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16. Abstract
The previous study *Impact of Edge Lines on Safety of Rural Two-Lane Highways* completed in 2005 concluded: with edge lines, centralization of vehicles' positions is more apparent during night time, which reduces the risk of run-off road (ROR) and head-on collisions, and edge line markings generally cause drivers to operate their vehicles away from the road edge, irrespective of the roadway alignment *[1]*.

Does the changed vehicle lateral position reduce the frequency of crashes? Answering this question is important to Louisiana Department of Transportation and Development (LADOTD) since implementing and maintaining edge lines on narrow two-lane highways require significant resources from LADOTD. More than 40 percent of rural, two-lane highways in Louisiana has a pavement width (excluding shoulders) less than 22 ft. with no edge lines. Thus, the goal of this project was to investigate the safety impact of edge lines on narrow, rural two-lane highways in Louisiana by analyzing crash frequencies before and after edge line implementations on a group of selected narrow, rural two-lane highways from all LADOTD districts.

Using the latest safety analysis statistical method, this project analyzed the crash data before and after edge line implementation and concluded that: placing pavement edge lines on rural two-lane highways in Louisiana can not only change vehicles' lateral positions but also reduce crashes. The crash modification factor (CMF) for edge line on narrow, rural two-lane highways is 0.78. Considering the decreasing trend in crashes in the state for the past three years, the modified CMF is 0.83, which implies that, on average, implementing edge lines can reduce 17 percent of crashes.

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LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

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Safety Improvement from Edge Lines on Rural Two-Lane Highways (with three-years before and one-year after crash data analysis)

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ABSTRACT

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Using the latest safety analysis statistical method, this project analyzed the crash data before and after edge line implementation and concluded that: placing pavement edge lines on rural two-lane highways in Louisiana can not only change vehicles' lateral positions but also reduce crashes. The crash modification factor (CMF) for edge line on narrow, rural two-lane highways is 0.78. Considering the decreasing trend in crashes in the state for the past three years, the modified CMF is 0.83, which implies that, on average, implementing edge lines can reduce 17 percent of crashes.

ACKNOWLEDGMENTS

The help and guidance from the project research committee is appreciated. The authors also wish to express their gratitude to the engineers from all nine LADOTD districts who implemented the edge lines for the study.

IMPLEMENTATION STATEMENT

Louisiana has about 5,600 miles of narrow, rural two-lane highways. Reducing crash frequency and alleviating crash severity on this type of highway calls for cost-effective remedies. The findings of this project provide such remedy actions. Whenever it is financially or operationally feasible, edge lines should be implemented on rural, two-lane highways since it improves safety. The recommendations made at the end of this project based on the analysis results should help LADOTD's future plan on improving the safety of rural, two-lane highways.

Particularly, the results of this project can be used by each LADOTD district in operating and maintaining roadways under their administration.

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INTRODUCTION

The previous LTRC sponsored study *Impact of Edge Lines on Safety of Rural Two-Lane Highways* completed in 2005 basically concluded *[1]*:

- With edge lines, centralization of a vehicle's position is more apparent during nighttime, which reduces the risk of Run-off Road (ROR) and head-on collisions.
- Edge line markings generally cause drivers to operate their vehicles away from the road edge, irrespective of the roadway alignment.

The magnitude of the impact of edge line markings is influenced by roadway width, operating speed, hour of the day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic from the opposite direction. These conclusions were drawn based on the analysis of vehicular lateral position data collected from 10 sites on narrow, rural two-lane highways that are under LADOTD District 3. Road tubes (Jamar Technologies, TRAX Plus I series) were used for the data collection for that study. With the carefully designed tube layout, the previous study was able to measure:

- Vehicles driving within 0 to1 feet from road edge,
- Vehicles driving within 1 to 2 feet from road edge,
- Vehicle driving 2 feet away from road edge and not crossing the centerline, and
- Vehicles crossing over the centerline.

Does the changed vehicle lateral position reduce the frequency of crashes? Answering this question is important to LADOTD since implementing and maintaining edge lines on narrow two-lane highways require significant resources from LADOTD. More than 40 percent of rural, two-lane highways in Louisiana have pavement width (excluding shoulders) less than 22 ft. with no edge lines. This project investigates the safety impact of edge lines on narrow, rural, two-lane highways in Louisiana by analyzing crash frequencies before and after edge line implementations on a group of selected narrow rural, two-lane highways from all LADOTD districts.

Unlike other types of potential crash countermeasures, there have not been many studies conducted on the safety impact of edge line on narrow rural, two-lane highways. The limited number of studies can be summarized in two groups. One group focused the vehicular lateral position and another on crash reduction. The early study on vehicle position was actually conducted in our state by Thomas in 1958 on a 24-ft. rural, two-lane highway in Louisiana to see if a broken or continuous line at various distances from the pavement edge had any impact on the lateral position of vehicles. This study concluded that the tendency of vehicles to move towards the center of edge-striped pavements did not appear significantly large to create any abnormal hazard on 24-ft. wide roadways *[2]*. In 1960, the same author repeated the study at different locations in Louisiana, which yielded the same conclusion *[3]*. Other similar studies on the vehicular location were conducted by the Missouri State Highway Department in 1969 and Hassan in 1971 *[4] [5]*. These two studies again gave the similar conclusions. A more recent research conducted by Steyvers et al. in The Netherlands in 2000 used video recording equipment to observe vehicles' position changes before-and-after edge line markings on four very narrow rural roadways with pavement widths between 13.5 ft. and 14.8 ft. *[6]*. It was observed that drivers took a more central position and approached the road edges less frequently when an edge line was present, and interestingly, no problems were encountered with oncoming vehicles on the edge-lined roadways as the vehicles traveling in both directions yielded to the side when passing each other. However, because the roadways in their study were unusually narrow, the findings provide little information to the study.

A comparison of highway crash occurrences before-and-after edge line markings was made by Musick on nine pairs of rural, two-lane highways in Ohio in 1960, which showed that the use of edge lines resulted in a significant reduction in fatality and injury crashes *[7]*. Crashes at intersections, alleys, and driveways were significantly decreased, but crashes between access points showed no significant changes. In the recently published first edition Highway Safety Manual, there is a CMF for placing standard edge line markings on rural, two-lane highways (without mentioning the width of pavement) *[8]*.

In summary, the majority of the past studies had stated that edge line marking generally does not cause negative effects on rural, two-lane highways. However, their findings are limited by the lack of investigation on narrow rural, two-lane highways.

OBJECTIVE

The goal of this project was to investigate the safety impact of edge lines on rural, two-lane highways in Louisiana. Specifically, the research objectives were:

- Identify the segments that will benefit from implementing a pavement edge line the most;
- Implement pavement edge lines at selected locations; and
- Conduct a before-and-after study at these locations to estimate the crash reduction factors.

SCOPE

To meet the objectives of this project, this study was conducted on selected narrow rural, two-lane highways with pavement width less than 22 ft. from all LADOTD districts. It was done with the collaboration of all LADOTD districts for edge line implementation. The annual crash frequencies of four years (2005, 2006, 2007 as the "before period," and 2009 as the "after period") from each site were counted and used in the statistical analysis.

METHODOLOGY

The study basically consists of three steps: **selection of the segments, edge line implementation, and crash analysis.**

Selection of Segment

There are three stages in the selection of segments starting from crash data collection followed by ranking segments mainly based on the safety performance of the segments. Due to the discrepancies of highway attributes (such as existence of edge lines and the type of highway), the last stage of the step one is to verify whether each selected segment is on a narrow rural two-lane highway with no edge line since the database researchers worked on may not have the most updated information.

The first step of this study is to select roadway segments for the edge line implementation. As shown in Figure 1, more than 40 percent of rural highways under LADOTD are narrow, two-lane roadways (pavement width less than 22 ft.) distributed in all nine districts according to the LADOTD database. To involve all districts in this study, the research team set out to select segments from each district. The selection process went through three stages.

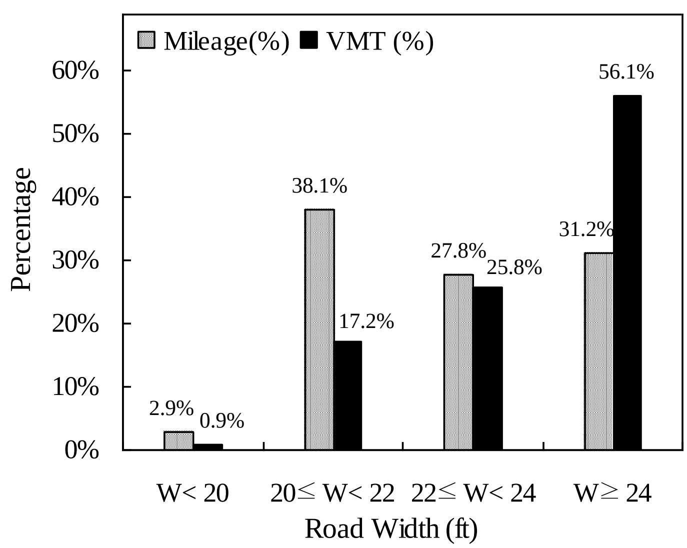


Figure 1
Distribution of rural, two-lane highway by width

Stage I: Crash Data Collection

The research team obtained eight years of crash data (2000-2007) from LADOTD that contain the control section information, then retrieved narrow rural, two-lane highways by performing a data inquiry (highway class = 1 and pavement width less than 22 ft.). The total number of sections under rural, two-lane highways varies each year as shown in Table 1. These control sections vary in length to ensure that the most important attributes such as pavement type and width and shoulder type and width are uniform within each section.

