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16. ABSTRACT

In 1973, the Organization of Petroleum Exporting Countries OPEC created a global energy crisis by reducing crude oil production. That event and others precipitated a fuel price increase of approximately 400%. This crisis triggered the establishment of the National Maximum Speed Limit (NMSL) of 55 mph by Congress on January 1, 1974. Consequently, to avoid losing federal highway funding, states were forced to reduce all higher speed limits to meet the NMSL. Subsequently, after the energy crisis subsided, the NMSL remained in effect for many years.

During the 1980s, the number of drivers who drove faster than 55 mph increased greatly. By 1987, nearly 85% of all drivers exceeded the 55 mph NMSL. Consequently, in 1987 the federal government allowed the states to increase speed limits on some rural interstate freeways from 55 mph to 65 mph. The state of California responded to this opportunity in May of 1987 by increasing the speed limit to 65 mph on 1155 miles of rural interstate freeways. Eighteen months later, the total reached 1307 miles. Finally, on November 28, 1995, the NMSL was repealed and the state of California increased the speed limit from 55 to 65 mph on December 19, 1995 on 2200 miles of freeway. Then, on January 8, 1996 the speed limits on the 1315 miles of rural interstate freeways were elevated to 70 mph.

The primary goal of this research effort is to determine if there is a statistically significant change in collision experience due to recent speed limit increases on California State highways.

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FINAL REPORT

COLLISION EXPERIENCE WITH SPEED LIMIT CHANGES ON SELECTED CALIFORNIA HIGHWAYS

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DISCLAIMER

The contents of this report reflect the views of the investigators and authors who are responsible for the facts and accuracy of the data presented. The contents of this report do not necessarily reflect the official views or policies of the state of California. This report does not constitute a standard specification, design standard, or regulation.

California Department of Transportation

Traffic Operation Program

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COLLISION EXPERIENCE WITH SPEED LIMIT CHANGES ON SELECTED CALIFORNIA HIGHWAYS

National Maximum Speed Limit

In 1973, the Organization of Petroleum Exporting Countries OPEC created a global energy crisis by reducing crude oil production. That event and others precipitated a fuel price increase of approximately 400 %. This crisis triggered the establishment of the National Maximum Speed Limit (NMSL) of 55 mph by Congress on January 1, 1974. Consequently, to avoid losing federal highway funding, states were forced to reduce all higher speed limits to meet the NMSL. With the reduction of highway speed limits, the fatal collision experience decreased as well. Subsequently, after the energy crisis subsided, the NMSL remained in effect for many years.

During the 1980s, the number of drivers who drove faster than 55 mph increased greatly. By 1987, nearly 85 % of all drivers exceeded the 55 mph NMSL. Consequently, in 1987 the federal government allowed the states to increase speed limits on some rural interstate freeways from 55 mph to 65 mph. The state of California responded to this opportunity in May of 1987 by increasing the speed limit to 65 mph on 1155 miles of rural interstate freeways. Eighteen months later, the total reached 1307 miles. Finally, on November 28, 1995, the NMSL was repealed and the state of California increased the speed limit from 55 to 65 mph on December 19, 1995, on 2200 miles of freeways. Then, on January 8, 1996 the speed limits on the 1315 miles of rural interstate freeways were elevated to 70 mph.

The primary goal of this research effort is to determine if there is a statistically significant change in collision experience due to recent speed limit increases on California State highways.

Previous Collision Studies

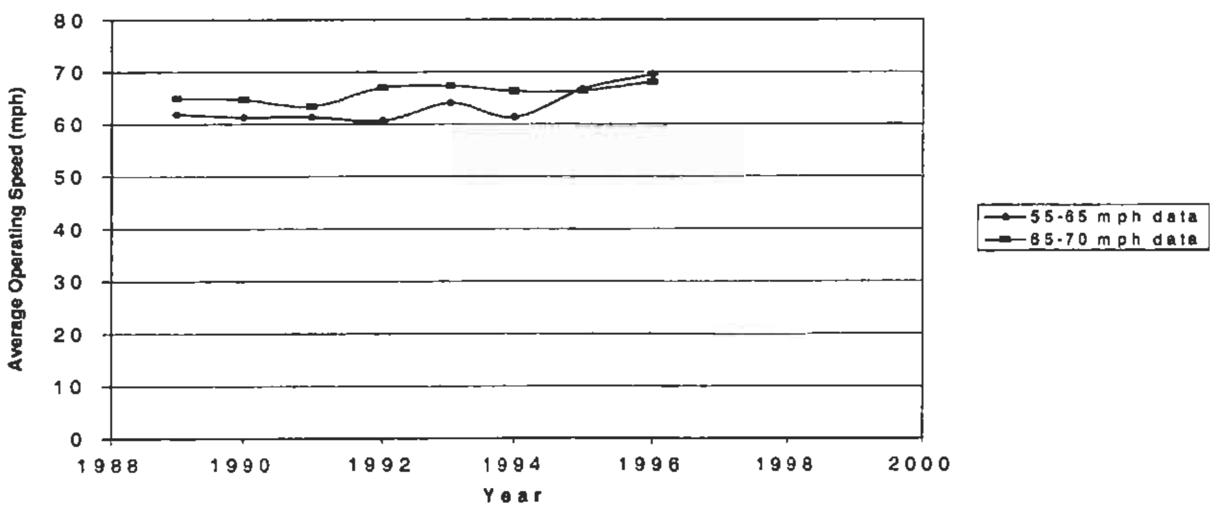
Several previous studies by Caltrans have been completed to investigate this matter. In September of 1989, J.D. Bamfield of Caltrans completed the first study while R.N. Smith, also of Caltrans, finished the next study in October of 1990. Ahmad Khorashadi, of Caltrans, completed two studies, in September of 1992 and a follow up study in June of 1994. The studies progressively included larger collision databases as the collision data after the speed limit

Research Approach

The collision data that was collected for each of three groups of highway segments included the number of total, fatal, wet (when pavement was wet), dark (nighttime), and fatal+injury collisions. Along with the total number of collisions, the other collision counts were included that would likely be affected by an increase in operating speed. This is the reason for including the fatal, fatal+injury, wet, and dark collisions. This data was provided each year for every segment of highway from 1989 through 1998. The groups include a 55-65 Group (segments upon which the speed limit increased from 55 to 65 mph), 65-70 Group (segments upon which the speed limit increased from 65 to 70 mph), and 55 Group (segments upon which the speed limit remained 55 mph). To evaluate traffic collision rates, traffic volume data was obtained for each segment from Caltrans annual volume reports.

In order to assess possible affects of traffic operating speeds, recorded speed data was obtained from the Caltrans weigh-in-motion sites and other permanent sites. Data was available from 1989 through 1996. Unfortunately, the number of observations was limited. There were 33 observations available in the 55-65 Group of which eight of the samples occurred after the speed limit was increased. For the 65-70 Group there were only 21 observations with three of them after the speed limit increase. Figure ES-1 illustrates the annual average of this speed data with the 1996 data showing the speed data after the speed limit increases.

Figure ES-1: Average Operating Speeds by Year (Weighted Average Used)



- For the 65-70 Group the number of fatal collisions increased approximately 34 percent higher than expected. This increase was found to be statistically significant using the Observational Before-After Comparison Study and marginally significant statistically from the ANOVA method.

Table ES-3: Comparison of the Collisions Counts in the Before Period vs After Period, and the Calculated Value for Expected Collisions vs Collision Counts in the After Period.

55-65 mph Speed Limit Increase

Collision Type	Before Collision Count	Actual After Collision Count	Percent Increase Between Before and After Periods	Expected* After Collision Count	Percent Actual is higher than Expected After Collision Counts
Total Col Cnt	130232	157482	20.9	133449	15.3
Fatal Col Cnt	940	972	3.4	624	35.8
Wet Col Cnt	19853	24679	24.3	22812	7.6
Dark Col Cnt	41241	47681	15.6	40804	14.4
Inj Col Cnt	46909	48850	4.1	46181	5.5
Fat+Inj Col Cnt	47849	49822	4.1	46805	6.1

65-70 mph Speed Limit Increase

Collision Type	Before Collision Count	Actual After Collision Count	Percent Increase Between Before and After Periods	Expected* After Collision Count	Percent Actual is higher than Expected After Collision Counts
Total Col Cnt	18266	20544	12.5	18717	8.9
Fatal Col Cnt	631	634	0.5	419	33.9
Wet Col Cnt	1666	2288	37.3	1914	16.3
Dark Col Cnt	7203	7719	7.2	7127	7.7
Inj Col Cnt	7363	7725	4.9	7401	4.2
Fat+Inj Col Cnt	7994	8359	4.6	7820	6.4

Notes: 1) The *before* period includes the number on collisions for the years of 1993-1995 and the *after* period includes the collisions for the years of 1996-1998.
2) The expected collision count for the after period was calculated from the Observational Before - After methodology.
3) Changes in collision counts do not consider increases in traffic volumes.

- The actual dark collisions in the *after* period for the 55-65 Group were approximately 15 percent higher than the expected number of collisions. This difference was statistically

1.0 INTRODUCTION

1.1 BACKGROUND

National Maximum Speed Limit.

In 1973, the Organization of Petroleum Exporting Countries (OPEC) created a global energy crisis by reducing crude oil production. That event and others precipitated fuel prices to increase approximately 400%. Additionally, gasoline stations in the western United States began rationing their fuel. This crisis triggered the establishment of the National Maximum Speed Limit (NMSL) of 55 mph. The NMSL was established by Congress and put into effect on January 1, 1974, to conserve energy. Consequently, to avoid losing federal highway funding, states were forced to reduce all higher speed limits to meet the NMSL. With the reduction of highway speed limits, the fatal collisions decreased as well (1). After the energy crisis subsided, the NMSL remained in effect for many years.

During the 1980s, the number of drivers exceeding the 55 mph speed limit increased significantly. By 1987, nearly 85% of all drivers exceeded the 55 mph NMSL.

In 1987, the federal government allowed the states to increase the speed limit from 55 mph to 65 mph on road segments that met criteria established by those states that elected to raise speed limits. The state of California responded to this opportunity in May of 1987 by increasing the speed limit to 65 mph on 1155 miles of rural interstate freeways. Within 18 months, California increased the speed limits on additional freeways, making a total of 1307 miles of freeway posted at 65 mph.

Prior collision studies. The California Department of Transportation (Caltrans) continually has been interested in how speed limit affects the collision experience on California freeways. Many studies have investigated this matter. Some of these studies are outlined in the following paragraphs to give some background on previous accomplishments.

The first study was done by JD Bamfield (2) of Caltrans that used Chi-Square methodology to compare two years of collision data prior to the speed limit increase to one year of *after* data. The major findings of the report are as follows:

- **Years of data used:**
  - *Before* time period: 6/82 – 5/87 (5 years)
  - *After* time period: 6/88 – 5/91 (3 years)
- **Results:**
  - There was a significant decrease in total, fatal, injury, and fatal+injury collision rates on rural interstates posted at 55 mph.
  - There was a significant increase in total, injury, and fatal+injury collision rates on rural interstates which experienced the speed limit increase from 55 to 65 mph.
  - There was a significant increase in total, injury, and fatal+injury collision rates on interstate freeway "look-alikes" (SR 99) which experienced the speed limit increase from 55 to 65 mph.

In a follow up study, completed in June 1994, by Khorashadi (5) 5 years of collision data *before* the speed limit increase in 1987 was compared with 5 years of *after* collision data. In this study, changes in various collision types including fatal, injury, wet, dark, rear end, hit object were investigated. Collisions with primary collision factors such as speeding, improper turn, etc. were also investigated. The study concluded that: both rural interstate freeways and the one "look-alike" freeway (SR 99) posted at 65 mph have experienced higher collision rates than rural interstate freeways retained at 55 mph. The increases in the *after* period were higher for SR 99, the look-alike, when compared to the interstate freeway segments posted at 65 mph.

On the surface, it would seem that as the studies progressively included a larger databases, the effect of the speed limit increase on collision rate became more evident. On the other hand, it may be that the application of more sophisticated methodologies made the effect of the speed limit increase more evident.

On November 28, 1995, the NMSL was repealed and the states were allowed to increase speed limits. On December 19, 1995, the state of California increased the speed limit from 55 to 65 mph on an additional 2200 miles of California freeway. The increases in speed limit were done based on work completed by Caltrans during the preceding year in anticipation of the NMSL repeal. The freeway segments, which were increased to 65 mph in May of 1987, were subsequently increased to 70 mph on January 8, 1996.

1.3 RESEARCH METHODOLOGY

Collecting data. Data was collected for 119 freeway and non-freeway segments, with a combined length of 1679 miles, which experienced a speed limit increased from 55 to 65 mph. Data was also collected for 27 freeway segments, with a combined length of 1305 miles, which experienced a speed limit increased from 65 to 70 mph. In addition, data was collected for a comparison group of 19 highway segments that were retained at 55 mph, which have a combined length of 100 miles.

