,778	$407,275	$123,778	($6,174)	($100,225)	16.23

Category	Before					After								
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-1415(1)															
$67,423	0	0	2	6	$27,751	0	0	5	14	$35,600	$55,751	$103,600	($5,648)	$16,916	-3.00
CS-TSF-1147(1)															
$52,550	0	0	1	0	$49,300	0	0	0	0	$12,012	$57,300	$12,012	($4,402)	($16,011)	3.64
FM-TSF-0077(1b)															
$60,000	0	1	15	9	$107,500	0	0	0	0	$17,403	$365,500	$17,403	($5,026)	($123,063)	24.49

2. Add New Signal(s) + Turn Lane(s)

Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-1425(1b)															
$134,900	0	1	6	11	$109,045	0	0	3	2	$40,633	$299,045	$68,633	($11,300)	($81,458)	7.21
CS-TSF-7057(3)															
$389,263	0	2	12	24	$146,855	0	0	3	9	$74,456	$530,855	$116,456	($32,607)	($146,503)	4.49
SN-TSF-3403(5)															
$881,485	1	1	6	10	$172,257	0	0	2	2	$31,800	1,160,257	$51,800	($73,839)	($391,873)	5.31
HES-192-0(14)															
$181,278	0	3	9	14	$68,469	0	4	4	7	$43,200	$528,469	$569,200	($15,185)	$14,400	-0.95
FM-TSF-0077(1c)															
$246,088	0	4	0	5	$122,600	0	0	2	4	$15,600	$612,600	$39,600	($20,614)	($202,573)	9.83
FM-TSF-0044(1)															
$155,757	2	3	9	17	$130,632	0	0	3	1	$70,400	2,196,632	$96,400	($13,047)	($742,496)	56.91
CS-TSF-0155(2)															
$430,184	0	2	5	6	$110,812	0	0	0	1	$9,279	$402,812	$11,279	($36,035)	($138,419)	3.84
CS-TSF-1425(1c)															
$132,100	0	2	2	5	$69,350	0	0	1	9	$65,456	$335,350	$91,456	($11,066)	($86,224)	7.79
CS-TSF-0155(3)															
$78,791	0	0	3	5	$54,311	0	0	3	7	$83,275	$88,311	$121,275	($6,600)	$11,654	-1.77
CS-TSF-6102(1)															
$50,104	1	2	5	11	$80,776	0	0	2	5	$51,912	1,182,776	$77,912	($4,197)	($390,603)	93.07
CS-TSF-1642(6)															
$535,893	0	2	3	8	$33,909	0	0	4	17	$78,237	$313,909	$144,237	($44,890)	($59,984)	1.34

Category			Before					After						
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
3. Add Turn Phasing Only															
CS-TSF-1867(1)															
$45,459	0	1	9	19	$132,932	0	2	6	7	$156,906	$362,932	$458,906	($3,808)	$33,930	-8.91
TSF-160-1(5)															
$61,917	0	1	2	5	$35,600	0	0	0	0	$11,856	$181,600	$11,856	($5,187)	($60,010)	11.57
4. Add Turn Phasing + Turn Lane(s)															
CS-TSF-1945(1)															
$1,154,302	0	2	12	25	$168,843	0	0	11	15	$84,350	$554,843	$202,350	($96,692)	($124,617)	1.29
HES-28-2(22)-2H-7															
$2,933,593	0	0	6	31	$232,638	0	1	1	8	$26,000	$342,638	$170,000	($245,737)	($61,033)	0.25
HES-20-3(63)															
$606,054	1	2	28	24	$270,969	0	0	7	17	$138,946	1,582,969	$228,946	($50,767)	($478,688)	9.43
HES-192-0(16b)															
$416,000	0	3	18	33	$224,415	1	1	8	5	$88,749	$794,415	1,082,749	($34,847)	$101,935	-2.93
CS-TSF-8260(1a)															
$440,300	1	1	8	19	$154,727	0	0	2	7	$45,511	1,176,727	$75,511	($36,882)	($389,313)	10.56
HES-192-0(16a)															
$416,000	0	0	12	20	$114,472	0	0	2	11	$34,406	$250,472	$72,406	($34,847)	($62,952)	1.81