Table 1
Summary of narrow rural two-lane highways in Louisiana

Year	Total mileage	Number of Control Sections
2000	6,143.49	2,559
2001	5,883.31	2,482
2002	5,685.34	2,432
2003	5,605.33	2,405
2004	5,334.9	2,272
2005	5,249.41	2,255
2006	5,054.49	2,139

Stage II: Ranking Sections

Crash frequency and rate have been two widely used black-spot identification methods in LADOTD. In recent years, several other methods have been proposed as complementary to the above two conventional methods. These methods consider not only crash frequency and rate but also level of severity, economical cost, and expected crash level. Due to the data availability, the combination of crash frequencies and crash rate were used in the selection.

The initial screening process yielded 86 segments from nine districts (marked by red colors) as shown in Figure 2.

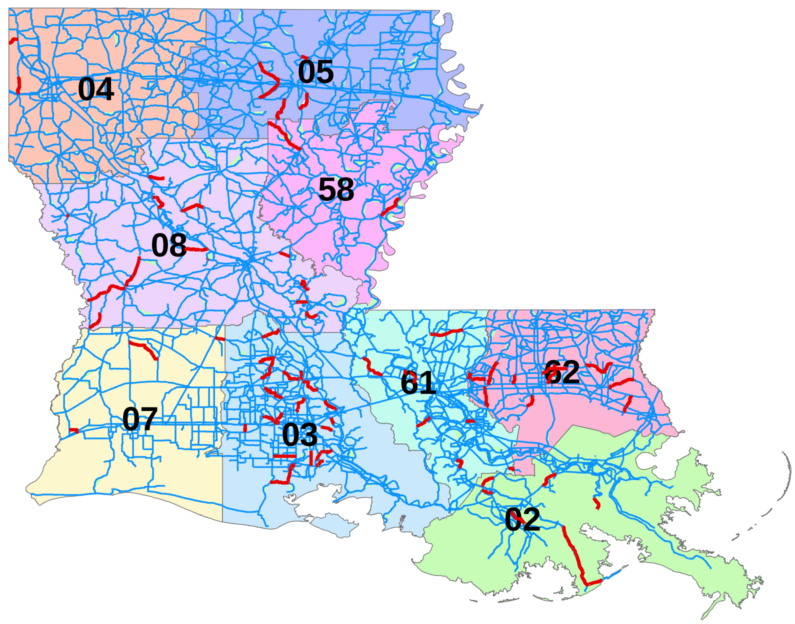


Figure 2
Spatial distribution of initial selection

Stage III: Verifying Sections

After selecting the top sections, the research team verified each section by reviewing images from the LADOTD biennial pavement condition survey since changes do occur each year, such as pavement widening and upgrading to a multilane highway, which are not reflected in the current highway database. All selected sections were reviewed at the LADOTD offices since the research team does not have direct access to the image data.

During the review, quite a few sections were identified as not eligible for the study because they already have edge lines, as shown in Figure 3a, or are not two-lane highways (Figure 3b), or on bridges (Figure 3c), or with curbs (Figure 3d). These sections were subsequently removed from the list.

Figure 3a
Sections already with edge lines

Figure 3b
Sections no longer a two-lane highway

Figure 3c
Sections on bridges

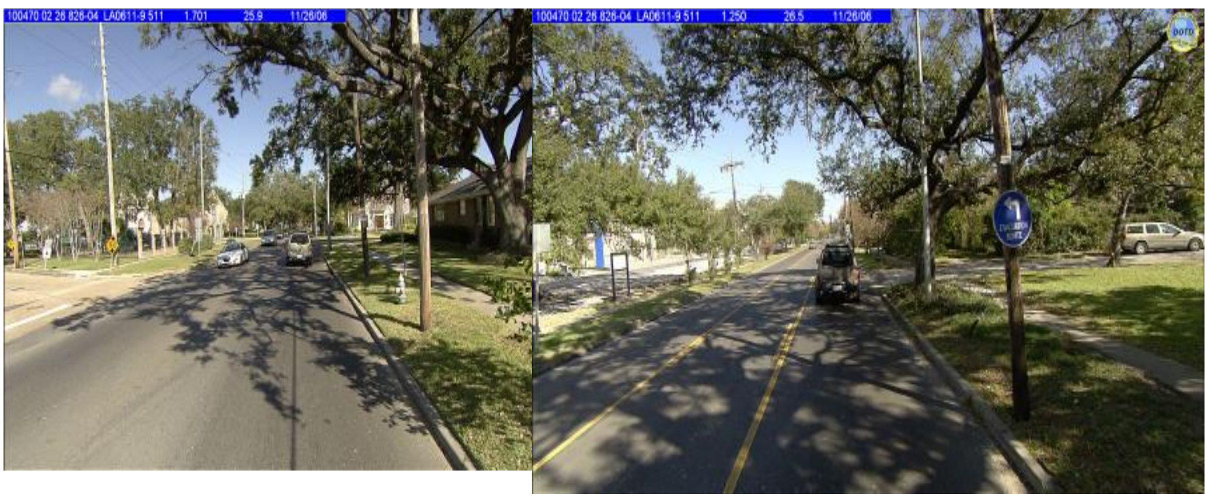


Figure 3d
Sections with curbs

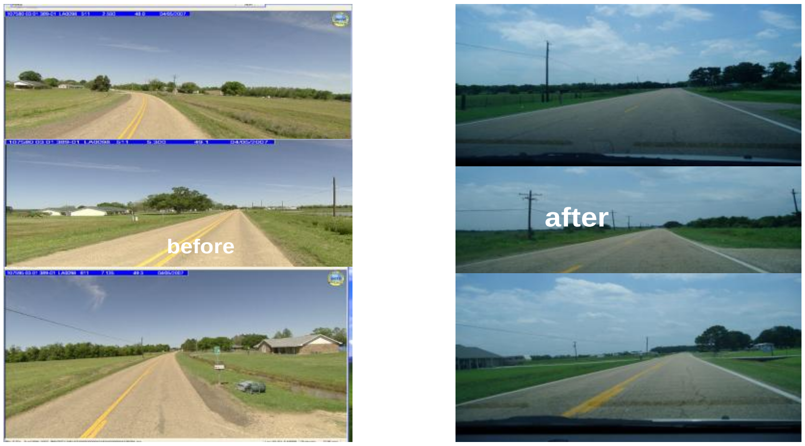
The final list submitted to each district for edge line implementation is summarized in Table 2.

Table 2
Summary of sections by districts

District	Section Length (mi)	No. of Control Sections
2	5.79	2
3	31.96	9
4	6.06	2
5	24.75	4
7	12.51	2
8	4.91	3
58	1.17	1
61	7.85	3
62	19.12	4
Total	114.12	30

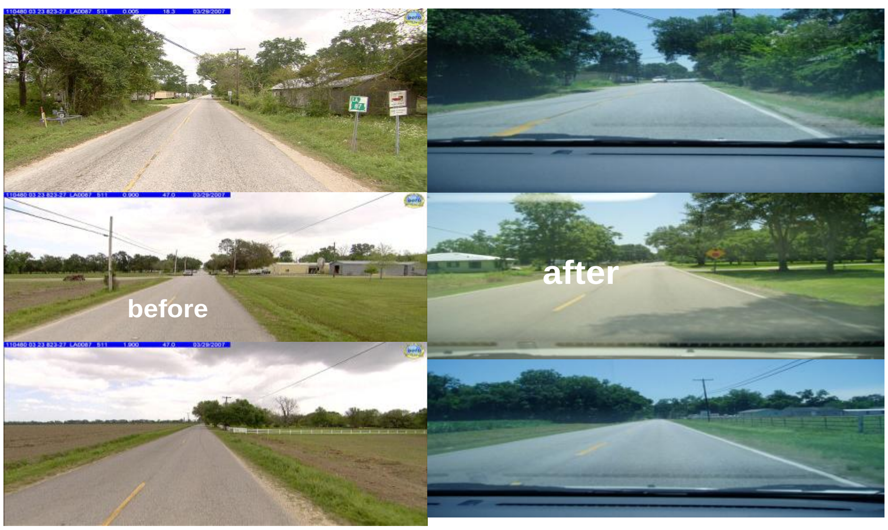
Implementation of Edge Lines

Edge lines were implemented on selected segments between March and June of 2008 by the districts and were partially verified by site-visits (nearly 64 percent site visits) during the 2008 summer by the research team. Figure 4 shows several segments before and after the edge line implementation. Due to the different image sources (the before images are from LADOTD video and the after images were taken by camera) and travel direction, the pictures do not appear exactly the same.