The data that was collected included total, fatal, wet, dark, and fatal+injury collision counts. Traffic volume data was also collected for all highway segments. Collision rates were calculated using the collision counts and the traffic volume data. In addition, operating speed data was collected on some of the highway segments.

Conducting the Analyses. The analysis was conducted using four analysis methods so the results of each could be compared. The following methods were used:

- Frequentist Methodology (with and without comparison groups)
- Analysis of Variance Methodology
- Observational Before-After Comparison Group Methodology developed by Hauer
- Multivariate Regression Methodology

The results of each analysis method were compared and the reliability of each analysis method was investigated and is discussed in chapter three.

Developing Findings and Conclusions. From the previous section, conducting the analyses, appropriate findings and conclusions were made concerning possible changes in traffic collision experience after the speed limit increase occurred. Additional findings and conclusions were established about the methodologies.

1.4 CRITERIA FOR CHANGING SPEED LIMITS

With the elimination of the NMSL, it became necessary to provide a rational mechanism for determining whether current speed limits should be increased. Modifications to the California Vehicle Code provided for a basic speed limit of 65 mph and required an "engineering and traffic survey" before speed limits were increased to 70 mph. Additionally, to provide specific guidance changes were made to appropriate chapters of the Caltrans Traffic Manual (7), both for a speed limit increase from 55 to 65 mph as well as an increase from 65 to 70 mph. In

2.0 DATA COLLECTION

2.1 INTRODUCTION

This research project explains how speed limits affect collisions on California freeways. The item of first importance was to gather data, which would be the basis of this study. This chapter describes the data that was used in this study and how that data was obtained and used.

2.2 GROUPING AND TYPES OF DATA

This chapter describes the data that was used in analysis. Highways are typically posted with 55, 65, or 70 mph speed based on many factors including safety performance of the highway, operating speeds (e.g. 85^{th} percentile speed), highway geometry, traffic volumes, and environmental conditions. The three highway groups (55, 65, and 70 mph) considered in this study have different geometric standards, traffic volume, and operational characteristics when compared to each other. For example, the 70 mph group consists of rural freeways, where as the 65 mph group predominantly consists of both urban and rural freeways, and on rare occasions expressways. The 55 mph group in general does not have the safety performance of the 65 and 70 mph groups. This is possibly due to lower geometric standards, operational characteristics, etc. Thus, the following three site categories were developed for the analysis:

- Segments raised from 65 to 70 mph (65 – 70 mph group)
- Segments raised from 55 to 65 mph (55 – 65 mph group)
- Segments retained at 55 mph (55 mph group)

The data for the analysis were obtained from various Caltrans sources including: 1) Collision data from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS). 2) The average daily traffic and average daily truck traffic (i.e. total truck volume and truck volume by number of axles) for all highway segments used in this study (8, 9). 3) Speed data from active Weigh-In-Motion (WIM) sites. The speed data from the Caltrans WIM program was available for a limited number of sites.

55 mph data. The third set of collision data was for freeway segments that had no change in the 55 mph speed limit for more than a decade. This data set consisted of the collisions during the years of 1990 -1998, which is one less year than was available for the other two segment groups. This provided 171 observations. A sample of this data is in Table B-6 of Appendix B. Collision data from these groups are illustrated on graphs and discussed later in section 2.3.4.

Two types of collision data files. Caltrans sent two data files:

1. One file contains collision data for collisions that occur only on the freeway lanes.
2. The other file includes these and in addition, collisions within the first three of the four areas of ramps as specified in Figure 1.

The four ramp areas are:

1. Within the ramp gore area and 50 feet onto the ramp proper.
2. On the ramp proper.
3. On the ramp within 50 feet of its terminus.
4. On the cross road at the ramp terminus.

2.3.3 Average daily traffic (ADT)

In order to account for differences in the travel exposure levels among the various highway segments, it was necessary to retrieve traffic volumes in the form of average daily traffic and average daily truck traffic. The Caltrans annual traffic volume reports for the same years as the collision data were used. To calculate the traffic volumes, the following procedure was used:

1. Each segment was divided into sub-segments where on-ramps or interchanges were reported with changed traffic volumes.
2. The length of each highway sub-segment and traffic volume of each was determined using the mile post information published by Caltrans.
3. The length of each sub-segment was multiplied by the traffic volume of the same sub-segment to determine Million Vehicle Miles of travel (MVM) of that sub-segment (i.e. $MVM = ADT*365*Length/10^6$).
4. The results from step three were added together for all sub-segments within the segment to obtain the total MVM for the segment.

2.3.4 Calculation of collision rates.

The average daily traffic (ADT) data and the TASAS collision data were used to calculate collision rates, wet collision rates, dark collision rate, and fatal+injury collision rates which all have the units of collisions per MVM. Fatal collision rates (fatal collisions per 100 MVM) were also calculated in the same manner using the TASAS and ADT data. These data are illustrated by year in figures two through seven.

The following figures (Figures 2-7) illustrate the data sets as they display the annual collision rates and the number of collision (counts) for each of the three data sets, and total collision types. To assist the reader with a review of these figures a comparison of the averages for three years *before* the speed limit change and three years *after* is provided to reveal trends in all data sets, if any trend existed. Recall that the 65-70 mph and 55-65 mph groups have ten years of data while the 55 mph Group only has nine years.

The first two figures contain data for the 65-70 mph Group. The collision rate for total collisions on Figure 2 had a 5% increase after the speed limits have been increased; however, the fatal collision rate declined approximately 6% while the fatal+injury collision rate declined 2%. While the dark collision rate had no change, the wet collision rate increased about 2%. On

Figure 2 Collision Rates for Highway Segments Raised from 65-70 mph

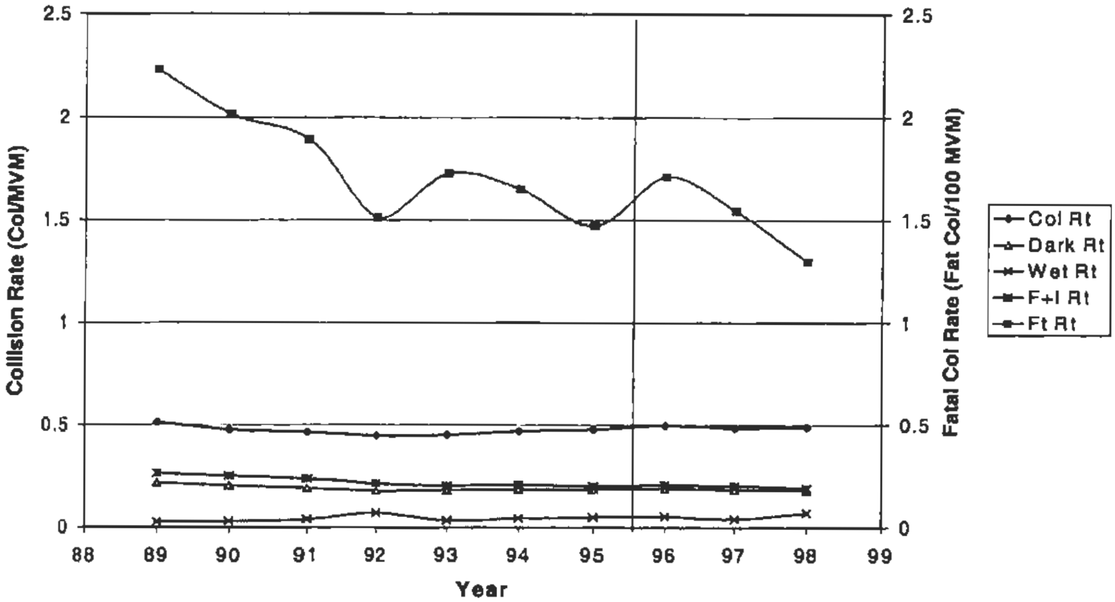


Figure 3 Collision Counts for Highway Segments Raised from 65-70 mph

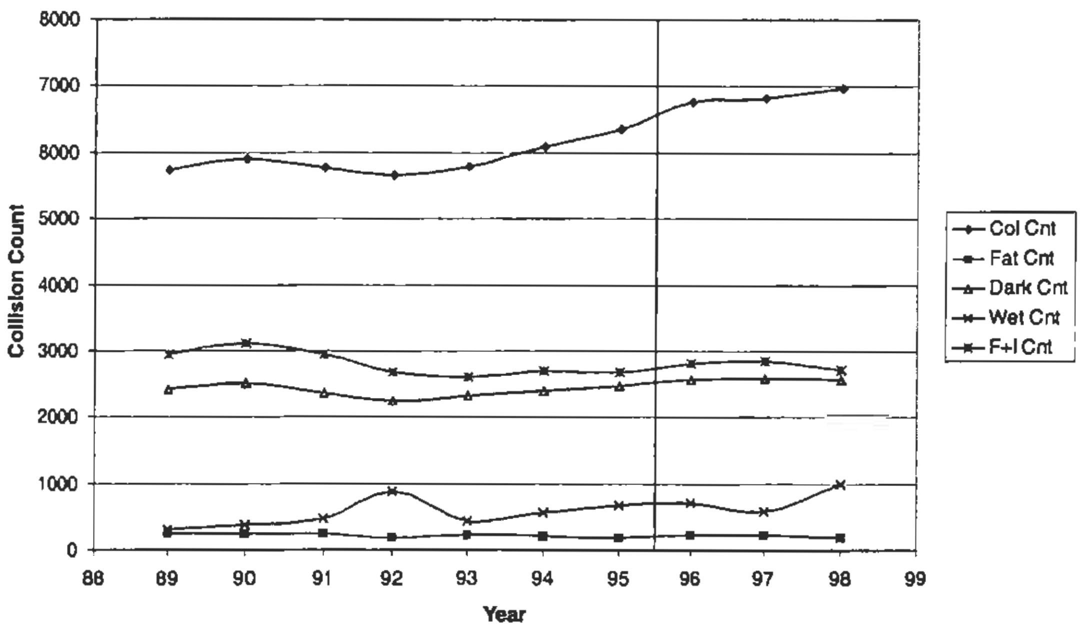


Figure 6 Collision Rates for Highway Segments Retained at 55 mph

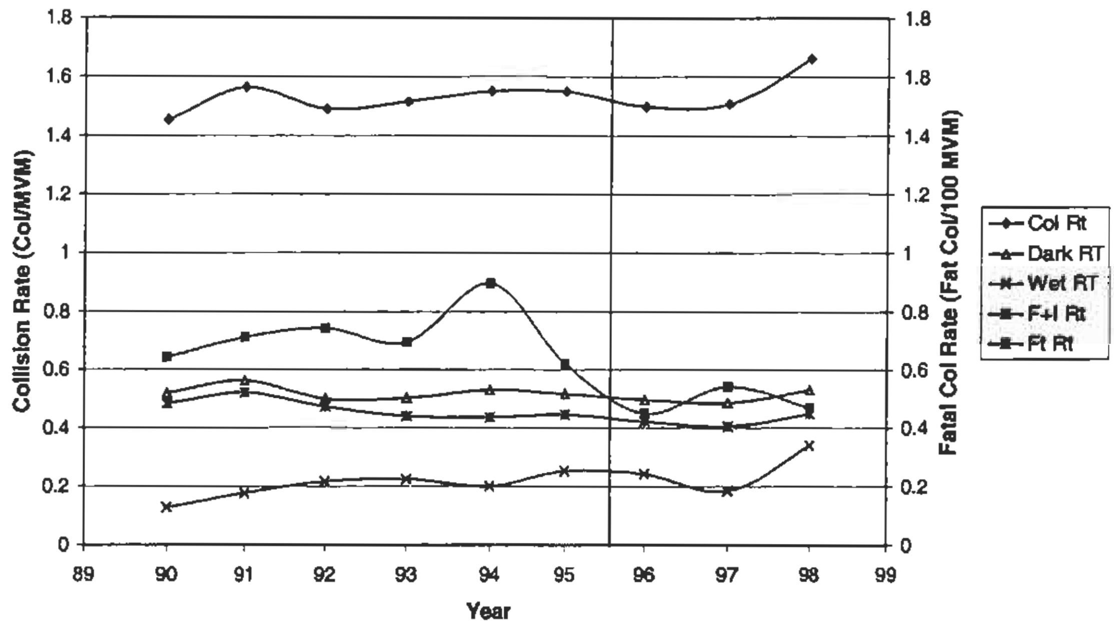
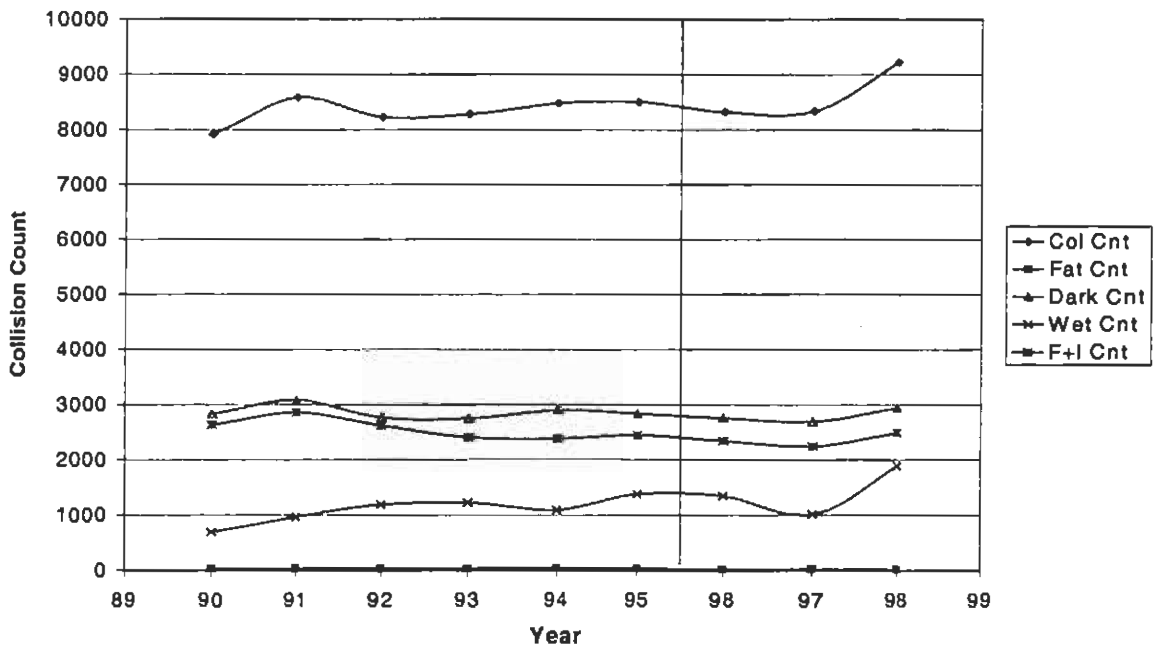