Category			Before					After			Before	After	Annualized	Annualized	
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Cost	Cost	Cost	Benefit	B/C
5. Replace Pedestal Mounts w/ Mast Arm Signals															
CS-TSF-1827(3e) $53,700	0	0	13	23	$208,861	0	0	6	11	$73,822	$358,861	$143,822	($4,498)	($76,023)	16.90
CS-TSF-1827(3a) $53,700	0	0	1	2	$90,342	0	0	1	6	$36,768	$102,342	$56,768	($4,498)	($16,112)	3.58
CS-TSF-1827(3b) $53,700	0	4	8	12	$106,589	0	0	2	4	$33,812	$674,589	$57,812	($4,498)	($218,049)	48.47
CS-TSF-1827(3d) $53,700	0	0	18	28	$258,649	0	0	1	9	$77,337	$458,649	$103,337	($4,498)	($125,614)	27.92
CS-TSF-1945(7b) $37,500	0	0	0	9	$58,921	0	1	5	10	$72,466	$76,921	$252,466	($3,141)	$62,060	-19.76
CS-TSF-1945(7j) $37,500	0	0	6	6	$64,013	0	0	1	2	$22,856	$124,013	$34,856	($3,141)	($31,520)	10.03
CS-TSF-1945(7i) $37,500	0	0	3	9	$67,259	0	0	0	4	$19,407	$109,259	$27,407	($3,141)	($28,937)	9.21
CS-TSF-1945(7h) $37,500	1	0	2	11	$94,203	0	1	0	0	$7,506	$932,203	$127,506	($3,141)	($284,485)	90.56
CS-TSF-1945(7g) $37,500	0	0	4	8	$61,712	0	2	2	9	$38,990	$109,712	$312,990	($3,141)	$71,865	-22.88
CS-TSF-1945(7f) $37,500	0	1	5	4	$105,341	0	0	6	9	$41,281	$273,341	$107,281	($3,141)	($58,707)	18.69
CS-TSF-1945(7e) $37,500	0	1	0	0	$37,734	0	0	1	1	$18,109	$157,734	$28,109	($3,141)	($45,826)	14.59
CS-TSF-1827(3c) $53,700	0	3	3	11	$99,124	0	2	1	6	$61,856	$505,124	$321,856	($4,498)	($64,791)	14.40
CS-TSF-1945(7c) $37,500	0	1	6	7	$114,521	0	1	4	3	$60,837	$296,521	$218,837	($3,141)	($27,464)	8.74
CS-TSF-1945(7a) $37,500	0	0	1	4	$44,876	0	0	2	8	$43,054	$60,876	$75,054	($3,141)	$5,012	-1.60
CS-TSF-1945(5l) $31,000	0	1	10	14	$128,506	0	1	1	4	$61,723	$356,506	$197,723	($2,597)	($56,135)	21.62