Control Section (D3)	Highway Number Log from and to	Suggestion Milepost (Log Mile)
389-01	0098 2.59-7.15	Starting at milepost 27 for 6 miles (log-mile 2 for 6 miles)

Figure 4a
Before and after edge line implementation (control section LA 389-01)



Control Section (District 3)	Highway Number Log from and to	Suggestion Mile post (Log Mile)
823-27	0087 0-1.89	Starting at milepost 4.0 for 3 miles (0.25 mile before the control section)

Figure 4b
Before and after edge line implementation (control section LA 823-27)

Control Section (D4)	Highway Number Log from and to	Suggestion Milepost (Log Mile)
048-02	0169 4.72-8.29	Starting at milepost 22 for 5 miles (log mile 4.5 for 5 miles)

Figure 4c
Before and after edge line implementation (control section LA 048-02)

Crash Analysis

The third step in this study was to find out whether edge lines have an impact on crash reduction by statistical methods.

The three years before crash data (2005, 2006, and 2007) and one year after crash data (2009) were used. Although it is ideal to use three years after data, the already extended deadline of this project limited the scope of the analysis. By adopting the latest crash data analysis techniques, the potential regression-to-the-mean effect is minimized.

To meet the objectives of this project, this study was conducted on selected narrow, rural two-lane highways with pavement width less than 22 ft. from all LADOTD districts. It was done with the collaboration of all LADOTD districts for edge line implementation. The annual crash frequencies of four years (2005, 2006, and 2007 as the "before period," and 2009 as the "after period") from each site were counted and used in the statistical analysis. The 2008 crash data were excluded because it was the edge line installation year. Three statistical analysis methods were used to show how the new method would work better comparing to the transitional once.

For comparison and discussion purposes, three crash data analysis methods were applied. The last procedure was based on the well-established procedures for highway safety analysis in Ezra Hauer's book "Observational Before and After Studies in Road Safety" published in 2002 *[9]*.The general methodology of these three methods are narrated in this chapter and district wise detailed calculations for the methods are shown in the Appendix.

Method One: Naïve Before and After Analysis

This method had been widely used in previous evaluation crash countermeasures. Based on the conventional statistical analysis, the relationship between two accident counts (x_1 before period and x_2 for after period) can be used to estimate the number of crashes/mile-year for different levels of confidence. It is called naïve before–after (B-A) method because it only recognizes the change caused by an intended treatment. When the before and after periods are the same in number of years or units of time, the required crash count for a desired detectable safety change is:

$$x_2 < x_1 + \frac{k^2}{2} - \frac{k}{2}\sqrt{8x_1 + k^2} \tag{1}$$

where,

x_1 = crash count for before period,

x_2 = crash count for after period, and

k = 1, 2 or, 3 depending on desired confidence level.

The number of crashes that occurred before and after the edge line implementation on the selected segments is summarized by district in Table 3, and the results of crash analysis are shown in Table 4.

Table 3
Crashes by district

District	2005	2006	2007	2005-07	2009
	Total Crashes	Total Crashes	Total Crashes	Total Crashes Before K(j)	Total Crashes After L(j)
2	23	34	24	81	19
3	86	68	67	221	81
4	12	16	8	36	21
5	84	74	84	242	90
7	21	30	14	65	10
8	16	13	15	44	10
58	5	3	4	12	2
61	32	36	17	85	15
62	85	103	83	271	70
	364	377	316	1057	318

Table 4
Calculation of method one

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	326	301	277

Based on this naïve method, crash reduction is somewhat confidently detectable.

One obvious weakness of the above analysis is that it does not account for traffic change. Average annual daily traffic (AADT) has been recognized as the most influential factor on annual crash occurrences.

Method Two: Naïve Before and After Analysis with Treatment for Different Duration of Time Period

Method Two, first introduced by Hauer, accounts for different time duration between the before and after periods *[9]*. In this method, traffic volume is not considered. The steps of the method are described next:

Step One: Estimating the safety if edge lines were not installed during the after period, $\hat{\pi}$, and the safety with edge lines installation $\hat{\lambda}$,

$$\hat{\lambda} = \sum L(j) \tag{2}$$
$$\hat{\pi} = r_d \sum K(j) \tag{3}$$

where,

$\hat{\lambda}$: estimated expected number of crashes in the after period with edge line,

$\hat{\pi}$: estimated expected number of accidents in the after period without edge line, and

r_d : duration of after period/duration of before period.

Step Two: Estimating $V\hat{A}R\{\hat{\lambda}\}$ and $V\hat{A}R\{\hat{\pi}\}$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) \tag{4}$$
$$V\hat{A}R(\hat{\pi}) = (r_d)^2 \sum K(j) \tag{5}$$

where,

$\hat{\lambda}$: estimated expected number of crashes in the after period with edge line, and

$\hat{\pi}$: estimated expected number of crashes in the after period without edge line.

where,

$V\hat{A}R\{\hat{\lambda}\}$: estimated variance of estimated expected number of crashes in the after period with edge line, and

$V\hat{A}R\{\hat{\pi}\}$: estimated variance of the estimated expected number of crashes in the after period if edge lines were not used.

Step Three:

Estimating the difference $\hat{\delta}$ and the ratio $\hat{\theta}$,

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} \tag{6}$$
$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] \tag{7}$$

where,

$\hat{\delta}$ = estimated safety impact of edge line

$\hat{\theta}$ = estimated unbiased expected crash modification factor

Step Four: Estimating the variance of $\hat{\delta}$ and $\hat{\theta}$

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{V\hat{A}R\{\hat{\pi}\} + V\hat{A}R\{\hat{\lambda}\}} \tag{8}$$

$$\hat{\sigma}\{\hat{\theta}\} = \hat{\theta}\sqrt{V\hat{A}R\{\hat{\lambda}\}/\hat{\lambda}^2) + (V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)} /(1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2) \tag{9}$$

The final results showed that the expected crash reduction is 34 with a standard deviation of 20.12, and the estimated crash modification factor is 0.90 with a standard deviation of 0.056. The details of the calculation are shown in Table 5.

Table 5
Summary table for method two

Dist	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	Years before	Years After	$r_d(j)$	$r_d(j)*K(j)$	$r_d(j)^2*K(j)$
2	5.79	23	34	24	81	19	3	1	0.33	27	9
3	31.96	86	68	67	221	81	3	1	0.33	74	25
4	6.06	12	16	8	36	21	3	1	0.33	12	4
5	24.75	84	74	84	242	90	3	1	0.33	81	27
7	12.51	21	30	14	65	10	3	1	0.33	22	7
8	4.91	16	13	15	44	10	3	1	0.33	15	5
58	1.17	5	3	4	12	2	3	1	0.33	4	1
61	7.85	32	36	17	85	15	3	1	0.33	28	9
62	19.12	85	103	83	271	70	3	1	0.33	90	30
	114.12	364	377	316	1057	318				352	117

Calculations details:

$$\hat{\lambda} = \sum L(j) = 318$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 318$$

$$\hat{\pi} = \sum r_d(j)K(j) = 352$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 117$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 34$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 405, \hat{\sigma}(\hat{\delta}) = 20.12$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 0.90$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.0031, \hat{\sigma}(\hat{\theta}) = 0.0556$$

Method Three: Improved Prediction Methods with Traffic Change

The objective of an unbiased observational before-after study is to evaluate a treatment when the roadways or facilities are unchanged (including AADT) except for the implementation of the treatment. However, it is impossible to control the changes of other factors in a highway safety study. Theoretically speaking, the true impact of a treatment should be the difference between the predicted safety after the treatment and the predicted safety in the after period if the treatment were not implemented.

To account for the change in traffic volume, the following procedure introduced by Hauer was used in estimating the unbiased crash changes before and after installation of the edge line *[9]*.

Step One: Estimating the safety if edge lines were not installed *during after period*, $\hat{\pi}$, and the safety with edge lines installation $\hat{\lambda}$,

$$\hat{\lambda} = L \tag{10}$$

$$\hat{\pi} = \hat{r}_{tf} K \tag{11}$$

where,

$\hat{\lambda}$: estimated expected number of crashes in the after period with edge line,

L: number of crashes in the after period with edge line,

$\hat{\pi}$: estimated expected number of crashes in the after period without edge line,

K: : number of crashes in the before period without edge line,

$\hat{r}_{tf}$: traffic flow correction factor

$$r_{tf} = \frac{\hat{A}_{avg}}{\hat{B}_{avg}} \tag{12}$$

$\hat{A}_{avg}$: average traffic flow during the after period, and

$\hat{B}_{avg}$: average traffic flow during the before period.

Step Two: Estimating $V\hat{A}R\{\hat{\lambda}\}$ and $V\hat{A}R\{\hat{\pi}\}$

$$\hat{VAR}\{\hat{\lambda}\} = L \tag{13}$$

$$\hat{VAR}\{\hat{r}_{tf}\} = (\hat{r}_{tf})^2 (v^2\{\hat{A}_{avg}\} + v^2\{\hat{B}_{avg}\}) \tag{14}$$

$$\hat{VAR}\{\hat{\pi}\} = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 \hat{VAR}\{\hat{r}_{tf}\}] \tag{15}$$

where*:*

$\hat{VAR}\{\hat{\lambda}\}$ *: estimated variance* $\hat{\lambda}$ *of*

v: the percent coefficient of variance for AADT estimates from Hauer [9],

$$\mathrm{v} = 1 + 7.7/\,(\text{number of count-days}) + 1650/\mathrm{AADT}^{0.82} \tag{16}$$

$\hat{VAR}\{\hat{\pi}\}$ *: estimated variance of* $\hat{\pi}$

r_d *: duration of after period/duration of before period*

Step Three: Estimating the difference $\hat{\delta}$ and the ratio $\hat{\theta}$.