Figure 7 Collision Counts for the Highway Segments Retained at 55 mph



3.0 ANALYSIS OF DATA

3.1 INTRODUCTION

The main objective of this research project was to determine whether the increase in speed limits on about January 1, 1996, affected the collision experience on California highways. *After* data was collected, a primary concern was the application of appropriate statistical analysis for this data and for making suitable analysis inferences. It was decided that the application of several statistical methods might provide better insight into the underlying relationships between collision occurrence and speed limit increases. This afforded the opportunity to assess whether the results are sensitive to analysis approach thereby garnering support for the consistency of any findings.

The generalized method for assessing the impact that speed limit changes may have on collision experience may be characterized as an "observational" Before-After study. This type of the study includes a "comparison" group, which is a portion of observations that are not treated with a speed limit change. Those observations that receive the treatment, the speed limit change, are characterized as the "treatment group." When developing the methodological design for the analysis of data, there were several potential problems, which needed some attention. These problems included the following:

1. Likely changes in traffic volumes, driver behavior, and vehicle fleet.
2. Whether or not other treatments may have been implemented.
3. The "property damage only" (PDO) collision reporting rates.
4. The group of highway segments selected for speed limit increases could suffer from the "regression to the mean" phenomena.

Clearly, the level of traffic volumes changed from year to year and there has been a change in the rate of collisions. From state highway collision and traffic volume data, a 1997 report by Caltrans (12 p. 85) provides relationships between collision rates and ADT. Except for low volume freeways, less than 15,000 ADT, this relationship is positive which means that collision rates increase when ADT increases. This is especially true for rural freeways. All three of the groups (65-70 mph, 55-65 mph and 55 mph) are dominated by highway segments, which exceed 15,000 ADT. Additionally, it is well known that urban freeways have higher collision rates than lower volume rural highways. Consequently, as a rural area becomes more urbanized,

3.1.2 Level of Significance

Two levels of significance will be used in this study and will be designated by the resulting "p". The first level of significance will be called "marginal significance" and represents a 10% level of significance. The other will be called "significant" and represents a 5% level of significance.

The threshold values that will be used in each test will relate to a two-tailed test. A two-tailed test is used to test for either a statistically significant increase or decrease in the collisions.

3.2 FREQUENTIST METHODOLOGY

Historically frequentist methodology has been used for many statistical analyses. Professors Nancy Carter and Neil Schartman of California State University, Chico mathematics faculty provided the frequentist methodology utilized in this research project. This methodology makes use of two types of analyses; the first uses a treatment group, while the second makes use of a comparison group as well as the treatment group.

3.2.1 Description of Frequentist Methodology without a Comparison Group

The first type of frequentist analysis, using the collision rate data for the treatment group but not a comparison group, determines a best-fit line for the each collision type in the form of:

$$Y=\beta_0+(\beta_1 X)$$

Where Y = collision rate,

X = year the collisions occurred, and

β_0 and β_1 = regression coefficients.

The best-fit lines were estimated using data for all segments in the database individually as well as the annual average rates based on all of the segments. Best-fit lines were determined for the periods *before* and *after* the speed limit increase. Y_{11} represents the best-fit line for the seven-year period *before* the speed limit increased and Y_{12} represents the best-fit line for the three-year period *after* the speed limit increase. The values of the slopes and y-intercepts of these best-fit lines are displayed in Tables D-9 and D-10 of Appendix D. The objective was to test whether any changes in slope for the regression lines from *before* period to *after* period is statistically significant. The test also determines whether $Y_{11}=Y_{12}$ or not. Here Y_{11} and Y_{12} are the computed values of collisions using the best-fit regression line for the mid-year of the *before* and *after* periods respectively. The hypothesis testing is shown in Table 1 below.

Now that the slope of the best-fit line can be evaluated, the next aspect, the magnitude of the collision rates, needs to be evaluated. To accomplish this, the Poisson postulate is used. It requires that: 1) the probability of a collision occurring in a very short time interval (t) is proportional to "t"; 2) the probability of two collisions occurring at the same time is zero; 3) collision occurrences are a function of time; 4) the probability of a collision during such a small interval of time is not depend upon what happened prior to that time interval and the probability of collisions occurring over a fixed distance is constant (i.e. the probability of a collision occurring is independent of the location on the roadway). The test statistic for the Poisson postulate is as follows:

$$Z_{MAGNITUDE} = Z_M = \frac{Y_{11} - Y_{12}}{\sqrt{Y_{11} + Y_{12}}}$$

After these Z-test statistics are calculated, they can be compared to publish values to determine the level of significance.

3.2.2 Description of Frequentist Methodology using a Comparison Group

The second type of frequentist analysis is much like the first type in that best-fit lines were determined for the treatment group. However, this methodology also requires that best-fit lines were determined for the comparison group (group that was retained with a speed limit of 55 mph) as well. The four best-fit lines for treatment and comparison groups are presented in Table 2 below. The values of the slopes and y-intercepts of these best-fit lines are displayed in Tables D-11 and D-12 of Appendix D. The test asks whether or not Y_{12}-Y_{11}=Y_{22}-Y_{21}. The test statistic for the frequentist method with a comparison group is as follows:

$$Z_{COMPARISON} = Z_C = \frac{(\overline{Y}_{12} - \overline{Y}_{11}) - (\overline{Y}_{22} - \overline{Y}_{21})}{\sqrt{\frac{\overline{Y}_{12}}{n_{12}} + \frac{\overline{Y}_{11}}{n_{11}} + \frac{\overline{Y}_{22}}{n_{22}} + \frac{\overline{Y}_{21}}{n_{21}}}}$$

For large samples, this test statistic is approximately a normal distribution.

3.2.4 Results of the Frequentist Methodology Analysis

The detailed tables for the 55 to 65 mph frequentist analyses are provided in Tables D-9 through D-12 of Appendix D. The frequentist analyses without a comparison group showed that the slope (Z_S) of the collision rate regression line had a statistically significant increase ($p = 0.03$) when the analysis was done using annual average data. This indicates that the slope of the collision rate increased after the speed limit increased. However, since collision rates usually increase as ADT increases (12) especially on rural freeways, the increase in slope may not be statistically significant. Indeed, when a comparison group was introduced the significance of the change disappears. As noted previously, the frequentist method should not be applied to the 65-70 mph data because collision rates may have been an important factor in selecting highway segments for a speed limit increase. The results of the frequentist analyses are displayed in Table 3 below.

Table 3 Results of Frequentist Analysis for 55-65 mph Speed Limit Increase

Methodology	Total Accidents	Fatal Accidents	Wet Accidents	Dark Accidents	Fatal + Injury Accidents
Frequentist with comparison using segment data	NS	NS	NS	NS	NS
Frequentist without comparison using segment data	NS	NS	NS	NS	NS
Frequentist with comparison using annual data	NS	NS	NS	NS	NS
Frequentist without comparison using annual data	slope $p = 0.03$	NS	NS	NS	NS

Table 4 Threshold Values for the 'F' Statistic for Analysis of Ten Years of Data

Years of data used:	10 years	9 years	6 years
p	Fa >	Fa >	Fa >
0.01	11.26	12.25	21.2
0.025	7.75	8.07	12.22
0.05	5.32	5.59	7.71
0.1	3.46	3.59	4.54

A 10-year analysis was used when the 55-65 mph or the 65-70 mph segments were analyzed separate from the comparison group (due to availability of data). When the comparison group was involved, nine-year analysis was used because there was only nine years of available data for the comparison group. In addition, a six-year analysis was used for ANOVA in order to be consistent with the analysis time-period for the Observational Before-After Method.

3.3.2 Results of ANOVA

The results which were obtained using the ANOVA Methodology for the 65 to 70 mph speed limit increase are displayed in Table 5 below:

Table 5 Results of ANOVA Using Data for Segments Changed from 65-70 mph

Ten Years of Data (1989-1995 compared to 1996-1998)		
Type	**F- Value**	**p**
Col Rt	2.08	NS
Ft Rt	2.24	NS
Wet Rt	1.55	NS
Dark Rt	0.73	NS
F+I Rt	2.86	NS

Six years of Data (1993-1995 compared to 1996-1998)		
Type	**F- Value**	**p**
Col Rt	7.68	**0.05**
Ft Rt	0.50	NS
Wet Rt	1.59	NS
Dark Rt	0.00	NS
F+I Rt	0.84	NS

From Table 5, the total collision rate increased and is statistically significant at p is approximately equal to 0.05 (Fa = 7.68 < F = 7.71, thus the total collision rate is statistically significant at p slightly greater than 0.05) when three years of *before* and *after* data are used, but not for the ten years of data. The remainder of the ANOVA results shows that none of the

Table 7 Results of ANOVA for Comparison Group (Retained 55 mph)

Type	p
Acc Rt	NS
Ft Rt	**< - 0.05 ***
Wet Rt	NS
Dark Rt	NS
F+I Rt	NS

* minus indicates a decrease in collision rate in after period.

The results of the 55 mph data do not show a significant increase in total collision rates, thus supporting the notion that the increases in Table 5 and 6 were indeed statistically significant. Note also that the fatal collision rate decreased significantly for the comparison group while it did not decrease for the treatment groups. This led the authors to perform another ANOVA. For this additional analysis, a ratio was computed for each year, 1990 through 1998. The annual mean fatal collision rates of each treatment group (65-70 mph and 55-65 mph) were divided by the corresponding fatal collision rates in the *before* and *after* period of the comparison group. The analysis for this ratio revealed a significant increase in fatal collision rates, for three years *before* and *after*, as follows:

1) A marginally significant increase ($p = 0.07$) for 65-70 group

2) A significant increase ($p \leq 0.05$) for 55-65 group.

For the six-year *before* and three-year *after* analyses, neither group of highways experienced a significant change.

Finally, ANOVA models were developed to contrast the difference in fatal collision rates between the comparison group and each treatment group. This test did not produce any significant results.

As discussed earlier, there was a significant decrease in fatal collision rate on the highway segments, which did not experience a speed limit increase. If the speed limit increase

Table 8 Hypothesis Testing for Observational Before-After Comparison Group Study

	Treatment Group	Comparison Group
Before Period	K	M
After Period	L, E(L)	N

H_o (Null): K = L $\qquad$ H_a(Alternate): K ≠ L

For this method to be utilized the relationship, $r_c/r_t = 1$, must be verified-or at least be very close to 1.0. If this cannot be verified, it means that the collision counts variation from year-to-year is too great for this observational comparison group study methodology to be applied. This indicated that a significant change in collision experience resulting from a speed limit change might not be detectable in the treatment group. To deal with this matter Hauer (10 p 121, 137) identifies the ratio, r_c/r_t, as the "odds ratio" (O), which can be estimated as follows:

$$O = \frac{\frac{K_i \cdot N_i}{L_i \cdot M_i}}{1 + \frac{1}{L_i} + \frac{1}{M_i}}$$

The subscript "i" indicates that the collision counts are for individual years rather than for the entire *before* or *after* periods. The value of O is determined for each consecutive pair of years for all available data, nine years in this case. Then, if the average is approximately 1.0 (and only then), a Before-After study may proceed. All of the data sets used in this research project survived the "odds ratio" evaluation.