Category			Before					After							
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-1945(5k)															
$31,000	0	0	4	12	$40,814	0	1	9	15	$55,702	$96,814	$277,702	($2,597)	$63,949	-24.63
CS-TSF-1945(5j)															
$31,000	0	0	1	6	$32,853	0	0	9	16	$71,385	$52,853	$175,385	($2,597)	$43,319	-16.68
CS-TSF-1827(6)															
$39,696	0	0	3	27	$133,591	0	0	0	2	$34,318	$211,591	$38,318	($3,325)	($61,257)	18.42
CS-TSF-1945(7d)															
$37,500	0	2	2	14	$57,856	0	0	2	2	$31,961	$341,856	$51,961	($3,141)	($102,487)	32.63
CS-TSF-1827(5)															
$40,400	0	0	6	19	$104,532	0	0	5	10	$81,227	$190,532	$141,227	($3,384)	($17,431)	5.15
CS-TSF-1945(5i)															
$31,000	0	1	9	12	$75,589	0	0	3	4	$37,904	$291,589	$69,904	($2,597)	($78,372)	30.18
CS-TSF-1945(2)															
$265,000	0	2	18	13	$177,800	0	3	20	32	$192,802	$587,800	$776,802	($22,198)	$66,818	-3.01
CS-TSF-1945(3b)															
$40,000	0	1	14	19	$174,190	1	7	16	28	$233,615	$444,190	2,057,615	($3,351)	$570,395	-170.23
CS-TSF-1945(5a)															
$31,000	0	1	6	10	$62,032	0	0	4	18	$65,957	$250,032	$133,957	($2,597)	($41,036)	15.80
CS-TSF-1945(5b)															
$31,000	0	1	4	12	$66,109	0	2	11	17	$81,350	$242,109	$443,350	($2,597)	$71,145	-27.40
CS-TSF-1945(5d)															
$31,000	0	5	6	17	$125,162	0	2	5	11	$83,668	$807,162	$385,668	($2,597)	($149,011)	57.38
CS-TSF-1945(5e)															
$31,000	0	0	2	3	$46,506	0	2	4	8	$29,928	$68,506	$317,928	($2,597)	$88,178	-33.96
CS-TSF-1945(5f)															
$31,000	0	2	2	2	$59,615	0	0	3	7	$58,256	$319,615	$96,256	($2,597)	($78,964)	30.41
CS-TSF-1945(5g)															
$31,000	0	4	11	14	$180,055	0	1	16	14	$130,771	$776,055	$406,771	($2,597)	($130,553)	50.28
CS-TSF-1945(5h)															
$31,000	0	0	4	10	$44,743	0	0	3	6	$74,951	$96,743	$110,951	($2,597)	$5,023	-1.93

Category	Before					After					Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $					
CS-TSF-1945(5c)															
$31,000	0	2	2	8	$64,400	0	0	0	2	$24,542	$336,400	$28,542	($2,597)	($108,837)	41.91
6. Add Turn Lane(s)															
CS-TSF-1945(6)															
$421,593	0	1	8	46	$243,444	1	6	20	37	$311,004	$519,444	2,065,004	($35,315)	$546,402	-15.47
TSF-34-9(64)															
$357,555	1	2	5	6	$86,304	0	0	0	8	$38,769	1,178,304	$54,769	($29,951)	($397,204)	13.26
STP-69-5(46)															
$832,187	0	0	1	11	$62,062	0	1	5	10	$140,459	$92,062	$320,459	($69,709)	$80,745	-1.16
CS-TSF-0077(9)															
$993,116	0	0	4	22	$173,338	0	1	9	25	$208,340	$249,338	$450,340	($83,190)	$71,060	-0.85
CS-TSF-7057(5)															
$413,901	0	6	9	15	$110,353	0	0	0	11	$35,303	$932,353	$57,303	($34,671)	($309,357)	8.92
CS-TSF-1945(3a)															
$260,000	0	2	5	21	$195,044	0	1	15	33	$236,680	$517,044	$542,680	($21,779)	$9,063	-0.42
HES-18-5(52)															
$599,955	0	2	10	20	$129,400	0	1	10	17	$185,626	$489,400	$419,626	($50,256)	($24,667)	0.49
7. Geometric Improvements															
HES-65-4(55)															
$602,000	0	1	2	3	$28,600	0	0	0	4	$18,065	$170,600	$26,065	($50,427)	($51,098)	1.01
(HES)STP-6-7(41)															
$2,254,000	0	1	10	23	$131,436	0	1	4	25	$68,781	$377,436	$270,781	($188,810)	($37,706)	0.20
CS-TSF-0187(1)															
$1,049,352	0	1	6	5	$94,285	0	0	1	3	$30,873	$272,285	$44,873	($87,901)	($80,397)	0.91
FM-TSF-0077(8)															
$735,132	0	0	0	2	$23,300	0	1	2	3	$44,049	$27,300	$186,049	($61,579)	$56,123	-0.91
HES-30-5(57)															
$1,200,000	2	10	17	23	$244,165	0	0	0	2	$40,000	3,226,165	$44,000	($100,520)	($1,124,992)	11.19