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} \tag{17}$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + \hat{VAR}\{\hat{\pi}\}/\hat{\pi}^2] \tag{18}$$

where,

$\hat{\delta}$ *: estimated safety impact of edge line*

$\hat{\theta}$ *: estimated unbiased expected crash modification factor*

Step Four: Estimating the variance of $\hat{\delta}$ and $\hat{\theta}$

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{\hat{VAR}\{\hat{\pi}\} + \hat{VAR}\{\hat{\lambda}\}} \tag{19}$$

$$\hat{\sigma}\{\hat{\theta}\} = \hat{\theta}\sqrt{\hat{VAR}\{\hat{\lambda}\}/\hat{\lambda}^2) + (\hat{VAR}\{\hat{\pi}\}/\hat{\pi}^2)}\,/(1 + \hat{VAR}\{\hat{\pi}\}/\hat{\pi}^2) \tag{20}$$

Table 6
Summary table for method three (Improved Predictive Method)

(a)

Dist.	2005		2006		2007		Before (2005-07)		2009	
	Total Crash	AADT	Total Crash	AADT	Total Crash	AADT	Total Crash K(j)	AADT	Total L(j)	AADT
2	23	2260	34	2100	24	2220	81	2193	19	3220
3	86	30260	68	31460	67	28660	221	30127	81	31810
4	12	2620	16	2760	8	2880	36	2753	21	3060
5	84	15600	74	15900	84	15900	242	15800	90	20200
7	21	4160	30	4180	14	4140	65	4160	10	4080
8	16	7300	13	7920	15	7950	44	7723	10	8460
58	5	3200	3	5900	4	6200	12	5100	2	3900
61	32	7520	36	7170	17	7180	85	7290	15	7970
62	85	26770	103	28070	83	28850	271	27895	70	30300
	364		377		316		1057		318	

(b)

Dist.									Before	After	Before	After
	Years before	Years After	$r_d(j)$	$r_{tf}(j)$	$r_{tf}(j)*r_d(j)*K(j)$	$r_d(j)^2*K(j)$	$r_d(j)^2*K(j)^2$	$r_{tf}(j)^2*r_d(j)^2*K(j)$	v^2	v^2	$r_{tf}(j)^2*v^2$	$r_{tf}(j)^2*v^2$
2	3	1	0.33	1.47	40	9	729	19	0.004	0.003	0.009	0.007
3	3	1	0.33	1.06	78	25	5427	27	0.002	0.002	0.002	0.002
4	3	1	0.33	1.11	13	4	144	5	0.004	0.003	0.005	0.004
5	3	1	0.33	1.28	103	27	6507	44	0.002	0.002	0.003	0.003
7	3	1	0.33	0.98	21	7	469	7	0.003	0.003	0.003	0.003
8	3	1	0.33	1.10	16	5	215	6	0.002	0.002	0.003	0.002
58	3	1	0.33	0.76	3	1	16	1	0.003	0.003	0.002	0.002
61	3	1	0.33	1.09	31	9	803	11	0.002	0.002	0.003	0.003
62	3	1	0.33	1.09	98	30	8160	36	0.002	0.002	0.002	0.002
					403	117	22470	156	0.034	0.033	0.042	0.039

Calculation details:

$$\hat{\lambda} = L = 318$$

$$V\hat{A}R(\hat{\lambda}) = L = 318$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 403$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 1973$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 85$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0809$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 2291, \hat{\sigma}(\hat{\delta}) = 47.87$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.78$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0206, \hat{\sigma}(\hat{\theta}) = 0.1435$$

The application of the unbiased Method Three shows a crash reduction of 85 with estimated unbiased crash modification factor 0.78 with a standard deviation of 0.144.

The results from all three methods are summarized in Table 7 and Table 8 (district wise detailed calculations are stated in the Appendix).

Table 7
Results by districts

	Changes in observed crashes	Naïve B-A Method 1	Naïve B-A Method 2		Improved Prediction Method	
District	The 3 year average vs. 2009	Somewhat detectible	Change in Crashes	Index of Effectiveness $\hat{\theta}$	Change in Crashes	Index of Effectiveness $\hat{\theta}$
2 (2)	-8	Yes	-8	0.70	-24	0.43
3(9)	8	No	8	1.10	12	1.16
4(2)	9	No	9	1.7	8	1.52
5(4)	9	No	9	1.11	3	1.02
7(2)	-12	Yes	-12	0.45	-9	0.51
8(3)	-5	Yes	-5	0.68	-6	0.58
58(1)	-2	Yes	-2	0.46	-1	0.60
61(3)	-13	Yes	-13	0.52	-17	0.46
62(4)	-20	Yes	-20	0.77	-28	0.71

Table 8
Overall results

	Naïve B-A Method 1	Naïve B-A Method 2				Improved Prediction Method			
District	Somewhat Confidently Detectable	Estimated Expected Changes in Crashes	Standard. Deviation	CMF	Standard. Deviation	Estimated Expected Changes in Crashes	Standard. Deviation	CMF	Standard. Deviation
All	Yes	-34	20.12	0.9	0.056	-85	47.87	0.78	0.144

DISCUSSION OF RESULTS

CMF Results from Three Methods

The crash modification factor from the analysis method two and three were 0.90 and 0.78 simultaneously with a standard deviation of 0.056 and 0.144. The result from the method three is more reliable, which accounts for traffic volume (AADT). Since the analysis method three is the most scientific analysis method, the results from this method were used in the following discussion. The analysis method one does not calculate CMF.

Positive Safety Trend

Although the results show a definite reduction in crashes on the selected sections, we must also consider the overall trend in crash reduction. For the past several years, the state along with the whole country has been experiencing a steady decline in annual crash frequencies. The total traffic fatalities in the United States has reduced from 38,648 in 2006 to 37,435, 34,172, and 30,797 in 2007, 2008, and 2009, respectively *[10]*. As illustrated in Table 9, the number of crashes in Louisiana has also decreased since 2007. During the study period, the total crashes were reduced by 2.70 percent.

Table 9
Total crashes by year

Year	Total Crashes	Percentage Change (from previous years)
2005	158,474	
2006	162,190	2.34%
2007	159,800	-1.47%
2008	158,020	-1.11%
2009	155,829	-1.39%
2005-2007 (average)	160,155	
2009	155,829	-2.70%

Considering the difference in types of highways, researchers also investigated the crash trends in rural, two-lane highways shown in Table 10.

Table 10
Decreasing trend of crashes on rural, two-lane highways

Year	Pavement Width (rural, two-lane highways)				
	Less than 20'	Less than 22' and bigger than or equal to 20'	22'	More than 22"	Total
2005	183	2,747	2,847	6,794	12,571
2006	163	2,741	2,891	7,041	12,836
2007	222	2,993	3,070	7,480	13,765
Average	189	2,827	2,936	7,105	13,057
2009	260	2,686	2,965	6,816	12,727
Change	37.32%	-4.99%	0.99%	-4.07%	-2.53%

It is clear that the crash reduction is nearly 2.53 percent for rural, two-lane highways of all pavement width and is 5 percent for narrow highways (less than 22 ft. and bigger than or equal to 20 ft.) during the study period. Considering the crash reduction trend, the estimated crash modification factor would be 0.83 (0.78+0.05) with a standard deviation 0.144.

Highway Safety Manual

According to the definition of Crash Modification Factors Clearinghouse, CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site *[11]*. The newly published *Highway Safety Manual* (HSM) has a CMF for placing edge lines as shown in Tables 11 and 12, which can be a good reference for this study's results *[8]*.

Table 11
Potential crash effects of placing standard edge line markings (4 to 6 in. wide) from HSM

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Place Standard Edge Line Marking	Rural (Two-Lane)	Unspecified	All types (Injury)	0.97*	0.04
			All types (Non-Injury)	0.97*	0.10
Base Condition: Absence of standard edge line markings. The asterisk indicates that the CMF value itself is within the range 0.90 to 1.10, but that the confidence interval defined by the CMF ± two times the standard error may contain the value 1.0. This is important to note since a treatment with such a CMF could potentially result in (a) a reduction in crashes (safety benefit), (b) no change, or (c) an increase in crashes (safety disbenefit). These CMFs should be used with caution.					

Table 12
Potential crash effects of placing wide (8 in.) edge line from HSM

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Place Wide (8 inches) Edge line Marking	Rural (Two-Lane)	Unspecified	All types (Injury)	1.05*	0.08
			All types (Non-Injury)	0.99*	0.20
Base Condition: Standard edge line markings (4 to 6 in. wide). The asterisk indicates that the CMF value itself is within the range 0.90 to 1.10, but that the confidence interval defined by the CMF ± two times the standard error may contain the value 1.0. This is important to note since a treatment with such a CMF could potentially result in (a) a reduction in crashes (safety benefit), (b) no change, or (c) an increase in crashes (safety disbenefit). These CMFs should be used with caution.					