The next sequential activity is to determine a threshold value that will determine when a change in the number of collisions will be statistically significant. To assess statistical significance Hauer introduced the "index of effectiveness" (IE) which can be easily determined, IE = L/E(L) (10 p. 62, 128). The next step is determining the threshold values for IE that will count increased significantly (p = 0.05) while the total collision count increased with marginal significance (p = 0.10) for the 65-70 mph speed limit increase. For the 55-65 mph increase, the total collision count, fatal collision count, and the dark collision count increased significantly (p = 0.05); while the wet and fatal+injury collision counts had no significant change.

Table 9 Results of the Observational Comparison Study for the 65-70 and 55-65 mph Speed Limit Increases

Accident Type	65 to 70 mph Highways	55 to 65 mph Highways
All	Marginal Increase	Increase
Fatal	Increase	Increase
Dark	No Change	Increase
Wet	No Change	No Change
Fatal + Injury	No Change	No Change

3.5 MULTIVARIATE REGRESSION METHODOLOGY

3.5.1 Description of the Multivariate Regression Methodology

The primary purpose of this method was to analyze various factors or characteristics, expressed as variables, which likely will affect the collision rates and/or counts. The purpose was not to seek a multivariate model that completely characterizes the collision rates. The particular interest was to determine whether or not operating speed and truck traffic volumes affect the collision rates. Another issue of concern is whether the speed limit affects collision rates and counts. Many variables, which may affect the collision rates and counts, were entered into the model using the Statistical Program for Social Science (SPSS) computer program. If these variables did not have a level of significance of 10%, the SPSS software would delete them from the model, leaving only the statistically significant variables. In the case of multiple significant variables, multicolinearity examinations were done on the independent variables. Some specifics of the data are illustrated in Table G-14 of Appendix G.

that, the truck traffic was excluded due to a level of significance of 81.1%. Finally, the only variable that was left in the model was total vehicular traffic (MVM) with a level of significance of 1.4%. The β (slope) value for this term was approximately -0.000533, which indicates that the fatal collision rate decreases as the total vehicular traffic (MVM) increases.

3.5.4 Results of the Multivariate Regression Analysis

Tables G-15 and G-16 of Appendix G display the results of the Multivariate Regression analysis for both the 65-70 mph and 55-65 mph speed limit increases. The tables shows the dependent variables, the statistically significant independent variables, the individual significance of each independent variable, and whether the independent variable caused an increase or decrease in the dependent variable (collision rate). From the statistically significant results of this analysis for the 55-65 mph highway segments it is clear that:

- Collision rate (all collisions) is positively associated with ADT.
- Fatal collision rate is negatively correlated with ADT.
- Collision rate, dark collision rates, fatal+injury collision rates are all positively correlated with truck ADT.
- Wet collision rate was positively correlated with both the speed limit and operating speed.

In the case of the 65-70 mph highway segments there were four independent variables related as follows:

- Rates for collisions, fatal collisions, dark collisions, and fatal+injury collisions were positively correlated with truck travel.
- Wet collision rate was positively correlated with large truck traffic, five or more axles.
- Fatal collision rate and collision rate were negatively correlated with speed limit.
- Dark, wet, and fatal+injury collision rates were all positively correlated with speed limit (Spd Lm).
- Fatal, dark, and fatal+injury collision rates were all negatively correlated with operating speed (Op Spd).

4.0 FINDINGS AND CONCLUSIONS

4.1 MAJOR FINDINGS

There are several major findings developed by this research activity. As mentioned above, there were previous studies associated with the evaluation of the speed limit change that occurred in 1987, when the speed limits on a number of rural freeways were allowed to increase to 65 mph. The most significant was the work done by Khorashadi who used three full years of *after* data. In the case of both the rural interstate and non-interstate freeways, the rates for total collisions, injury collisions, and fatal+injury collisions indicated a significant increase after the speed limit was increased.

Another analysis sponsored by the Automobile Club of Southern California evaluated collision experience before and after the speed increases to 65 mph which occurred in December 1995 and again in April 1996. This study indicated that the injury collision rates increased following speed limit changes in December 1995, but decreased following speed limit changes in April 1996. For the speed limit increase on local highways in April 1996, the study showed a significant decline in fatal collision rates.

The major findings of this research project are recorded in Table 10 and discussed below. Table 10 displays the results of the Frequentist, ANOVA, and Observational Before-After Comparison Group analyses. For clarity, the notation used in the table is defined directly beneath the table rather than in the notation section.

1. For the 55-65 mph Group, all three methodologies indicated a significant increase in the total collision experience after the speed limits were increased.
2. According to the ANOVA and Observational studies (level of significance of 10% or less), there was also a significant increase in the total collision experience for the 65-70 mph Group.
3. For both of these groups that experienced speed limit increases, the fatal collision experience increased significantly as well based on the ANOVA and Observational methods. (However, for the 65-70 mph Group the ANOVA methods revealed a level of significance of less than 10% while the others were significant at 5% or less.)
4. For the dark collision experience for the 55-65 mph Group, both the ANOVA and Observational methods indicated a significant increase.

on truck traffic. In the case of fatal collision rates, the only positive correlation occurred with one of the truck travel variables.

Table 11 Composite Summary of Multivariate Analysis for Both 55-65 and 65-70 Highway Segments

	ADT	TADT	T5ADT	MVM	TMVM	T5MVM	Spd Lm	Op Spd
Col Rt	P	P			P		mN	
Ft Rt	N			N	P		N	N
Dark Rt		P			P		P	mN
Wet Rt			P				P, P	P
F+I Rt		P		P	P		N	N

Note: P – positive correlation, N – negative correlation, mN – marginally significant negative correlation.

Regarding the speed variables-speed limit and operating speed- a clear pattern of association could not be established, in part probably due to the relatively small database. The fatal and fatal+injury collision rates were negatively both speed variables. This is not surprising because the fatal collision rate decreased in the *after* period. The total collision rate was negatively correlated with speed limit at a marginally significant statistical level. The dark and wet collision rates were dominated by positive correlation with the speed variables. However, the dark collision rates were negatively correlated with operating speed (although only marginally significant).

4.2 MAJOR CONCLUSIONS

The following are five major conclusions that have been formulated from the analysis that has been completed:

1. Clearly, it may be concluded that the total collisions and fatal collisions, and for one group the Dark collisions, experienced a statistically significant increase after the speed limits were increased. Since the fatal collisions experienced a much larger increase than expected, it may be suggested that higher speeds influenced the collision experience.
2. The most significant finding of the multivariate regression analyses was that earlier work has been confirmed because there is a positive association between collision rates and the amount of travel, especially for rural freeways. This is consistent with other work and

5.0 REFERENCES

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Appendix A

Highways Segment Lists

Appendix A contains listings of the highway segments which were used in this study. Included are lists of the highway segments in the following three types of highway segments:

- Highway segments which experienced a speed limit increase from 65 to 70 mph (Table A-1) – 65-70 mph Group
- Highway segments which experienced a speed limit increase from 55 to 65 mph (Table A-2) – 55-65 mph Group
- Highway segments which were retained with a speed limit of 55 mph (Table A-3) – 55 mph Group

Table A-2 Highway Segments which Experienced a Speed Limit Increase from 55-65 mph

Segment #	Route	Begin Post Mile	End Post Mile
1	29	LAK R 40.876	LAK R048.389
2	101	DN R 0.347	DN R003.646
3	101	HUM R 5.900	HUM R048.935
4	101	DN R 27.770	DN R031.023
5	101	MEN R 42.472	MEN R042.959
6	101	HUM R 50.775	HUM M054.296
7	101	HUM 59.105	HUM 075.103
8	101	MEN R 83.881	MEN R090.537
9	101	HUM R 90.134	HUM R106.283
10	101	MEN R 97.000	MEN R104.069
11	299	HUM 0.000	HUM R005.929
12	5	SHA R 11.800	SHA R027.499
13	395	LAS R 2.102	LAS R004.999
14	5	SAC 14.100	YOL 002.799
15	50	YOL 0.000	ED 017.014
16	65	YUB R 4.738	YUB R009.176
17	65	PLA R 4.863	PLA R005.474
18	70	YUB R 6.625	YUB 013.603
19	70	BUT 13.509	BUT 020.142
20	80	YOL 0.000	PLA 033.130
21	99	SAC 0.123	SAC R024.349
22	99	BUT R 30.404	BUT R036.999
23	99	SAC R 32.124	SAC 036.862
24	4	CC R 4.940	CC R016.874
25	4	CC 20.774	CC T031.509
26	13	ALA 4.262	ALA R009.620
27	17	SCL 7.150	SCL 013.948
28	24	CC R 0.400	CC 009.143
29	24	ALA R 1.847	ALA R005.839
30	37	SOL 10.390	SOL R012.000
31	80	SOL 0.780	SOL R044.719
32	80	ALA 2.720	CC 013.479
33	84	ALA R 3.400	ALA R005.479
34	92	ALA R 2.700	ALA 006.449
35	101	MRN 12.520	MRN R023.270
36	242	CC R 0.000	CC R003.389
37	380	SM 5.064	SM 006.329
38	680	SCL M 0.000	CC 024.869
39	680	SOL M 0.760	SOL 013.119
40	880	SCL 0.000	ALA 024.181
41	980	ALA 0.009	ALA 002.035
42	1	MON 74.932	MON R091.019
43	1	MON R101.443	SCR 008.349
44	101	SB R 0.000	SB 001.120
45	101	MON R 0.000	MON 043.185
46	101	SB 1.224	SB R007.139
47	101	SB R 13.965	SB 027.198

Segment #	Route	Begin Post Mile	End Post Mile
96	120	TUO R 0.500	TUO T006.799
97	5	SD R 0.090	SD R072.366
98	8	SD L 0.710	SD R021.814
99	8	IMP R 94.900	IMP R096.899
100	15	SD R 0.000	SD R004.116
101	15	SD R 5.840	SD R036.699
102	67	SD R 0.000	SD R005.478
103	78	SD 0.004	SD R017.442
104	94	SD 1.416	SD R012.999
105	163	SD 3.714	D R011.661
106	805	SD 0.149	SD 028.873
107	905	SD 3.181	SD 005.163
108	22	ORA T 0.156	ORA R013.163
109	57	ORA 10.789	ORA R022.550
110	91	ORA R 0.023	ORA R018.904
111	405	ORA 0.230	ORA 024.177
112	605	ORA 3.438	ORA R001.642

Appendix B

Example Collision Data Tables

Appendix B includes sample data tables illustrating the types of data used for this research study. Each table exemplifies one of the three groups of highway data: 65-70 mph Group, 55-65 Group, and the 55 mph Group.

Table B-5 Example Data Table for Highway Segments which Experienced a Speed Limit Increase from 55-65 mph