Benefit/Cost Ratios by Project Type - Method 2

Category	Before					After									
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
1. Add New Signal(s)															
CS-TSF-8260(4)															
$73,265	0	0	7	14	$99,479	0	0	2	10	$76,409	$183,479	$112,409	($6,137)	($25,125)	4.09
CS-TSF-0187(4)															
$75,000	0	3	1	8	$64,653	0	0	2	14	$58,800	$448,653	$102,800	($6,282)	($122,270)	19.46
TSF-6-4(103)															
$90,982	0	0	5	7	$85,356	0	2	1	18	$102,300	$139,356	$386,300	($7,621)	$87,302	-11.46
L-TSF-0077(2)															
$60,000	0	4	10	15	$122,050	1	0	6	6	$58,056	$712,050	$238,056	($5,026)	($167,571)	33.34
FM-TSF-0078(1)															
$93,917	0	1	6	2	$65,206	0	2	2	5	$72,300	$237,206	$338,300	($7,867)	$35,740	-4.54
FM-TSF-0077(1a)															
$60,000	0	0	1	0	$32,524	0	1	2	8	$65,450	$40,524	$217,450	($5,026)	$62,549	-12.45
CS-TSF-8260(1b)															
$153,900	0	0	8	10	$166,885	0	1	1	1	$40,001	$250,885	$170,001	($12,892)	($28,595)	2.22
CS-TSF-5657(1b)															
$52,500	0	3	4	9	$24,815	0	0	0	0	$2,186	$434,815	$2,186	($4,398)	($152,947)	34.78
CS-TSF-5657(1a)															
$52,500	0	0	1	0	$4,400	0	0	4	4	$48,910	$12,400	$88,910	($4,398)	$27,049	-6.15
CS-TSF-3127(1)															
$66,160	0	0	4	4	$56,703	0	2	4	14	$67,150	$96,703	$367,150	($5,542)	$95,611	-17.25
CS-TSF-3125(2)															
$138,107	0	1	14	16	$156,648	1	2	13	24	$213,624	$420,648	$725,624	($11,569)	$107,818	-9.32
CS-TSF-1945(4)															
$23,000	0	0	6	2	$71,256	0	0	3	4	$51,506	$123,256	$83,506	($1,927)	($14,053)	7.29
CS-TSF-1425(1a)															
$73,700	0	2	9	9	$77,275	0	0	3	12	$75,778	$407,275	$123,778	($6,174)	($100,225)	16.23