CONCLUSIONS

Based on the analysis results and discussion, the following conclusions can be drawn:

1. Placing pavement edge lines on rural, two-lane highways in Louisiana can not only change vehicle lateral positions but also reduce crashes.

2. The most reliable CMF for edge lines on narrow, rural two-lane highways is 0.78 (based on Method Three).

3. Considering the safety trend in Louisiana, the final estimated CMF is 0.83, which means there is a 17 percent expected crash reduction in edge line implementation on narrow, rural two-lane highways.

4. The statistically estimated standard deviation for the CMF is 0.144.

RECOMMENDATIONS

This project recommends the use of edge lines on narrow, rural two-lane highways whenever it is financially feasible and operationally feasible. Since each LADOTD district shoulders the responsibility of implementing pavement markings, LADOTD may want to establish a policy asking each district to implement edge lines if sufficient resources are available. Under financial or operational constraints, roadways with higher traffic volumes should have priority to have edge lines implemented.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
CMF	Crash Modification Factor
FHWA	Federal Highway Administration
HSM	Highway Safety Manual
ROR	Run-off Road
VMT	Vehicle Mile Traveled
ft.	foot (feet)
in.	inch(es)
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center

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APPENDIX

This appendix gives the detailed calculations with all three methods and by each district.

Calculation Details for Method One (Tables 13-30)

Table 13
Crashes at before and after periods at District 2

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005	2006	2007	2005-07	2009
					Total Crash	Total Crash	Total Crash	Total Crash K(j)	Total L(j)
412-02	5.21	0.80	2	4.41	19	30	21	70	19
845-02	0.00	1.38	2	1.38	4	4	3	11	0
					23	34	24	81	19

Table 14
Method one calculation District 2

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	20	14	9

Table 15
Crashes at before and after periods at District 3

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)
823-27	0.00	1.89	3	1.89	12	8	2	22	7
392-01	0.54	1.45	3	0.91	5	6	3	14	2
820-29	0.00	5.85	3	5.85	11	12	8	31	10
	5.85	7.10		1.25					7
857-25	0.00	0.60	3	0.60	11	11	16	38	2
	0.60	9.04		8.44					9
389-01	2.59	7.15	3	4.56	13	11	9	33	8
204-03	1.97	5.12	3	3.15	7	5	7	19	3
056-05	0.00	0.24	3	0.24	4	3	6	13	3
801-09	0.61	4.00	3	3.39	11	10	11	32	25
210-04	3.67	5.35	3	1.68	12	2	5	19	5
					86	68	67	221	81

Table 16
Method one calculation District 3

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	62	51	41

Table 17
Crashes at before and after periods at District 4

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)
048-02	4.72	8.29	4	3.57	9	10	6	25	18
079-01	2.95	5.44	4	2.49	3	6	2	11	3
					12	16	8	36	21

Table 18
Method one calculation District 4

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	8	4	1

Table 19
Crashes at before and after periods at District 5

<table>
<tr><th rowspan="2">Control Section</th><th rowspan="2">Logmile From</th><th rowspan="2">Logmile To</th><th rowspan="2">Dist.</th><th rowspan="2">Sec. Length</th><th>2005</th><th>2006</th><th>2007</th><th>2005-07</th><th>2009</th></tr>
<tr><th>Total Crash</th><th>Total Crash</th><th>Total Crash</th><th>Total Crash K(j)</th><th>Total L(j)</th></tr>
<tr><td>158-01</td><td>3.10</td><td>5.41</td><td>5</td><td>2.31</td><td>9</td><td>4</td><td>2</td><td>15</td><td>4</td></tr>
<tr><td>158-01</td><td>5.45</td><td>10.19</td><td>5</td><td>4.74</td><td>20</td><td>23</td><td>25</td><td>68</td><td>37</td></tr>
<tr><td rowspan="2">837-08</td><td>0.00</td><td>7.19</td><td rowspan="2">5</td><td>7.19</td><td rowspan="2">14</td><td rowspan="2">15</td><td rowspan="2">21</td><td rowspan="2">50</td><td>8</td></tr>
<tr><td>7.19</td><td>9.46</td><td>2.27</td><td>4</td></tr>
<tr><td>156-02</td><td>0.30</td><td>6.58</td><td>5</td><td>6.28</td><td>19</td><td>13</td><td>14</td><td>46</td><td>20</td></tr>
<tr><td>156-01</td><td>0.00</td><td>1.96</td><td>5</td><td>1.96</td><td>22</td><td>19</td><td>22</td><td>63</td><td>17</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>84</td><td>74</td><td>84</td><td>242</td><td>90</td></tr>
</table>

Table 20
Method one calculation District 5

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	68	57	47

Table 21
Crashes at before and after periods at District 7

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)
066-05	2.58	4.18	7	1.60	7	14	5	26	2
189-01	0.00	10.91	7	10.91	14	16	9	39	8
					21	30	14	65	10

Table 22
Method one calculation District 7

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	16	10	6

Table 23
Crashes at before and after periods at District 8

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)
835-09	0.00	0.04	8	0.04	0	1	0	1	0
805-32	1.51	1.58	8	0.07	0	1	1	2	1
147-04	0.63	5.43	8	4.80	16	11	14	41	9
					16	13	15	44	10

Table 24
Method one calculation District 8

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	10	6	2

Table 25
Crashes at before and after periods at District 58

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005	2006	2007	2005-07	2009
					Total Crash	Total Crash	Total Crash	Total Crash K(j)	Total L(j)
068-04	18.71	19.88	58	1.17	5	3	4	12	2
					5	3	4	12	2

Table 26
Method one calculation District 58

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	2	0	0

Table 27
Crashes at before and after periods at District 61

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005	2006	2007	2005-07	2009
					Total Crash	Total Crash	Total Crash	Total Crash K(j)	Total L(j)
219-05	0.39	4.51	61	4.12	11	11	8	30	8
847-04	0.00	1.51	61	1.51	12	15	6	33	5
227-03	0.00	2.22	61	2.22	9	10	3	22	2
					32	36	17	85	15

Table 28
Method one calculation District 61

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	21	15	10

Table 29

Crashes at before and after periods at District 62

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)
281-04	1.85	5.80	62	3.95	14	25	22	61	23
281-04	5.80	11.50	62	5.70	15	9	10	34	5
853-27	0.34	2.04	62	1.70	9	15	1	25	11
853-27	2.04	8.30	62	6.26	33	35	36	104	23
270-02	0.00	0.18	62	0.18	5	4	0	9	0
848-07	0.67	2.00	62	1.33	9	15	14	38	8
					85	103	83	271	70

Table 30

Method one calculation District 62

	Somewhat Confidently Detectable	Confidently Detectable	Virtually Confidently Detectable
k	1.00	2.00	3.00
Required After Number of Accidents	77	65	54

Calculation Details for Method Two (Tables 31-40)

Table 31
Crash data for before and after periods (Method Two)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	2005	2006	2007	2005-07	2009	Years before	Years After	$r_d(j)$	$r_d(j)*K(j)$	$r_d(j)^2*K(j)$
					Total Crash	Total Crash	Total Crash	Total Crash K(j)	Total L(j)					
412-02	5.21	0.80	2	4.41	19	30	21	70	19	3	1	0.33	23	8
845-02	0.00	1.38	2	1.38	4	4	3	11	0	3	1	0.33	4	1
823-27	0.00	1.89	3	1.89	12	8	2	22	7	3	1	0.33	7	2
392-01	0.54	1.45	3	0.91	5	6	3	14	2	3	1	0.33	5	2
820-29	0.00	5.85	3	5.85	11	12	8	31	10	3	1	0.33	10	3
	5.85	7.10		1.25					7					
857-25	0.00	0.60	3	0.60	11	11	16	38	2	3	1	0.33	13	4
	0.60	9.04		8.44					9					
389-01	2.59	7.15	3	4.56	13	11	9	33	8	3	1	0.33	11	4
204-03	1.97	5.12	3	3.15	7	5	7	19	3	3	1	0.33	6	2
056-05	0.00	0.24	3	0.24	4	3	6	13	3	3	1	0.33	4	1
801-09	0.61	4.00	3	3.39	11	10	11	32	25	3	1	0.33	11	4
210-04	3.67	5.35	3	1.68	12	2	5	19	5	3	1	0.33	6	2
048-02	4.72	8.29	4	3.57	9	10	6	25	18	3	1	0.33	8	3
079-01	2.95	5.44	4	2.49	3	6	2	11	3	3	1	0.33	4	1
158-01	3.10	5.41	5	2.31	9	4	2	15	4	3	1	0.33	5	2
158-01	5.45	10.19	5	4.74	20	23	25	68	37	3	1	0.33	23	8
837-08	0.00	7.19	5	7.19	14	15	21	50	8	3	1	0.33	17	5
	7.19	9.46		2.27					4					
156-02	0.30	6.58	5	6.28	19	13	14	46	20	3	1	0.33	15	5
156-01	0.00	1.96	5	1.96	22	19	22	63	17	3	1	0.33	21	7
066-05	2.58	4.18	7	1.60	7	14	5	26	2	3	1	0.33	9	3
189-01	0.00	10.91	7	10.91	14	16	9	39	8	3	1	0.33	13	4
835-09	0.00	0.04	8	0.04	0	1	0	1	0	3	1	0.33	0	0
805-32	1.51	1.58	8	0.07	0	1	1	2	1	3	1	0.33	1	0
147-04	0.63	5.43	8	4.80	16	11	14	41	9	3	1	0.33	14	5
068-04	18.71	19.88	58	1.17	5	3	4	12	2	3	1	0.33	4	1
219-05	0.39	4.51	61	4.12	11	11	8	30	8	3	1	0.33	10	3
847-04	0.00	1.51	61	1.51	12	15	6	33	5	3	1	0.33	11	4
227-03	0.00	2.22	61	2.22	9	10	3	22	2	3	1	0.33	7	2
281-04	1.85	5.80	62	3.95	14	25	22	61	23	3	1	0.33	20	7
281-04	5.80	11.50	62	5.70	15	9	10	34	5	3	1	0.33	11	4
853-27	0.34	2.04	62	1.70	9	15	1	25	11	3	1	0.33	8	3
853-27	2.04	8.30	62	6.26	33	35	36	104	23	3	1	0.33	35	12
270-02	0.00	0.18	62	0.18	5	4	0	9	0	3	1	0.33	3	1
848-07	0.67	2.00	62	1.33	9	15	14	38	8	3	1	0.33	13	4
					364	377	316	1057	318				352	117