HIGHWAY SEGMENT	TOT	FAT	INJ	F+I	WET	DARK	ACC RT	FT RT	F+I RT	Wet RT	Dark RT	MVM	ADT
0029 LAK R 40.876 THRU LAK R048.389	9	0	5	5	2	4	0.43029	0	0.2391	0.096	0.19124	20.916	7630.36
0101 DN R 0.347 THRU DN R003.646	3	0	1	1	0	2	0.68088	0	0.227	0	0.45392	4.4061	3659.124
0101 HUM R 5.900 THRU HUM R048.935	45	1	26	27	7	20	0.58576	1.302	0.3515	0.091	0.26034	76.823	4907.286
0101 DN R 27.770 THRU DN R031.023	2	0	1	1	0	0	0.21497	0	0.1075	0	0	9.3036	7835.598
0101 MEN R 42.472 THRU MEN R042.959	1	0	0	0	0	0	0.41064	0	0	0	0	2.4352	13700
0101 HUM R 50.775 THRU HUM M054.29	5	0	2	2	1	0	0.38686	0	0.1547	0.077	0	12.925	9465.437
0101 HUM 59.105 THRU HUM 075.103	50	0	22	22	10	15	0.50684	0	0.223	0.101	0.15205	96.65	16894.16
0101 MEN R 83.881 THRU MEN R090.537	4	0	3	3	2	2	0.32299	0	0.2422	0.161	0.16149	12.384	5097.826
0101 HUM R 90.134 THRU HUM R106.28	31	0	15	15	8	6	0.59777	0	0.2892	0.154	0.1157	51.659	8653.383
0101 MEN R 97.666 THRU MEN R104.069	11	0	3	3	3	5	0.90895	0	0.2479	0.248	0.41316	12.102	5125.352
0299 HUM 0.000 THRU HUM R005.929	11	0	5	5	2	1	0.60997	0	0.2773	0.111	0.05545	18.034	8333.193
0005 SHA R 11.800 THRU SHA R027.499	93	2	36	40	5	27	0.56528	1.216	0.2431	0.03	0.16411	164.52	28711.34
0395 LAS R 2.102 THRU LAS R004.999	2	0	2	2	0	1	0.27415	0	0.2742	0	0.13708	7.2951	6899.103
0005 SAC 14.100 THRU YOL 002.799	309	4	137	141	56	101	0.55807	0.722	0.2547	0.101	0.18241	553.69	64969.23
0050 YOL 0.000 THRU ED 017.014	904	8	379	387	149	262	0.70549	0.624	0.302	0.116	0.20447	1281.4	77099.57
0065 YUB R 4.738 THRU YUB R009.176	5	0	4	4	1	3	0.30114	0	0.2409	0.06	0.18068	16.604	10249.93
0065 PLA R 4.863 THRU PLA R005.474	0	0	0	0	0	0	0	0	0	0	0	3.3006	14800
0070 YUB R 6.625 THRU YUB 013.603	34	2	15	17	4	15	0.80621	4.754	0.4041	0.095	0.35656	42.068	21511.01
0070 BUT 13.509 THRU BUT 020.142	21	0	11	11	8	8	0.61738	0	0.3234	0.235	0.23519	34.014	14049.49
0080 YOL 0.000 THRU PLA 033.130	832	8	313	321	133	268	0.51395	0.494	0.1983	0.062	0.16555	1618.8	71110.39
0099 SAC 0.123 THRU SAC R024.349	457	3	207	210	39	130	0.84678	0.556	0.3891	0.072	0.24088	539.69	61033.7
0099 BUT R 30.404 THRU BUT R036.999	68	1	25	26	11	22	0.89802	1.321	0.3434	0.145	0.29054	75.722	31456.91
0099 SAC R 32.124 THRU SAC 036.862	12	1	7	8	1	3	0.3633	3.027	0.2422	0.03	0.09082	33.031	19100
0004 CC R 4.940 THRU CC R016.874	173	1	54	55	26	43	0.85645	0.495	0.2723	0.129	0.21288	202	48570.74

Appendix C

Operating Speed Sites

Appendix C includes three tables listing the highway sites where data that were used in this study were collected. There is one table for each of the two highway segments that had operating speed data available: 65-70 mph Group and 55-65 mph Group.

Table C-8 Weight In Motion Sites on Highway Segments which Experienced a Speed Limit Increase from 55-65 mph

Traffic Station	County	Route	Post Mile	Leg	Years of Data
110	HUM	101	65.54	A	5
309	SHA	5	24.08	A	3
44	SAC	5	29.022	B	2
409	YOL	50	0.35	A	2
300	SAC	80	16.685	A	2
501	SAC	99	6.008	A	2
901	SOL	80	29.859	A	2
334	SOL	80	15.815	B	3
155	ALA	680	6.396	B	2
635	FRE	99	25	O	1
120	LA	60	26.57	A	2
715	LA	110	2.771	B	1
540	LA	134	12.09	B	1
902	CC	80	7.615	O	1
902	LA	405	42.9	A	2
226	ORA	91	1.317	O	2

Legend

A - After post mile

B - Before post mile

O - Volumes on legs A and B are equal

Table D-9 Frequentist Analysis Results for 55-65 mph Speed Limit Increase, Using Annual Average Data Without Comparison Group

	Before Change - Yr 1-7				After Change - Yr 8-10					
Type	Slope	Y-Int	SE of slope	Y11 at yr 4	Slope	Y-Int	SE of slope	Y12 at yr 9	Slope - Z	Mag. - Z
Col Rt	-0.0011	0.759	0.004	0.754	0.035	0.547	0.009	0.864	-3.70 #	-0.086
Ft Rt	-0.0707	0.949	0.013	0.668	-0.034	0.837	0.019	0.535	-1.61	0.120
Dark Rt	-0.0036	0.260	0.001	0.246	-0.003	0.233	0.005	0.204	-0.072	0.062
Wet Rt	0.010	0.056	0.003	0.096	0.022	-0.07	0.02	0.135	-0.615	-0.081
F+I Rt	-0.0046	0.303	0.004	0.285	0.003	0.249	0.004	0.273	-1.290	0.015

significant increase in *after* period

Table D-10 Frequentist Analysis Results for 55-65 mph Speed Limit Increase, Using Highway Segment Data Without Comparison Group

	Before Change - Yr 1-7				After Change - Yr 8-10					
Type	Slope	Y-Int	SE of slope	Y11 at yr 4	Slope	Y-Int	SE of slope	Y12 at yr 9	Slope - Z	Mag. - Z
Col Rt	-0.011	0.73	0.006	0.686	0.022	0.567	0.023	0.767	-1.40	-0.067
Ft Rt	-0.034	1.162	0.041	1.03	-0.089	1.709	0.143	0.907	0.371	0.086
Dark Rt	-0.0057	0.254	0.002	0.231	0.003	0.213	0.008	0.240	-1.06	-0.013
Wet Rt	0.0074	0.067	0.002	0.097	0.018	-0.018	0.008	0.140	-1.23	-0.090
F+I Rt	-0.0098	0.311	0.003	0.272	-0.006	0.326	0.009	0.268	-0.356	0.005

Note: No increase was statistically significant

Table D-12 Frequentist Analysis Results for 55-65 mph Speed Limit Increase, Using Highway Segment Data with a Comparison Group

	Before Speed Limit Increase (Yr. 1-7)				After Speed Limit Increase (Yr. 8-10)				
Type	Slope	Y-Int	Y11,21 at yr 4		Slope	Y-Int	Y12,22 at yr 9		Z - Value
Col Rt	-0.011	0.730	0.686		0.022	0.567	0.767		0.049
Col Rt-55	0.007	1.191	1.220		0.062	0.726	1.282		
Ft Rt	-0.034	1.162	1.026		-0.089	1.709	0.907		0.428
Ft Rt-55	-0.028	0.867	0.753		-0.182	2.148	0.510		
Dark Rt	-0.006	0.254	0.231		0.003	0.213	0.240		0.072
Dark Rt-55	0.000	0.425	0.425		0.009	0.338	0.418		
Wet Rt	0.007	0.067	0.097		0.018	-0.018	0.140		-0.091
Wet Rt-55	0.016	0.095	0.159		0.042	-0.160	0.217		
F+I Rt	-0.010	0.311	0.272		-0.006	0.326	0.268		0.116
F+I Rt-55	-0.013	0.463	0.409		0.006	0.329	0.381		

n11	112	Observations in before period of treatment group
n12	112	Observations in before period of comparison group
n21	19	Observations in after period of treatment group
n22	19	Observations in after period of comparison group

Note: No increase was statistically significant

ANOVA was used to analyze all of the collision types for the 55-65 mph and the 65-70 mph changes. The following is an example of ANOVA for the collision rate of the 55-65 mph speed limit increase based on the methodology from the Mendenhall and Sincich book (13).

The data that is used for ANOVA is the average annual collision rate data for the treatment group. This data is in the following table.

Year	ACC RT
1989	0.771851
1990	0.771789
1991	0.739838
1992	0.729259
1993	0.739592
1994	0.757367
1995	0.770841
Treatment	
1996	0.83487
1997	0.85398
1998	0.905369

The first two values which must be calculated are SN and SS. The equations and values of SN and SS are as follows:

$$SN = \sum_{i=1}^{n} y_i = 7.8748 \qquad SS = \sum_{i=1}^{n} {y_i}^2 = 6.23137$$

Using these values, we can calculate CM and then we can calculate SStotal.

$$CM = \frac{SN^2}{n} = \frac{(7.8748)^2}{10} = 6.2012$$

$$SStotal = SS - CM = 6.23137 - 6.2012 = 0.0256$$

Using the preceding results we can calculate SST.

$$SST = \frac{T_1^2}{n_1} + \frac{T_2^2}{n_2} - CM = \frac{(5.2805)^2}{7} + \frac{(2.5942)^2}{3} - 6.2012 = 0.0256$$

Appendix F

Application of the Hauer Method

$$E(L) = (L\ ) \cdot r_c = 130{,}232 \cdot 1.0247 = 133{,}448 \text{ collisions}$$

Now we calculate the variance of the expected collision count that is above. To calculate the variance, we use the following equation:

$$Var[E(L)] = [E(L)]^2 * [\frac{1}{K} + \frac{1}{M} + \frac{1}{N} + Var(w)]$$

One needs to calculate the odds ratio, "O", to be able to calculate the Var(w) term. To calculate "O", we use several years before the speed limit increase to show that the past trends were similar in the comparison and treatment groups. The calculation of "O" is as follows in Table F-13:

Table F-13 Calculation of Odds Ratio for the Hauer Analysis

Year	Comparison Collisions	Treatment Collisions	O
1990	7914	42800	
1991	8585	41024	0.883465
1992	8230	40979	1.041839
1993	8284	41730	1.011542
1994	8477	43394	1.016056
1995	8502	45108	1.036296
1996	8320	49314	1.116999
1997	8342	52102	1.053602
1998	9226	56071	0.972938
		Average O value=	**1.016592**
		Standard Deviation of O=	**0.0214**

Since the mean odds ratio value is within one standard deviation of 1.0, the comparison group is a legitimate comparison group.

Next, the sample variance of the odds ratio, $s^2(O)$, must be calculated in order to calculate Var(w). To calculate this $s^2(O)$, the following equation is used:

$$s^2(O) = \frac{\sum (O - \overline{O})^2}{n-1}$$

The value of $s^2(O)$ can be calculated using a spreadsheet as follows:

Since $\mathbb{E}$ (1.175) > $\mathbb{E}_{INC\_5\%}$ (1.133), the conclusion is that the increase in the collision count after the speed limit increase from 55 to 65 **is statistically significant with a level of significance less than 5%.**

The final step is to calculate the difference between the expected collision count and the actual collision count for the *after* period of the treatment group.

$$\delta = E(AC_{12}) - AC_{12} = 133{,}448 - 157{,}487 = -24{,}038 \text{ collisions}$$

The preceding value indicates that **24,038 more collisions than expected occurred** on the freeway segments after the speed limit was increased from 55 to 65 mph. This value corresponds to over a **15% increase in collisions.**

Database used for Multivariate Regression Analysis

The database used for the Multivariate Regression analysis included collision rate data, traffic volume data, and a modest amount of actual operating speed data. The general statistics for the data is displayed in the following table (Table G-14):

Table G-14 Simple Statistics for Database Used for the Multivariate Regression Analysis.

65 to 70 mph data					
Variable	n	Mean	St Dev	Max	Min
Col Rt	21	0.484	0.089	0.666	0.267
Ft Rt	21	1.695	0.728	3.153	0.000
Dark Rt	21	0.196	0.045	0.299	0.079
Wet Rt	21	0.046	0.024	0.104	0.011
F+I Rt	21	0.226	0.060	0.350	0.094
ADT	21	28494	8811	44033	9796
Trk ADT	21	6799	1911	9749	1778
Trk 5 ADT	21	5202	1632	7578	1179
MVM	21	1253	742	2368	64
Trk MVM	21	307	166	504	11
Trk 5 MVM	21	229	122	391	8
Op Spd	21	66.2	2.35	72.3	62.4

55 to 65 mph data					
Variable	n	Mean	St Dev	Max	Min
Col Rt	33	0.721	0.264	1.296	0.399
Ft Rt	33	0.841	0.953	5.61	0.000
Dark Rt	33	0.230	0.083	0.451	0.114
Wet Rt	33	0.118	0.047	0.225	0.043
F+I Rt	33	0.260	0.085	0.432	0.140
ADT	33	102245	64126	229128	18320
Trk ADT	33	8448	4591	23387	1482
Trk 5 ADT	33	4228	2377	10844	673
MVM	33	1135	759	2561	107
Trk MVM	33	93.9	63.3	260	8.65
Trk 5 MVM	33	47.9	33.3	121	3.93
Op Spd	33	64.1	5.28	74.1	57.8

Note: Terms are defined in Appendix H.