Category	Before					After								
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-1415(1)															
$67,423	0	0	2	6	$27,751	0	0	5	14	$35,600	$55,751	$103,600	($5,648)	$16,916	-3.00
CS-TSF-1147(1)															
$52,550	0	0	1	0	$49,300	0	0	0	0	$12,012	$57,300	$12,012	($4,402)	($16,011)	3.64
FM-TSF-0077(1b)															
$60,000	0	1	15	9	$107,500	0	0	0	0	$17,403	$365,500	$17,403	($5,026)	($123,063)	24.49
2. Add New Signal(s) + Turn Lane(s)															
CS-TSF-1425(1b)															
$134,900	0	1	6	11	$109,045	0	0	3	2	$40,633	$299,045	$68,633	($11,300)	($81,458)	7.21
CS-TSF-7057(3)															
$389,263	0	2	12	24	$146,855	0	0	3	9	$74,456	$530,855	$116,456	($32,607)	($146,503)	4.49
SN-TSF-3403(5)															
$881,485	1	1	6	10	$172,257	0	0	2	2	$31,800	$480,257	$51,800	($73,839)	($151,473)	2.05
HES-192-0(14)															
$181,278	0	3	9	14	$68,469	0	4	4	7	$43,200	$528,469	$569,200	($15,185)	$14,400	-0.95
FM-TSF-0077(1c)															
$246,088	0	4	0	5	$122,600	0	0	2	4	$15,600	$612,600	$39,600	($20,614)	($202,573)	9.83
FM-TSF-0044(1)															
$155,757	2	3	9	17	$130,632	0	0	3	1	$70,400	1,516,632	$96,400	($13,047)	($502,095)	38.48
CS-TSF-0155(2)															
$430,184	0	2	5	6	$110,812	0	0	0	1	$9,279	$402,812	$11,279	($36,035)	($138,419)	3.84
CS-TSF-1425(1c)															
$132,100	0	2	2	5	$69,350	0	0	1	9	$65,456	$335,350	$91,456	($11,066)	($86,224)	7.79
CS-TSF-0155(3)															
$78,791	0	0	3	5	$54,311	0	0	3	7	$83,275	$88,311	$121,275	($6,600)	$11,654	-1.77
CS-TSF-6102(1)															
$50,104	1	2	5	11	$80,776	0	0	2	5	$51,912	$502,776	$77,912	($4,197)	($150,202)	35.79
CS-TSF-1642(6)															
$535,893	0	2	3	8	$33,909	0	0	4	17	$78,237	$313,909	$144,237	($44,890)	($59,984)	1.34

Category			Before					After							
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
3. Add Turn Phasing Only															
CS-TSF-1867(1)															
$45,459	0	1	9	19	$132,932	0	2	6	7	$156,906	$362,932	$458,906	($3,808)	$33,930	-8.91
TSF-160-1(5)															
$61,917	0	1	2	5	$35,600	0	0	0	0	$11,856	$181,600	$11,856	($5,187)	($60,010)	11.57
4. Add Turn Phasing + Turn Lane(s)															
CS-TSF-1945(1)															
$1,154,302	0	2	12	25	$168,843	0	0	11	15	$84,350	$554,843	$202,350	($96,692)	($124,617)	1.29
HES-28-2(22)-2H-7															
$2,933,593	0	0	6	31	$232,638	0	1	1	8	$26,000	$342,638	$170,000	($245,737)	($61,033)	0.25
HES-20-3(63)															
$606,054	1	2	28	24	$270,969	0	0	7	17	$138,946	$902,969	$228,946	($50,767)	($238,288)	4.69
HES-192-0(16b)															
$416,000	0	3	18	33	$224,415	1	1	8	5	$88,749	$794,415	$402,749	($34,847)	($138,466)	3.97
CS-TSF-8260(1a)															
$440,300	1	1	8	19	$154,727	0	0	2	7	$45,511	$496,727	$75,511	($36,882)	($148,913)	4.04
HES-192-0(16a)															
$416,000	0	0	12	20	$114,472	0	0	2	11	$34,406	$250,472	$72,406	($34,847)	($62,952)	1.81