Table 32
Crashes at before and after periods at District 2 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$* K(j)	$r_d(j)^2$*K (j)
412-02	5.21	0.80	2	19	30	21	70	19	0.33	23	8
845-02	0.00	1.38	2	4	4	3	11	0	0.33	4	1
				23	34	24	81	19		27	9

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 19$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 19$$

$$\hat{\pi} = \sum r_d(j)K(j) = 27$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 9$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 8$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 28, \hat{\sigma}(\hat{\delta}) = 5.29$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 0.70$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.0306, \hat{\sigma}(\hat{\theta}) = 0.1749$$

Table 33
Crashes at before and after periods at District 3 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
823-27	0.00	1.89	3	12	8	2	22	7	0.33	7	2
392-01	0.54	1.45	3	5	6	3	14	2	0.33	5	2
820-29	0.00	5.85	3	11	12	8	31	10	0.33	10	3
	5.85	7.10						7			
857-25	0.00	0.60	3	11	11	16	38	2	0.33	13	4
	0.60	9.04						9			
389-01	2.59	7.15	3	13	11	9	33	8	0.33	11	4
204-03	1.97	5.12	3	7	5	7	19	3	0.33	6	2
056-05	0.00	0.24	3	4	3	6	13	3	0.33	4	1
801-09	0.61	4.00	3	11	10	11	32	25	0.33	11	4
210-04	3.67	5.35	3	12	2	5	19	5	0.33	6	2
				86	68	67	221	81		73	24

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 81$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 81$$

$$\hat{\pi} = \sum r_d(j) K(j) = 73$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 24$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -8$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 105, \hat{\sigma}(\hat{\delta}) = 10.25$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 1.10$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.0202, \hat{\sigma}(\hat{\theta}) = 0.1421$$

Table 34
Crashes at before and after periods at District 4 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
048-02	4.72	8.29	4	9	10	6	25	18	0.33	8	3
079-01	2.95	5.44	4	3	6	2	11	3	0.33	4	1
				12	16	8	36	21		12	4

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 21$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 21$$

$$\hat{\pi} = \sum r_d(j)K(j) = 12$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 4$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -9$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 25, \hat{\sigma}(\hat{\delta}) = 5$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 1.70$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.2069, \hat{\sigma}(\hat{\theta}) = 0.4548$$

Table 35
Crashes at before and after periods at District 5 (Method Two)

<table>
<tr><th rowspan="2">Control Section</th><th rowspan="2">Logmile From</th><th rowspan="2">Logmile To</th><th rowspan="2">Dist.</th><th>2005</th><th>2006</th><th>2007</th><th>2005-07</th><th>2009</th><th rowspan="2">$r_d(j)$</th><th rowspan="2">$r_d(j)*K(j)$</th><th rowspan="2">$r_d(j)^2*K(j)$</th></tr>
<tr><th>Total Crash</th><th>Total Crash</th><th>Total Crash</th><th>Total Crash K(j)</th><th>Total L(j)</th></tr>
<tr><td>158-01</td><td>3.10</td><td>5.41</td><td>5</td><td>9</td><td>4</td><td>2</td><td>15</td><td>4</td><td>0.33</td><td>5</td><td>2</td></tr>
<tr><td>158-01</td><td>5.45</td><td>10.19</td><td>5</td><td>20</td><td>23</td><td>25</td><td>68</td><td>37</td><td>0.33</td><td>23</td><td>8</td></tr>
<tr><td rowspan="2">837-08</td><td>0.00</td><td>7.19</td><td rowspan="2">5</td><td rowspan="2">14</td><td rowspan="2">15</td><td rowspan="2">21</td><td rowspan="2">50</td><td>8</td><td rowspan="2">0.33</td><td rowspan="2">17</td><td rowspan="2">5</td></tr>
<tr><td>7.19</td><td>9.46</td><td>4</td></tr>
<tr><td>156-02</td><td>0.30</td><td>6.58</td><td>5</td><td>19</td><td>13</td><td>14</td><td>46</td><td>20</td><td>0.33</td><td>15</td><td>5</td></tr>
<tr><td>156-01</td><td>0.00</td><td>1.96</td><td>5</td><td>22</td><td>19</td><td>22</td><td>63</td><td>17</td><td>0.33</td><td>21</td><td>7</td></tr>
<tr><td></td><td></td><td></td><td></td><td>84</td><td>74</td><td>84</td><td>242</td><td>90</td><td></td><td>81</td><td>27</td></tr>
</table>

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 90$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 90$$

$$\hat{\pi} = \sum r_d(j)K(j) = 81$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 27$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -9$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 117, \hat{\sigma}(\hat{\delta}) = 10.81$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 1.11$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.0187, \hat{\sigma}(\hat{\theta}) = 0.1367$$

Table 36

Crashes at before and after periods at District 7 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
066-05	2.58	4.18	7	7	14	5	26	2	0.33	9	3
189-01	0.00	10.91	7	14	16	9	39	8	0.33	13	4
				21	30	14	65	10		22	7

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 10$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 10$$

$$\hat{\pi} = \sum r_d(j)K(j) = 22$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 7$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 12$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 17, \hat{\sigma}(\hat{\delta}) = 4.12$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.45$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0231, \hat{\sigma}(\hat{\theta}) = 0.1520$$

Table 37
Crashes at before and after periods at District 8 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
835-09	0.00	0.04	8	0	1	0	1	0	0.33	0	0
805-32	1.51	1.58	8	0	1	1	2	1	0.33	1	0
147-04	0.63	5.43	8	16	11	14	41	9	0.33	14	5
				16	13	15	44	10		15	5

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 10$$

$$\hat{VAR}(\hat{\lambda}) = \sum L(j) = 10$$

$$\hat{\pi} = \sum r_d(j)K(j) = 15$$

$$\hat{VAR}(\hat{\pi}) = \sum r_d(j)^2 K(j) = 5$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 5$$

$$\hat{VAR}(\hat{\delta}) = \hat{VAR}(\hat{\pi}) + \hat{VAR}(\hat{\lambda}) = 15, \hat{\sigma}(\hat{\delta}) = 3.87$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + \hat{VAR}\{\hat{\pi}\} / \hat{\pi}^2] = 0.68$$

$$\hat{VAR}(\hat{\theta}) = \frac{\theta^2[(\hat{VAR}(\hat{\lambda}) / \lambda^2) + (\hat{VAR}(\hat{\pi}) / \pi^2)]}{[1 + (\hat{VAR}(\hat{\pi}) / \pi^2)]^2}] = 0.0521, \hat{\sigma}(\hat{\theta}) = 0.2282$$

Table 38

Crashes at before and after periods at District 58 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005	2006	2007	2005-07	2009	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
				Total Crash	Total Crash	Total Crash	Total Crash K(j)	Total L(j)			
068-04	18.71	19.88	58	5	3	4	12	2	0.33	4	1
				5	3	4	12	2		4	1

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 2$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 2$$

$$\hat{\pi} = \sum r_d(j)K(j) = 4$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 1$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 2$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 3, \hat{\sigma}(\hat{\delta}) = 1.73$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.46$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.1059, \hat{\sigma}(\hat{\theta}) = 0.3207$$

Table 39
Crashes at before and after periods at District 61 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)*K(j)$	$r_d(j)^2*K(j)$
219-05	0.39	4.51	61	11	11	8	30	8	0.33	10	3
847-04	0.00	1.51	61	12	15	6	33	5	0.33	11	4
227-03	0.00	2.22	61	9	10	3	22	2	0.33	7	2
				32	36	17	85	15		28	9