Multivariate Regression Models

The following are the four models that were used to complete the multivariate regression analyses:

- Model 1: Col Rt = $\beta_0 + \beta_1$(Spd Lm) + β_2(MVM) + β_3(Trk MVM) + β_4(Trk 5 MVM)

- Model 2: Col Rt = $\beta_5 + \beta_6$(Op Spd) + + β_7(MVM) + β_8(Trk MVM) + β_9(Trk 5 MVM)

- Model 3: Col Rt = $\beta_{10} + \beta_{11}$(Spd Lm) + β_{12}(ADT) + β_{13}(Trk ADT) + β_{14}(Trk 5 ADT)

Results of Multivariate Regression Analysis

Table G-15 Results of the Multivariate Regression Analysis for the 55-65 mph Speed Limit Increase

Dependant Variable	Significant Indep. Variable	Significance	Increase or Decrease
Col Rt	Trk ADT	Significant	Increase
Col Rt	ADT	Significant	Increase
Ft Rt	MVM	Significant	Decrease
Ft Rt	ADT	Significant	Decrease
Dark Rt	Trk ADT	Significant	Increase
Wet Rt	Spd Lm	Significant	Increase
Wet Rt	Op Spd	Significant	Increase
F+I Rt	Trk ADT	Significant	Increase

Table G-16 Results of the Multivariate Regression Analysis for the 65-70 mph Speed Limit Increase

Dependant Variable	Significant Indep. Variable	Significance	Increase or Decrease
Col Rt	Trk MVM	Significant	Increase
Col Rt	Spd Lm	Marginal	Decrease
Ft Rt	Spd Lm	Significant	Decrease
Ft Rt	Trk MVM	Significant	Increase
Ft Rt	Op Spd	Significant	Decrease
Dark Rt	Spd Lm	Significant	Increase
Dark Rt	Trk MVM	Significant	Increase
Dark Rt	Op Spd	Marginal	Decrease
Wet Rt	Spd Lm	Significant	Increase
Wet Rt	Trk 5 ADT	Significant	Increase
F+I Rt	MVM	Significant	Increase
F+I Rt	Trk MVM	Significant	Increase
F+I Rt	Spd Lm	Significant	Decrease
F+I Rt	Op Spd	Significant	Decrease

Note: Collision rates have the units of (Col/MVM) with the exception of fatal collision rates, which have the units of (Col/100 MVM).

Notation

β_0, β_5, β_{10}, β_{15} – regression constants

β_i – regression coefficient

δ - change in collision count (negative = increase)

σ - symbol for standard deviation

A – refers to road section *after* the post-mile (*increasing* post-mile number)

ADT – average daily traffic – average number of vehicles per day

ANOVA – Analysis of Variance (a statistical method)

B – refers to road section *behind* the post-mile (*decreasing* post-mile number)

Caltrans – California Department of Transportation

COL RT – collision rate (collisions per MVM)

Comparison group –group of segments which maintained a 55 mph

DARK - number of collisions occurring in dark conditions

DARK RT – dark collision rate (dark collisions per MVM)

$E(L)$ – expected number of collisions in treatment group after treatment

F - F ratio test statistic used in AVOVA

F+I – fatality collision count plus injury collision count

F+I RT – fatality plus injury collision rate ({fatality collisions + injury collisions} per MVM)

FAT – fatality collision count

FT RT – fatality collision rate (fatality collisions per 100 MVM)

H_a – alternate hypothesis

H_o – null hypothesis

$\overline{O}$ - average value of the sample odds ratio (Hauer Method)

Op Spd – operating speed

p – level of significance

r_c - ratio of *after* and *before* collision counts for the comparison group

r_t - ratio of *after* and *before* collision counts for the treatment group

$s^2(O)$ - sample variance of the sample odds ratio

SI – Significant Increase

Spd Lm – speed limit

SR – State Route

St Dev – standard deviation

TASAS – Caltrans traffic collision surveillance and analysis system

TOT – total collision count

Treatment group – group of segments which had a speed limit increase

Trk 5 ADT – average daily truck traffic for trucks with 5 or more axles

Trk ADT – average daily truck traffic

Trk 5 MVM – million vehicle miles of 5+ axle truck travel

Trk MVM – million vehicle miles of truck travel

Var – variance

WET – number of collisions occurring in wet conditions

WET RT – wet collision rate (wet collisions per MVM)

Y_{11} – collision rate of the treatment group *before* the speed limit increase

Y_{12} - collision rate of the treatment group *after* the speed limit increase

Y_{21} – collision rate of the comparison group *before* the speed limit increase

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16. ABSTRACT

The primary objective of this research effort is to determine if there has been a statistically significant change in traffic collisions (total, fatal, fatal plus injury, wet pavement, and nighttime) due to recent speed limit increases on California state highways. Analysis of both collision counts and rates was preformed for speed limit increases from 55 to 65 mph, and from 65 to 70 mph that occurred at the beginning of 1996. A comparison group of highways that remained at 55 mph was also developed. The Analysis of Variance (ANOVA) and an Observational study by Hauer, the primary methodologies, revealed very similar results especially for statistically significant increases in total and fatal collision rates and counts. These methodologies also recorded a significant increase in nighttime collisions for the 55-65 mph Group. The only differences were that the Observational method only detected a marginally significant increase with total collisions for the 65-70 mph Group. Also, the ANOVA indicated that the fatality collision rates for 65-70 Group was only marginally significant. Earlier studies analyzing speed limit changes in California were also discussed and evaluated.

17. KEY WORDS	18. Distribution Statement
Speed limit change, collision counts, collision rates, fatal collisions, observational study, analysis of variance, frequentists, multivariate regression, autoregressive integrated moving average method.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

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APPENDICES

LIST OF TABLES IN APPENDICES

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increases became available. A summary of the finding from these studies is provided in Table ES-1.

Table ES-1 Results of Analysis Based on 1987 Speed Limit Increase

	Collision Rates					
Study Author	**Total**	**Fatality**	**Dark**	**Wet**	**Fat+Inj**	**Injury**
Bamfield (1989)	NS	NS	NS	NS	NS	NS
Smith (1990)	NS	*	NS	NS	NS	NS
Khorashadi (1994)						
Remained 55 Rural Interstate Freeways	D	D	D		D	
55-65 Rural Interstate Freeways	I	NS	NS	NS	I	I
55-65 Non-Interstate Freeways	I	NS	NS	NS	I	I

NS - No statistically significant change in collision rate
* - Fatality collision rate increased on SR 99. Others were not statistically different.
D - Statistically significant decrease in collision rate
I - Statistically significant increase in collision rate

The most recent study by Bloch and DeYoung (1996) was completed for the Automobile Club of Southern Califomia. This study examined the 55 to 65 speed limit increases that became effective on December 19, 1995. Additionally, this effort analyzed April 1, 1996 speed limit increases for some highways under local jurisdiction. The results are contained in Table ES-2.

Table ES-2 Results of Analysis done by the Automobile Club of Southern California Based on the 1996 Speed Limit Increase

	Collision Rates					
Study Author	**Total**	**Fatality**	**Dark**	**Wet**	**Fat+Inj**	**Injury**
Automobile Club of Southern Ca.						
State and Local Highways	NA	NS	NA	NA	NS	I
Local Highways	NA	I	NA	NA	NS	NS

NA - Analysis is not applicable to the collison type
NS - No statistically significant change in collision rate
I - Statistically Significant increase in collision rate

The collision data was analyzed by three different methodologies: 1) Frequentist, 2) ANOVA, and 3) Observational Before-After Comparison Study developed by Hauer. The first two utilize collision rates while the latter uses the number of the collisions. The Multivariate Regression Analysis method utilized the speed data as well as the collision data.

Major Findings and Conclusions

The collision data was analyzed to address the question whether or not there was any statistically significant increase in traffic collisions on major California highways after speed limit increases occurred. Table ES-3 was prepared to compare the number of collisions for each type of collision for three years *before* the speed limit changes vs. the three-year *after* period. In addition, this table compares the "expected" number of collisions vs. the actual collision counts in the after period. This expected number of collisions is based on a calculation -- assuming no speed limit changes -- from the Observation Before-After Comparison Study method. (This calculation is different from the calculation used by Caltrans to compute "expected collision rates" that are found in the annual collision data reports published by Caltrans.) It should also be noted that the Observation Before and After Comparison Study method may return different results depending upon which highway segments were selected for the comparison group. It can be seen from Table ES-3 that for every type of collision, the actual collision counts in the *after* period was greater than the expected (computed from Observation Before and After Comparison Study) count; however, not all of these differences were statistically significant. The findings and conclusions of the application of the methodologies are listed below.

- For the 55-65 Group the total collision counts were about 15 percent higher (statistically significant) than expected in the *after* period.
- In the case of the total collision counts for the 65-70 Group, the *after* period count was approximately 9 percent higher than expected. This difference was found to be statistically significant with the ANOVA methodology and marginally significant statistically using the Observational Before-After Comparison Study method.
- The ANOVA and Observational Before-After Comparison Study methodologies both revealed that the fatal collisions for 55-65 Group experienced a statistically significant increase. The number of fatal collisions was nearly 35 percent higher than expected.

significant according to both the ANOVA and Observational Before-After Comparison Study methodologies.

- For the 65-70 Group there was no statistically significant change in dark collisions.
- None of the analyses for the fatal+injury and wet collisions indicated a significant change.
- Clearly, it may be concluded that the total collisions and fatal collisions, and for one group the Dark collisions, experienced a statistically significant increase after the speed limits were increased. Since the fatal collisions experienced a much larger increase than expected, it may be suggested that higher speeds influenced the collision experience.
- The most significant finding of the multivariate regression analyses was that earlier work has been confirmed because there is a positive association between collision rates and the amount of travel, especially for rural freeways. This is consistent with other work and supports the use of the Observational Before-After methodology that uses collision counts.
- Future speed limit increases should continue to follow the Caltrans Traffic Manual because of the important guidance it provides when speed limit changes are being considered.
- Another aspect, which is beyond the scope of this project, is the assessment of the impact of truck-involved collisions associated with speed limit changes.
- Based on the findings of this research study, it would seem appropriate to review the collision experience of other state departments of transportation since the speed limit changes resulting from the repeal of the NMSL in November 28, 1995. This may be an area where more research could be conducted.

- **Years of data used:**
  - *Before* time period: 6/85 – 5/87 (2 years)
  - *After* time period: 6/87 – 5/88 (1 year)
- **Results:** There were no significant changes reported in the collision rates after the speed limit increase.

R.N. Smith (3) of Caltrans conducted the next study. This effort compared two year of collision data *before* the speed limit increase with two years of *after* data on the selected California interstate freeways. The study also included a comparison of two years of *before* data with one year of *after* data on a "look-alike" freeway, State Route (SR) 99, that had lower design standards.

- **Years of data used:**
  - *Before* time period: 6/85 – 5/87 (2 years)
  - *After* time period: 6/87 – 5/89 (2 years)
- **Results:**
  - After adjusting for traffic volume, fatalities, fatal collisions and injury collisions increased by 5 to 10%. The increases in fatalities and fatal collisions were not statistically significant, however the increase in injury collisions was significant (3 p.3)
  - On routes retained at 55 mph, "...the accident rates were actually down. None of the changes are statistically significant." (3 p.7).
  - There was a significant increase in fatalities at a level of significance of 10% ($p = 0.10$), fatal collisions ($p=0.02$), and injury collisions ($p = 0.15$) on the 'look-alike' freeway, SR 99.

The next study was completed by A. Khorashadi (4) in September of 1992. In this study, five years of data *before* was compared to three years of data *after* the speed limit increase using Analysis of Variance (ANOVA). The more significant points of this study are as follows:

As this research study was in progress, Bloch and DeYoung (6) completed a study for the Automobile Club of Southern California (ACSC) investigating the impact on traffic collisions of the December 1995 speed limit increase (55 to 65 mph) of 2800 miles (6 p.2) of state highways in California. Later, around April 1, 1996 local governments increase the speed limit on an additional 3300 miles (6 p.2) of roadways. The authors used a different analytical approach which is entitled Autoregressive Integrated Moving Average (ARIMA) (6 p.7). The major points of this report are as follows:

- **Years of data used:**
  - *Before* time period: 1/90 – 12/95 (6 years)
  - *After* time period: 12/95 – 12/97 (2 years)
- **Data included in study:** All traffic collisions in California from January 1990 through December 1997 (6 p. 7).
- **Types of collision rates studied:** fatal, fatal+severe injury, and injury.
- **Results:**
  - For the December 1995 speed limit increase: no change in the rates of fatal collision and fatal+severe injury collisions; increase in the injury collision rates
  - For the April 1996 speed limit increase: no change in fatal+severe injury collision rates; fatal collision rates decreased; reduction in the injury collision rates

1.2 RESEARCH GOAL AND OBJECTIVES

Research Goals. The primary goal is to determine if there is a statistically significant change in total, fatal, wet, dark, and fatal+injury collision counts and rates due to speed limit increases on California state highways. Research has been done for each discrete speed limit increase; namely, the 55 to 65 mph, and the 65 to 70 mph speed limit increase, which occurred around the beginning of 1996.

Research Objectives. In order to attain this goal, the following two research objectives were used:

1. To collect relevant collision, speed, and traffic volume data.
2. To conduct appropriate statistical testing and modeling.

Section 8-03.3 of this manual the District Director for each Caltrans district is authorized to issue orders regulating the speed limit of traffic, up to an including 65 mph, as described in sections 2, 3, 5, and 8. On December 18, 1995, the speed limit on many freeway segments was increased to 65 mph in consequence to the repeal of the NMSL. On January 8, 1996, segments of rural interstate freeways were increased to 70 mph. The data considered were the collision rates and operating speeds that could have influenced whether or not a highway segment was raised to 70 mph.