Category	Before					After					Before	After	Annualized	Annualized	
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Cost	Cost	Cost	Benefit	B/C
5. Replace Pedestal Mounts w/ Mast Arm Signal															
CS-TSF-1827(3e)															
$53,700	0	0	13	23	$208,861	0	0	6	11	$73,822	$358,861	$143,822	($4,498)	($76,023)	16.90
CS-TSF-1827(3a)															
$53,700	0	0	1	2	$90,342	0	0	1	6	$36,768	$102,342	$56,768	($4,498)	($16,112)	3.58
CS-TSF-1827(3b)															
$53,700	0	4	8	12	$106,589	0	0	2	4	$33,812	$674,589	$57,812	($4,498)	($218,049)	48.47
CS-TSF-1827(3d)															
$53,700	0	0	18	28	$258,649	0	0	1	9	$77,337	$458,649	$103,337	($4,498)	($125,614)	27.92
CS-TSF-1945(7b)															
$37,500	0	0	0	9	$58,921	0	1	5	10	$72,466	$76,921	$252,466	($3,141)	$62,060	-19.76
CS-TSF-1945(7j)															
$37,500	0	0	6	6	$64,013	0	0	1	2	$22,856	$124,013	$34,856	($3,141)	($31,520)	10.03
CS-TSF-1945(7i)															
$37,500	0	0	3	9	$67,259	0	0	0	4	$19,407	$109,259	$27,407	($3,141)	($28,937)	9.21
CS-TSF-1945(7h)															
$37,500	1	0	2	11	$94,203	0	1	0	0	$7,506	$252,203	$127,506	($3,141)	($44,084)	14.03
CS-TSF-1945(7g)															
$37,500	0	0	4	8	$61,712	0	2	2	9	$38,990	$109,712	$312,990	($3,141)	$71,865	-22.88
CS-TSF-1945(7f)															
$37,500	0	1	5	4	$105,341	0	0	6	9	$41,281	$273,341	$107,281	($3,141)	($58,707)	18.69
CS-TSF-1945(7e)															
$37,500	0	1	0	0	$37,734	0	0	1	1	$18,109	$157,734	$28,109	($3,141)	($45,826)	14.59
CS-TSF-1827(3c)															
$53,700	0	3	3	11	$99,124	0	2	1	6	$61,856	$505,124	$321,856	($4,498)	($64,791)	14.40
CS-TSF-1945(7c)															
$37,500	0	1	6	7	$114,521	0	1	4	3	$60,837	$296,521	$218,837	($3,141)	($27,464)	8.74
CS-TSF-1945(7a)															
$37,500	0	0	1	4	$44,876	0	0	2	8	$43,054	$60,876	$75,054	($3,141)	$5,012	-1.60
CS-TSF-1945(5l)															
$31,000	0	1	10	14	$128,506	0	1	1	4	$61,723	$356,506	$197,723	($2,597)	($56,135)	21.62

Category			Before					After			Before	After	Annualized	Annualized	
Project Cost	Fatal	Major	Minor	Poss	PDO $	Fatal	Major	Minor	Poss	PDO $	Cost	Cost	Cost	Benefit	B/C
CS-TSF-1945(5k)															
$31,000	0	0	4	12	$40,814	0	1	9	15	$55,702	$96,814	$277,702	($2,597)	$63,949	-24.63
CS-TSF-1945(5j)															
$31,000	0	0	1	6	$32,853	0	0	9	16	$71,385	$52,853	$175,385	($2,597)	$43,319	-16.68
CS-TSF-1827(6)															
$39,696	0	0	3	27	$133,591	0	0	0	2	$34,318	$211,591	$38,318	($3,325)	($61,257)	18.42
CS-TSF-1945(7d)															
$37,500	0	2	2	14	$57,856	0	0	2	2	$31,961	$341,856	$51,961	($3,141)	($102,487)	32.63
CS-TSF-1827(5)															
$40,400	0	0	6	19	$104,532	0	0	5	10	$81,227	$190,532	$141,227	($3,384)	($17,431)	5.15
CS-TSF-1945(5i)															
$31,000	0	1	9	12	$75,589	0	0	3	4	$37,904	$291,589	$69,904	($2,597)	($78,372)	30.18
CS-TSF-1945(2)															
$265,000	0	2	18	13	$177,800	0	3	20	32	$192,802	$587,800	$776,802	($22,198)	$66,818	-3.01
CS-TSF-1945(3b)															
$40,000	0	1	14	19	$174,190	1	7	16	28	$233,615	$444,190	1,377,615	($3,351)	$329,994	-98.49
CS-TSF-1945(5a)															
$31,000	0	1	6	10	$62,032	0	0	4	18	$65,957	$250,032	$133,957	($2,597)	($41,036)	15.80
CS-TSF-1945(5b)															
$31,000	0	1	4	12	$66,109	0	2	11	17	$81,350	$242,109	$443,350	($2,597)	$71,145	-27.40
CS-TSF-1945(5d)															
$31,000	0	5	6	17	$125,162	0	2	5	11	$83,668	$807,162	$385,668	($2,597)	($149,011)	57.38
CS-TSF-1945(5e)															
$31,000	0	0	2	3	$46,506	0	2	4	8	$29,928	$68,506	$317,928	($2,597)	$88,178	-33.96
CS-TSF-1945(5f)															
$31,000	0	2	2	2	$59,615	0	0	3	7	$58,256	$319,615	$96,256	($2,597)	($78,964)	30.41
CS-TSF-1945(5g)															
$31,000	0	4	11	14	$180,055	0	1	16	14	$130,771	$776,055	$406,771	($2,597)	($130,553)	50.28
CS-TSF-1945(5h)															
$31,000	0	0	4	10	$44,743	0	0	3	6	$74,951	$96,743	$110,951	($2,597)	$5,023	-1.93