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 15$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 15$$

$$\hat{\pi} = \sum r_d(j)K(j) = 28$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 9$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 13$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 24, \hat{\sigma}(\hat{\delta}) = 4.90$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.52$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0210, \hat{\sigma}(\hat{\theta}) = 0.1449$$

Table 40
Crashes at before and after periods at District 62 (Method Two)

Control Section	Logmile From	Logmile To	Dist.	2005 Total Crash	2006 Total Crash	2007 Total Crash	2005-07 Total Crash K(j)	2009 Total L(j)	$r_d(j)$	$r_d(j)$*K(j)	$r_d(j)^2$*K(j)
281-04	1.85	5.80	62	14	25	22	61	23	0.33	20	7
281-04	5.80	11.50	62	15	9	10	34	5	0.33	11	4
853-27	0.34	2.04	62	9	15	1	25	11	0.33	8	3
853-27	2.04	8.30	62	33	35	36	104	23	0.33	35	12
270-02	0.00	0.18	62	5	4	0	9	0	0.33	3	1
848-07	0.67	2.00	62	9	15	14	38	8	0.33	13	4
				85	103	83	271	70		90	30

Calculation Details:

$$\hat{\lambda} = \sum L(j) = 70$$

$$V\hat{A}R(\hat{\lambda}) = \sum L(j) = 70$$

$$\hat{\pi} = \sum r_d(j)K(j) = 90$$

$$V\hat{A}R(\hat{\pi}) = \sum r_d(j)^2 K(j) = 30$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 20$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 100, \hat{\sigma}(\hat{\delta}) = 10$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.77$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0106, \hat{\sigma}(\hat{\theta}) = 0.1030$$

Calculation Details for Method Two (Tables 31-40)

Table 41a
Crash data for before and after periods (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$* K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
412-02	5.21	0.80	2	4.41	70	1313	19	2200	1.68	39	8	544	22	0.007	0.004	0.019	0.012
845-02	0.00	1.38	2	1.38	11	880	0	1020	1.16	4	1	13	2	0.010	0.008	0.013	0.011
823-27	0.00	1.89	3	1.89	22	2300	7	1380	0.60	4	2	54	1	0.004	0.006	0.002	0.002
392-01	0.54	1.45	3	0.91	14	1313	2	1300	0.99	5	2	22	2	0.007	0.007	0.006	0.007
820-29	0.00	5.85	3	5.85	31	1960	10	2100	1.07	11	3	105	4	0.005	0.004	0.005	0.005
	5.85	7.10		1.25			7										
857-25	0.00	0.60	3	0.60	38	1937	2	1930	1.00	12	4	157	4	0.005	0.005	0.005	0.005
	0.60	9.04		8.44			9										
389-01	2.59	7.15	3	4.56	33	8567	8	7300	0.85	9	4	121	3	0.002	0.002	0.002	0.002
204-03	1.97	5.12	3	3.15	19	1750	3	1670	0.95	6	2	40	2	0.005	0.005	0.005	0.005
056-05	0.00	0.24	3	0.24	13	4600	3	4400	0.96	4	1	19	1	0.003	0.003	0.002	0.003
801-09	0.61	4.00	3	3.39	32	3867	25	3700	0.96	10	4	114	3	0.003	0.003	0.003	0.003
210-04	3.67	5.35	3	1.68	19	3833	5	4000	1.04	7	2	40	2	0.003	0.003	0.003	0.003
048-02	4.72	8.29	4	3.57	25	2300	18	2600	1.13	9	3	69	4	0.004	0.004	0.005	0.005
079-01	2.95	5.44	4	2.49	11	453	3	460	1.01	4	1	13	1	0.021	0.021	0.022	0.021
158-01	3.10	5.41	5	2.31	15	2167	4	2300	1.06	5	2	25	2	0.004	0.004	0.005	0.005
158-01	5.45	10.19	5	4.74	68	2733	37	2800	1.02	23	8	514	8	0.004	0.004	0.004	0.004

Table 41
Crash data for before and after periods (Method Three) (continued)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *K(j)^2	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
837-08	0.00	7.19	5	7.19	50	3000	8	3200	1.07	18	5	272	6	0.003	0.003	0.004	0.004
	7.19	9.46		2.27			4										
156-02	0.30	6.58	5	6.28	46	2900	20	3600	1.24	19	5	235	8	0.004	0.003	0.005	0.005
156-01	0.00	1.96	5	1.96	63	5000	17	5100	1.02	21	7	441	7	0.003	0.003	0.003	0.003
066-05	2.58	4.18	7	1.60	26	3300	2	3400	1.03	9	3	75	3	0.003	0.003	0.003	0.003
189-01	0.00	10.91	7	10.91	39	860	8	680	0.79	10	4	169	3	0.010	0.013	0.006	0.008
835-09	0.00	0.04	8	0.04	1	523	0	560	1.07	0	0	0	0	0.005	0.016	0.000	0.001
805-32	1.51	1.58	8	0.07	2	4033	1	4400	1.09	1	0	0	0	0.003	0.003	0.003	0.003
147-04	0.63	5.43	8	4.80	41	3167	9	3500	1.11	15	5	187	6	0.003	0.003	0.004	0.004
068-04	18.71	19.88	58	1.17	12	5100	2	3900	0.76	3	1	16	1	0.003	0.003	0.002	0.002
219-05	0.39	4.51	61	4.12	30	2067	8	2900	1.40	14	3	100	7	0.005	0.004	0.009	0.007
847-04	0.00	1.51	61	1.51	33	3533	5	3500	0.99	11	4	121	4	0.003	0.003	0.003	0.003
227-03	0.00	2.22	61	2.22	22	1690	2	1570	0.93	7	2	54	2	0.005	0.006	0.005	0.005
281-04	1.85	5.80	62	3.95	61	4433	23	5100	1.15	23	7	413	9	0.003	0.003	0.004	0.003
281-04	5.80	11.50	62	5.70	34	1063	5	1100	1.03	12	4	128	4	0.008	0.008	0.009	0.008
853-27	0.34	2.04	62	1.70	25	7333	11	7900	1.08	9	3	69	3	0.002	0.002	0.003	0.002
853-27	2.04	8.30	62	6.26	104	7333	23	7900	1.08	37	12	1202	13	0.002	0.002	0.003	0.002
270-02	0.00	0.18	62	0.18	9	2500	0	3000	1.20	4	1	9	1	0.004	0.003	0.006	0.005
848-07	0.67	2.00	62	1.33	38	5233	8	5300	1.01	13	4	160	4	0.003	0.003	0.003	0.003
					1057		318			380	117	5504	141	0.170	0.167	0.194	0.181

Table 42
Crashes at before and after periods at District 2 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)								Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
412-02	5.21	0.80	2	4.41	70	1313	19	2200	1.68	39	8	544	22	0.007	0.004	0.019	0.012
845-02	0.00	1.38	2	1.38	11	880	0	1020	1.16	4	1	13	2	0.010	0.008	0.013	0.011
					81		19			43	9	558	23	0.016	0.013	0.032	0.023

Calculation Details:

$$\hat{\lambda} = L = 19$$

$$V\hat{A}R(\hat{\lambda}) = L = 19$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 43$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 54$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 24$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0553$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 73, \hat{\sigma}(\hat{\delta}) = 8.544$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.4293$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0397, \hat{\sigma}(\hat{\theta}) = 0.1992$$

Table 43
Crashes at before and after periods at District 3 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07) Total Crash K(j)	Before (2005-07) AADT	After (2009) Total L(j)	After (2009) AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	Before v^2	After v^2	Before $r_{tf}(j)^2$ *v^2	After $r_{tf}(j)^2$ *v^2
823-27	0.00	1.89	3	1.89	22	2300	7	1380	0.60	4	2	54	1	0.004	0.006	0.002	0.002
392-01	0.54	1.45	3	0.91	14	1313	2	1300	0.99	5	2	22	2	0.007	0.007	0.006	0.007
820-29	0.00	5.85	3	5.85	31	1960	10	2100	1.07	11	3	105	4	0.005	0.004	0.005	0.005
	5.85	7.10		1.25			7										
857-25	0.00	0.60	3	0.60	38	1937	2	1930	1.00	12	4	157	4	0.005	0.005	0.005	0.005
	0.60	9.04		8.44			9										
389-01	2.59	7.15	3	4.56	33	8567	8	7300	0.85	9	4	121	3	0.002	0.002	0.002	0.002
204-03	1.97	5.12	3	3.15	19	1750	3	1670	0.95	6	2	40	2	0.005	0.005	0.005	0.005
056-05	0.00	0.24	3	0.24	13	4600	3	4400	0.96	4	1	19	1	0.003	0.003	0.002	0.003
801-09	0.61	4.00	3	3.39	32	3867	25	3700	0.96	10	4	114	3	0.003	0.003	0.003	0.003
210-04	3.67	5.35	3	1.68	19	3833	5	4000	1.04	7	2	40	2	0.003	0.003	0.003	0.003
					221		81			69	24	671	22	0.036	0.039	0.033	0.034

Calculation Details:

$$\hat{\lambda} = L = 81$$

$$V\hat{A}R(\hat{\lambda}) = L = 81$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 69$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 66$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -12$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0665$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 147, \hat{\sigma}(\hat{\delta}) = 12.12$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 1.160$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.0477, \hat{\sigma}(\hat{\theta}) = 0.2184$$