2.3 DATA REQUIREMENTS

2.3.1 Highway Groups.

65-70 mph Group. The first data set (group) received from Caltrans consisted of the 27 highway segments that experienced a speed limit increase from 65 to 70 mph beginning January 8, 1996. The total length of these segments is 1315 miles; this includes only rural freeways. These segments are listed in Table A-1 of Appendix A.

55-65 mph Group. This data group included 149 highway segments that experienced a speed limit increase from 55 to 65 mph beginning December 18, 1995. It was necessary to remove 32 segments from this data set because these segments were missing data in some years. Some of these segments had significant reconstruction since 1989. An additional five segments were removed from the data set due to unusual conditions on those segments (i.e. earthquake damage on Interstate 280 (I-280) in the San Francisco bay area). Consequently, a total of 37 segments were removed from the data set, leaving 112 segments. These segments encompass a total length of 1674 miles and consist of both urban and rural freeways. There are also a small number of highway segments that are divided, non-freeway highways. Table A-2 of Appendix A is a listing of these segments.

55 mph Group. The final group of data is the highway segments that have remained at a 55 mph speed limit throughout the time frame of study. The 19 segments are predominantly urban freeways and have a total length of 100 miles. A listing of these 19 segments appears in Table A-3 of Appendix A.

2.3.2 Collision data.

65-70 mph data. The collision data for these road segments included: total collisions, fatal collisions, fatal+injury collisions, collisions when pavement was wet, and collisions in dark lighting conditions. A sample of this data is in Table B-4 of Appendix B. This set provided collision data for each year and each segment of highway from 1989 through 1998 that totals 270 observations.

55-65 mph data. The collision data for these road segments is the same as that of the 65-70 mph segments. Segments retained for analysis remained virtually unchanged over the ten-year collision history studied totaling 1120 observations. A sample of this data is in Table B-5 of Appendix B.

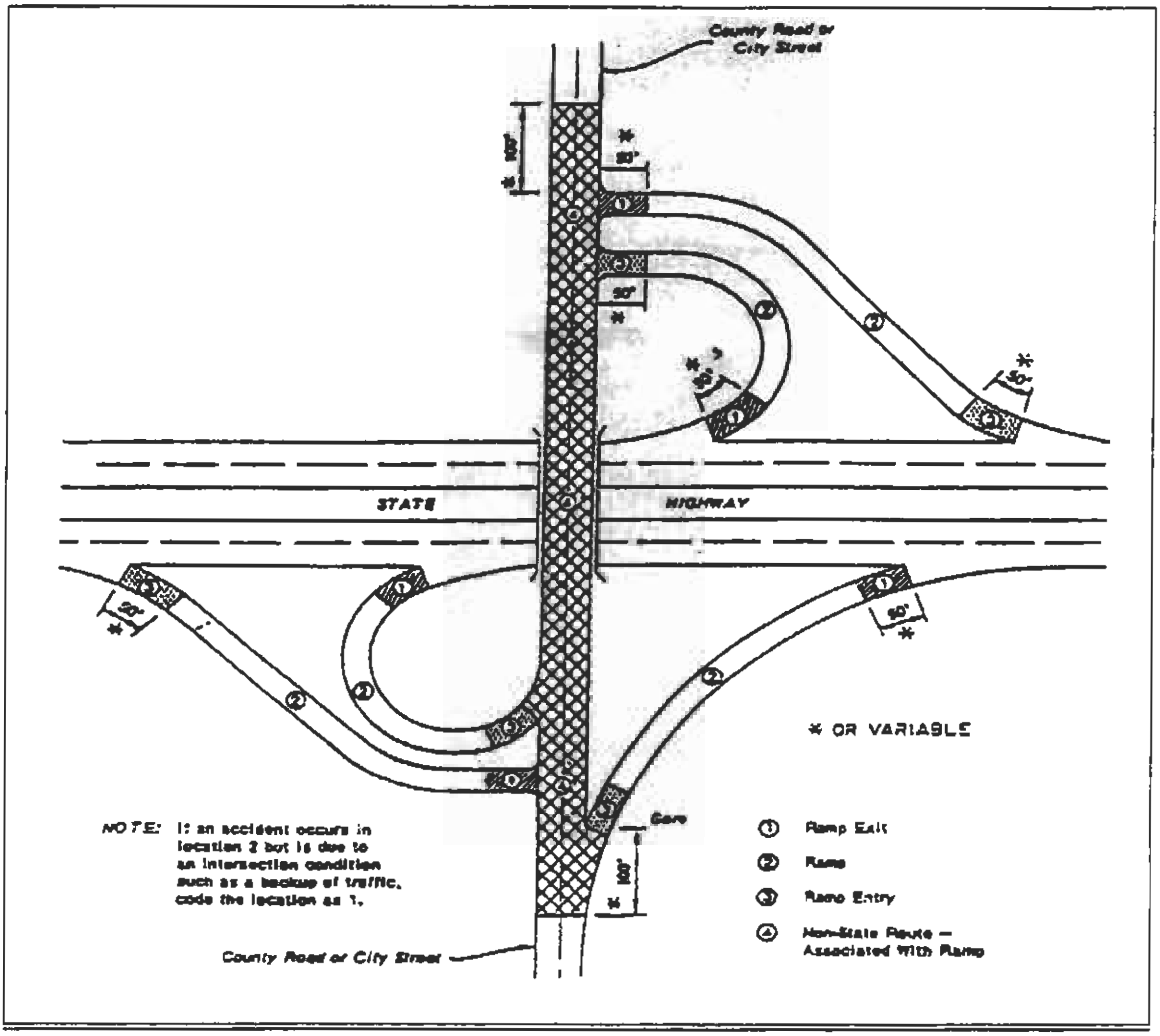


Figure 1: Ramp Collision Locations. (Source: Caltrans)

The collisions in location number 4 (from above) would likely be heavily influenced by traits unrelated to the freeway because collisions are located on the surface street intersecting a freeway ramp. For this reason these collisions were not used in any part of the analysis.

In the data for the segments that were raised from 65 to 70 mph, the collision rates that include ramp collisions are on average 6.9% higher than the collision rate that does not include ramp collisions. Higher speeds on the highway mainline would likely results in higher speed on ramps, so ramp collisions would likely be influenced by speed. Due to this influence of speed, the collision data used in the analysis will include the first three types of ramp collisions in addition to the collisions on the highway mainline.

Figure 3, the counts for all collision types increased. The total collisions increased about 13%, while fatal collision counts increased less than one percent. The fatal+injury collision counts increase about 5%, dark collision counts 7% and wet collision counts 37% respectively.

The next two figures contain data for the 55-65 mph Group. All of the collision rates increased on Figure 4 except for the fatal collision rate, which decreased approximately 2%. The collision rate for total collisions increased about 14%, while the dark collision rate increased about 9%, wet collision rate increased about 18%and the fatal+injury collision rate increased about 4%. All of count collision data on Figure 5 increased. The total collisions increased about 21%, while fatal collision increased two percent and the fatal+injury collision counts increases about 4%. The dark collision counts increased 16% and wet collision counts 24%.

The last two figures, Figures 6-7, contain data for the 55 mph Group. The collision rate for total collisions and wet collisions on Figure 6 increased approximately 7% and 13% respectively. The fatal collision rate declined 34% while the dark collision rate and fatal+injury collision rate both declined about 2%. Figure 7 illustrates the collision counts for the 55 mph Group that paralleled the collision rate data of Figure 6. Both the overall collision counts and wet collision counts increase 2% and 15% respectively. The other three counts, fatal, dark, fatal+injury, all declined 33%, 1%, and 2% respectively.

2.3.5 Operating speed data.

In order to assess possible affects of traffic operating speeds, recorded speed data was obtained from the Caltrans weigh-in-motion sites and other permanent sites. The annual data retrieved included the operating speeds from the last eight days of April. This time of year was selected to avoid the higher summer traffic volumes and a high rate of recreational vehicles, which may bias the data. The operating speed used in this study was calculated for the 7-8 p.m. hour in order to provide free-flow speed under daylight conditions. At some sites, the percentage of high-speed vehicles declined during nighttime travel. For example, in 1990, on Interstate-15 the average operating speed from 7-8 p.m. was 2.6 mph higher than the average operating speed from midnight to 1:00 a.m. Furthermore, in 1994, on Interstate-8 the average operating speed was 1.3 mph higher for the same hours.

Figure 4 Collison Rates for Highways Segments Raised from 55-65 mph

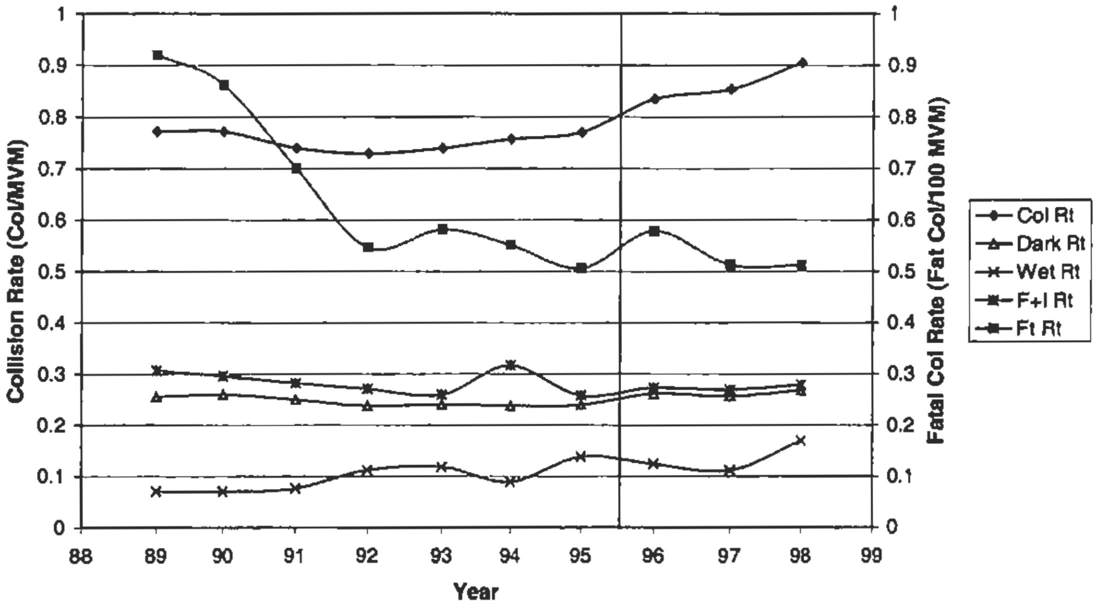
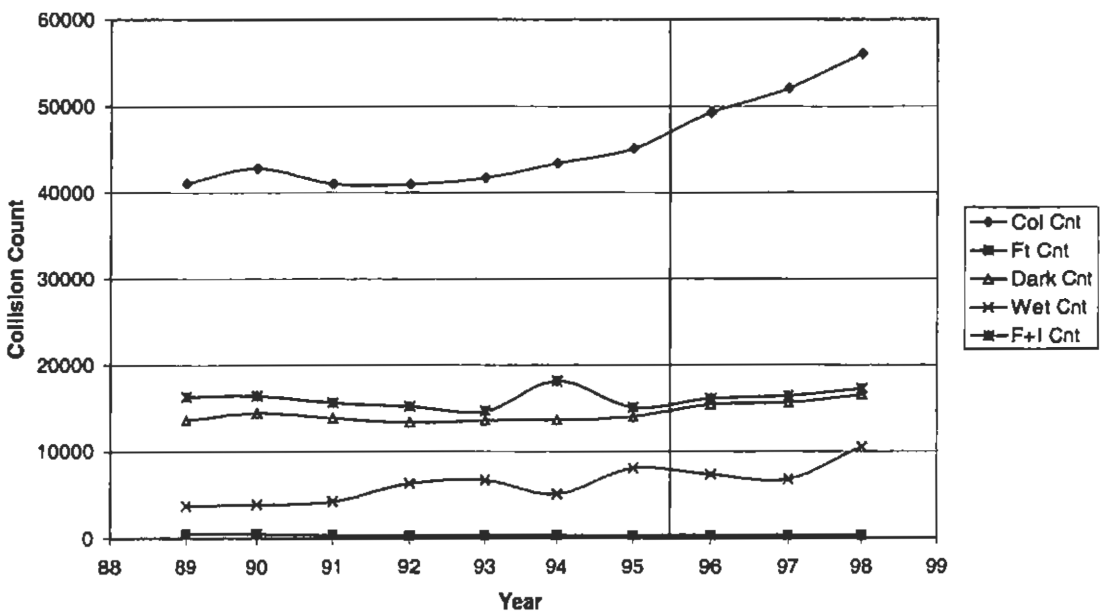


Figure 5 Collison Counts for the Highways Raised from 55-65 mph



The 7-8 p.m. hour also proved to be the best time to preserve free-flow operating speeds in urban areas. Although, several urban sites still showed signs of non free-flow traffic conditions in one direction. Lack of speed data on a large number of sites imposed significant limitations on making conclusive inferences about the impact of change in operating speed on collision experience on highway sites.