Category Project Cost	Before Fatal	Major	Minor	Poss	PDO $	After Fatal	Major	Minor	Poss	PDO $	Before Cost	After Cost	Annualized Cost	Annualized Benefit	B/C
CS-TSF-1945(5c)															
$31,000	0	2	2	8	$64,400	0	0	0	2	$24,542	$336,400	$28,542	($2,597)	($108,837)	41.91
6. Add Turn Lane(s)															
CS-TSF-1945(6)															
$421,593	0	1	8	46	$243,444	1	6	20	37	$311,004	$519,444	1,385,004	($35,315)	$306,002	-8.66
TSF-34-9(64)															
$357,555	1	2	5	6	$86,304	0	0	0	8	$38,769	$498,304	$54,769	($29,951)	($156,803)	5.24
STP-69-5(46)															
$832,187	0	0	1	11	$62,062	0	1	5	10	$140,459	$92,062	$320,459	($69,709)	$80,745	-1.16
CS-TSF-0077(9)															
$993,116	0	0	4	22	$173,338	0	1	9	25	$208,340	$249,338	$450,340	($83,190)	$71,060	-0.85
CS-TSF-7057(5)															
$413,901	0	6	9	15	$110,353	0	0	0	11	$35,303	$932,353	$57,303	($34,671)	($309,357)	8.92
CS-TSF-1945(3a)															
$260,000	0	2	5	21	$195,044	0	1	15	33	$236,680	$517,044	$542,680	($21,779)	$9,063	-0.42
HES-18-5(52)															
$599,955	0	2	10	20	$129,400	0	1	10	17	$185,626	$489,400	$419,626	($50,256)	($24,667)	0.49
7. Geometric Improvements															
HES-65-4(55)															
$602,000	0	1	2	3	$28,600	0	0	0	4	$18,065	$170,600	$26,065	($50,427)	($51,098)	1.01
(HES)STP-6-7(41)															
$2,254,000	0	1	10	23	$131,436	0	1	4	25	$68,781	$377,436	$270,781	($188,810)	($37,706)	0.20
CS-TSF-0187(1)															
$1,049,352	0	1	6	5	$94,285	0	0	1	3	$30,873	$272,285	$44,873	($87,901)	($80,397)	0.91
FM-TSF-0077(8)															
$735,132	0	0	0	2	$23,300	0	1	2	3	$44,049	$27,300	$186,049	($61,579)	$56,123	-0.91
HES-30-5(57)															
$1,200,000	2	10	17	23	$244,165	0	0	0	2	$40,000	2,546,165	$44,000	($100,520)	($884,591)	8.80