Table 44
Crashes at before and after periods at District 4 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07) Total Crash K(j)	Before (2005-07) AADT	After (2009) Total L(j)	After (2009) AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	Before v^2	After v^2	Before $r_{tf}(j)^2$ *v^2	After $r_{tf}(j)^2$ *v^2
048-02	4.72	8.29	4	3.57	25	2300	18	2600	1.13	9	3	69	4	0.004	0.004	0.005	0.005
079-01	2.95	5.44	4	2.49	11	453	3	460	1.01	4	1	13	1	0.021	0.021	0.022	0.021
					36		21			13	4	83	5	0.025	0.025	0.027	0.026

Calculation Details:

$$\hat{\lambda} = L = 21$$

$$V\hat{A}R(\hat{\lambda}) = L = 21$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 13$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 9$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -8$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0532$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 30, \hat{\sigma}(\hat{\delta}) = 5.48$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 1.52$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.2528, \hat{\sigma}(\hat{\theta}) = 0.5028$$

Table 45
Crashes at before and after periods at District 5 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07) Total Crash K(j)	Before (2005-07) AADT	After (2009) Total L(j)	After (2009) AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	Before v^2	After v^2	Before $r_{tf}(j)^2$ *v^2	After $r_{tf}(j)^2$ *v^2
158-01	3.10	5.41	5	2.31	15	2167	4	2300	1.06	5	2	25	2	0.004	0.004	0.005	0.005
158-01	5.45	10.19	5	4.74	68	2733	37	2800	1.02	23	8	514	8	0.004	0.004	0.004	0.004
837-08	0.00	7.19	5	7.19	50	3000	8	3200	1.07	18	5	272	6	0.003	0.003	0.004	0.004
	7.19	9.46		2.27			4										
156-02	0.30	6.58	5	6.28	46	2900	20	3600	1.24	19	5	235	8	0.004	0.003	0.005	0.005
156-01	0.00	1.96	5	1.96	63	5000	17	5100	1.02	21	7	441	7	0.003	0.003	0.003	0.003
					242		90			87	27	1487	31	0.018	0.017	0.021	0.020

Calculation Details:

$$\hat{\lambda} = L = 90$$

$$V\hat{A}R(\hat{\lambda}) = L = 90$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 87$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 92$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = -3$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0406$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 182, \hat{\sigma}(\hat{\delta}) = 13.49$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 1.02$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.036, \hat{\sigma}(\hat{\theta}) = 0.1897$$

Table 46
Crashes at before and after periods at District 7 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K (j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
066-05	2.58	4.18	7	1.60	26	3300	2	3400	1.03	9	3	75	3	0.003	0.003	0.003	0.003
189-01	0.00	10.91	7	10.91	39	860	8	680	0.79	10	4	169	3	0.010	0.013	0.006	0.008
					65		10			19	7	244	6	0.013	0.016	0.010	0.012

Calculation Details:

$$\hat{\lambda} = L = 10$$

$$V\hat{A}R(\hat{\lambda}) = L = 10$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 19$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 11$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 9$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0213$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 21, \hat{\sigma}(\hat{\delta}) = 4.58$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.5055$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0577, \hat{\sigma}(\hat{\theta}) = 0.2402$$

Table 47
Crashes at before and after periods at District 8 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
835-09	0.00	0.04	8	0.04	1	523	0	560	1.07	0	0	0	0	0.005	0.016	0.000	0.001
805-32	1.51	1.58	8	0.07	2	4033	1	4400	1.09	1	0	0	0	0.003	0.003	0.003	0.003
147-04	0.63	5.43	8	4.80	41	3167	9	3500	1.11	15	5	187	6	0.003	0.003	0.004	0.004
					44		10			16	5	187	6	0.011	0.022	0.008	0.008

Calculation Details:

$$\hat{\lambda} = L = 10$$

$$V\hat{A}R(\hat{\lambda}) = L = 10$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 16$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 16$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 6$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0536$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 26, \hat{\sigma}(\hat{\delta}) = 5.10$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.5821$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0966, \hat{\sigma}(\hat{\theta}) = 0.3108$$

Table 48
Crashes at before and after periods at District 58 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	v^2	v^2	$r_{tf}(j)^2$ *v^2	$r_{tf}(j)^2$ *v^2
068-04	18.71	19.88	58	1.17	12	5100	2	3900	0.76	3	1	16	1	0.003	0.003	0.002	0.002
					12		2			3	1	16	1	0.003	0.003	0.002	0.002

Calculation Details:

$$\hat{\lambda} = L = 2$$

$$V\hat{A}R(\hat{\lambda}) = L = 2$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 3$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 1$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 1$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0032$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 3, \hat{\sigma}(\hat{\delta}) = 1.73$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2] = 0.6004$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda})/\lambda^2) + (V\hat{A}R(\hat{\pi})/\pi^2)]}{[1 + (V\hat{A}R(\hat{\pi})/\pi^2)]^2}] = 0.2432, \hat{\sigma}(\hat{\theta}) = 0.4931$$

Table 49
Crashes at before and after periods at District 61 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07) Total Crash K(j)	Before (2005-07) AADT	After (2009) Total L(j)	After (2009) AADT	$r_{tf}(j)$	$r_{tf}(j)$* $r_d(j)$*K(j)	$r_d(j)^2$ *K(j)	$r_d(j)^2$ *$K(j)^2$	$r_{tf}(j)^2$ *$r_d(j)^2$ *K(j)	Before v^2	After v^2	Before $r_{tf}(j)^2$ *v^2	After $r_{tf}(j)^2$ *v^2
219-05	0.39	4.51	61	4.12	30	2067	8	2900	1.40	14	3	100	7	0.005	0.004	0.009	0.007
847-04	0.00	1.51	61	1.51	33	3533	5	3500	0.99	11	4	121	4	0.003	0.003	0.003	0.003
227-03	0.00	2.22	61	2.22	22	1690	2	1570	0.93	7	2	54	2	0.005	0.006	0.005	0.005
					85		15			32	9	275	12	0.013	0.012	0.017	0.015

Calculation Details:

$$\hat{\lambda} = L = 15$$

$$V\hat{A}R(\hat{\lambda}) = L = 15$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 32$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 21$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 17$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.0315$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 36, \hat{\sigma}(\hat{\delta}) = 6$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.4629$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.03712, \hat{\sigma}(\hat{\theta}) = 0.1927$$

Table 50
Crashes at before and after periods at District 62 (Method Three)

Control Section	Logmile From	Logmile To	Dist.	Sec. Length	Before (2005-07)		After (2009)							Before	After	Before	After
					Total Crash K(j)	AADT	Total L(j)	AADT	$r_{tf}(j)$	$r_{tf}(j)*r_d(j)*K(j)$	$r_d(j)^2*K(j)$	$r_d(j)^2*K(j)^2$	$r_{tf}(j)^2*r_d(j)^2*K(j)$	v^2	v^2	$r_{tf}(j)^2*v^2$	$r_{tf}(j)^2*v^2$
281-04	1.85	5.80	62	3.95	61	4433	23	5100	1.15	23	7	413	9	0.003	0.003	0.004	0.003
281-04	5.80	11.50	62	5.70	34	1063	5	1100	1.03	12	4	128	4	0.008	0.008	0.009	0.008
853-27	0.34	2.04	62	1.70	25	7333	11	7900	1.08	9	3	69	3	0.002	0.002	0.003	0.002
853-27	2.04	8.30	62	6.26	104	7333	23	7900	1.08	37	12	1202	13	0.002	0.002	0.003	0.002
270-02	0.00	0.18	62	0.18	9	2500	0	3000	1.20	4	1	9	1	0.004	0.003	0.006	0.005
848-07	0.67	2.00	62	1.33	38	5233	8	5300	1.01	13	4	160	4	0.003	0.003	0.003	0.003
					271		70			98	30	1983	35	0.022	0.021	0.026	0.024

Calculation Details:

$$\hat{\lambda} = L = 70$$

$$V\hat{A}R(\hat{\lambda}) = L = 70$$

$$\hat{\pi} = r_d \hat{r}_{tf} K = 98$$

$$V\hat{A}R(\hat{\pi}) = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R(\hat{r}_{tf})] = 135$$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = 28$$

$$V\hat{A}R(\hat{r}_{tf}) = (\hat{r}_{tf})^2[v^2(\hat{A}_{avg}) + v^2(\hat{B}_{avg})] = 0.050$$

$$V\hat{A}R(\hat{\delta}) = V\hat{A}R(\hat{\pi}) + V\hat{A}R(\hat{\lambda}) = 205, \hat{\sigma}(\hat{\delta}) = 14.32$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2] = 0.7053$$

$$V\hat{A}R(\hat{\theta}) = \frac{\theta^2[(V\hat{A}R(\hat{\lambda}) / \lambda^2) + (V\hat{A}R(\hat{\pi}) / \pi^2)]}{[1 + (V\hat{A}R(\hat{\pi}) / \pi^2)]^2}] = 0.0270, \hat{\sigma}(\hat{\theta}) = 0.1643$$