Operating speed data was collected for only two of the three categories of sites used in this study. Speed data sites on highway segments that were raised from 65-70 mph provided 21 observations and are listed in Table C-7 of Appendix C. Speed data sites on highway segments that were raised from 55 to 65 mph are listed in Table C-8 of Appendix C and totaled 33 observations. Note that there were no operating speed sites available for the 55 mph segments

2.4 SUMMARY

Data was obtained for the same highway segments for ten separate years (1989-1998). The following list summarizes the data that was collected and was used in the analysis:

1. Collision Data
    - Total collision count and rate
    - Fatal collision count and rate
    - Fatal+Injury collision count and rate
    - Wet collision count and rate
    - Dark collision count and rate
2. Average Daily Traffic
    - Average daily traffic
    - Average daily truck traffic
    - Average daily 5+ axle truck traffic (5 or more axle trucks)
3. Operating Speeds

one would expect the collision rates to increase. While the overall collision rates are increasing, it is common for the fatal collision rates to decline as the ADT increases.

Many factors, i.e. changes in driver behavior and vehicle fleet and minor roadway improvements, may influence the change in collision occurrence from the *before* to the *after* period. The use of a comparison group in the analysis is designed to exclude the impact of factors other than the change in speed limit. The *before* interval and the *after* interval for this portion of the analysis did not exceed three years. That way if there are such changes that were not addressed by the comparison group, they will be minimized. A three-year interval *before* and *after* speed limit changes was needed to provide reasonable assurances that any "regression to the mean" would not be a problem (11).

The use of PDO collisions raises concerns because up to 60% of reportable collisions may not be reported to law enforcement agencies (10 p.36). Despite the fact that many of these collisions are not reported, they are still sufficiently numerous, in many cases, that they could over power fatal and injury collisions. Consequently, some of the analyses for this project were directed towards only the fatal and injury collisions.

The analysis methodologies that were used for this research project include: Frequentist, Analysis of Variance (ANOVA), an Observational Before-After Comparison Group study, and Multivariate Regression.

3.1.1 Types of Collision Data Analyzed

For the methodologies identified above, the data has been organized to examine the five pairs of traffic collision types listed below. The traffic collision rates were evaluated using a frequentist methodology, ANOVA, and multivariate regression analysis. The collision counts were investigated using an Observational Before-After method developed by Hauer (10 pp. 115-148).

- Total Collision Count and Rate
- Fatal Collision Count and Rate
- Dark Collision Count and Rate
- Wet Collision Count and Rate
- Severity (Fatal + Injury) Collision Count and Rate

The above two null hypotheses would establish whether there was a statistically significant change in collision rates from the *before* to the *after* period. To accomplish this, the following two tasks needed to be accomplished: 1) Determine whether or not the slope of the regression line is significantly different *before* (β_{11}) and *after* (β_{12}) the speed limit change occurred and 2) Determine whether or not the magnitudes (Y) of the two regression equations are significantly different *before* (Y_{11}) and *after* (Y_{12}) the speed limit change; where Y_{11} and Y_{12} are defined above.

Table 1 Hypothesis Testing without a Comparison Group

To test slopes of the regression line: H_o(Null): $\beta_{11} = \beta_{12}$

H_a(Alternate): $\beta_{11} \neq \beta_{12}$

To test magnitude of collision rates : H_o(Null): $Y_{11} = Y_{12}$

H_a(Alternate): $Y_{11} \neq Y_{12}$

Note: The structure of this test is a two-tailed test, which allows testing significance for an increase or a decrease in collision rates.

This frequentist method type required three assumptions. The first is that a large sample of observations (number of observations > 30) is available. Next, the estimated slope (β_1) must be normally distributed, and thirdly both the treatment and comparison groups, *before* speed change and *after* speed change, are independent. The significance test formula for the slope is as follows:

$$Z_{SLOPE} = Z_S = \frac{\beta_{11} - \beta_{12}}{\sqrt{SE\beta_{11}\text{^}2 + SE\beta_{12}\text{^}2}}$$

Where β_{11} is the slope of best fit line before the speed limit was changed,

β_{12} is the slope of the best fit line after the speed limit was changed,

$SE\beta_{11}$ is the "standard error" of β_{11}, and

$SE\beta_{12}$ is the "standard error" of β_{12}.

3.2.3 Validity of the Frequentist Methodology

As mentioned earlier, an assumption of the frequentist methodology is that the two groups (treatment and comparison) *before* and *after* the speed change are independent. This is of concern because collision experience was one of the considerations that Caltrans engineers used to justify increasing the speed limits. This is especially true for segments that were raised from 65-70 mph. These segments had a significantly better safety record than the segments in the comparison group. In fact the 65-70 mph segments are all rural interstate freeways that had experienced a speed limit increase from 55-65 in 1987 based on low collision rates, superior level of service, and geometric design standards. (This is demonstrated by the fact that 55% of a large sample of the 65-70 mph segments before the 1996 speed limit increase were below the statewide mean collision rates.) For these reasons, the frequentist methodology was not used for analyzing collision rates of the 65-70 mph group and was only applied to the 55-65 mph group.

Table 2 Hypothesis Testing with Comparison Group

Accident Rates	Before Change	After Change
Highways with Speed Limit Change (Treatment Group)	Y11	Y12
Highways with no Speed Limit Change (Comparison Group)	Y21	Y22

$$H_o\text{(Null)}: Y_{12} - Y_{11} = Y_{22} - Y_{21}$$

$$H_a\text{(Alternate)}: Y_{12} - Y_{11} \neq Y_{22} - Y_{21}$$

3.3 ANALYSIS OF VARIANCE (ANOVA) METHODOLOGY

3.3.1 Discussion of ANOVA

The ANOVA model used in this study was a straightforward method to compare the mean of a population *before* and *after* it has experienced a type of treatment. This method was taken from a statistics book by Mendenhall and Sinich (13 pp. 729-734). ANOVA was used to compare the following two *before* and *after* periods:

1) *Before* period: 1989-1995 (6 years) compared to *after* period: 1996-1998 (3 years)

2) *Before* period: 1993-1995 (3 years) compared to *after* period: 1996-1998 (3 years)

This second *before* and *after* period was accomplished using the same time period that was used for the Observational B-A method developed by Hauer (discussed later) to see how the ANOVA results compare to the results from the observational method.

The hypothesis for the ANOVA methodology is as follows:

H_0: $\mu_1 = \mu_2$, H_A: $\mu_1 \neq \mu_2$

Where μ_1 = mean of *before* data and μ_2 = mean of *after* data.

The ANOVA analysis yields the 'F' statistic, which is compared with tabulated values (Fa) for determining statistical significance. If the F-value is greater than the published value of Fa, then H_o is rejected and one may assume that $\mu_1 \neq \mu_2$. The finding would be that there is a significant difference in the mean collision rates of the *before* and *after* periods. On the other hand if F is less than or equal to Fa, then H_o is accepted and $\mu_1 = \mu_2$. In this case there would not be a significant difference in the mean collision rates of the *before* and *after* periods. To obtain the value of Fa for years of data used, a published table was used with the following degrees of freedom: v_1 = (treatments – 1) and v_2 = [(years of data used) – (treatments)], where there were two treatments. Using these degrees of freedom the threshold Fa-value for the given levels of significance (p) are provided in Table 4 below.

changes in any other types of collision rates are statistically significant. This result needs to be tempered with the same concern as for the frequentist method. Specifically, the total collision rates tend to increase with the traffic volumes (ADT) as referenced early.

Table 6 presents the results of ANOVA for the 55-65 mph of data. As can be seen from this table, the total collision rate increased with less than a one percent level of significance ($p < 0.01$) in both the six-year and the ten-year analyses. The dark collision rate increases with a minimum of 2.5% level of significance ($p < 0.025$) in both the ten-year and the six-year analyses. The wet collision rate increased with marginal significance ($p = 0.08$) in only the ten-year analysis.

Table 6 Results of ANOVA Using Data for Segments Raised from 55 to 65 mph

Ten Years of Data (1989-1995 compared to 1996-1998)		
Type	**F- Value**	**p**
Acc Rt	44.40	**<0.01**
Ft Rt	1.75	NS
Wet Rt	4.17	**0.08**
Dark Rt	7.63	**0.025**
F+I Rt	0.57	NS

Six years of Data (1993-1995 compared to 1996-1998)		
Type	**F- Value**	**p**
Acc Rt	22.55	**<0.01**
Ft Rt	0.14	NS
Wet Rt	0.80	NS
Dark Rt	46.53	**<0.01**
F+I Rt	0.05	NS

The ANOVA analysis was also applied to the data for the highway segments that were retained at 55 mph. This was done to see if there were detectable changes in collision patterns, which may not be related to the speed limit increase. The results of this analysis is shown in Table 7:

did not affect the fatal collision rate, we would expect to see the same decrease in fatal collision rate on the treated highway segments (those that experienced a speed limit increase). The fatal collision rate had no significant change for both the 65-70 mph and the 55-65 mph treatment groups. This suggests that the speed limit increase may be related to an increase in fatal collision rates because the rates failed to decrease after the speed limit was increased.

3.4 OBSERVATIONAL BEFORE-AFTER COMPARISON GROUP STUDY

3.4.1 Description of Methodology

The next methodology, observational before-after, utilized for this research effort has been characterized and developed by Hauer (10 p. 115) as a "comparison group study." This method was designed specifically to conduct traffic collision *before* and *after* studies in order to address many of the concerns expressed earlier in this chapter. In contrast, the other methodologies were developed for general application and then applied specifically to the matters of traffic collisions. This methodology deals with the likely changes in traffic volumes, which often affect collision rates, by relying upon traffic collision counts rather than collision rates. Since this is a relatively new analysis procedure, a full sample application is provided for the reader in Appendix F.

The concerns of driver behavior, vehicle fleet, etc. are addressed by Hauer (10 p 120) with the use a comparison group and the ratio (r_c). The ratio (r_c) is the ratio of the number of collisions in the comparison group before the speed limit increase (M) to the number of collisions after the increase (N) (i.e. $r_c = N/M$). A similar ratio (r_t) can be developed for the treatment group data (i.e. $r_t = K/L$). If the collision experience for the comparison and treatment groups are the same except for the treatment, these ratios will be the same i.e. $r_c/r_t = 1$. This means that the treatment group collision count, after the treatment, can be estimated. If K is the treatment group collision count prior to treatment, then number of collisions in the treatment group, after treatment, can be estimated (i.e. $E(L) = r_c \cdot K$). This expected collision count E(L) can then be compared with the actual collisions count (L) of the treatment group in the *after* period to determine if there is a significant change in the collision count of the *after* period attributable to the speed limit increase. Table 8 illustrates the structure and hypothesis testing of this observational comparison group study.

indicate a significant change. If L is sufficiently low then one may conclude that the treatment was effective in reducing collisions. On the other hand, if L is sufficiently large the conclusion may be that the treatment contributed to an increase in collisions. Hauer (10 p. 77, 83) indicates that a "useful rule of thumb" is the common use of two standard deviations from the mean value. This useful rule will establish a 5% level of significance threshold for statistical testing. Recall that the expected collision count E(L) can be determined and Hauer assumes a Poisson distribution (10 p. 66) for collision counts. Consequently, the variance also equals E(L). Subsequently, statistically significant IE thresholds are as follows:

$$IE_{inc\,5\%} = [E(L) + 2\ SD^*\{E(L)\}] / E(L)$$

$$IE_{dec\,5\%} = [E(L) - 2\ SD^*\{E(L)\}] / E(L)$$

Where SD = standard deviation.

This means that if L is sufficiently small, then $IE < IE_{dec\,5\%}$ and one may conclude that the treatment, speed limit increase, reduced traffic collisions at a statistically significant level. On the other hand, if L is sufficiently large, then $IE > IE_{inc\,5\%}$ and the data suggest that the collisions increased after the speed limit was raised.

Using these threshold values of IE, the statistical hypothesis tests are summarized is as follows:

- Increase in collisions-

  H_o(Null): $IE < IE_{inc}$

  H_A(Alternate): $IE \geq IE_{inc}$

- Decrease in collisions-

  H_o(Null): $IE > IE_{dec}$

  H_A(Alternate): $IE \leq IE_{dec}$

An example of the calculations for this observational comparison study is included in Appendix E.

3.4.2 Results of the Observational Before-After Comparison Group Study

Table 9 below includes the results of the observational comparison study for both the 65-70 mph and 55-65 mph speed limit increases. As can be seen from this table, the fatal collision

Several multiple regression models were used to determine the variables that affect collision rates. These specific independent variables were selected using correlation table values. The multiple regression models that were utilized take the following form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \text{---} + \text{Error}$$

Where β_1 is a regression coefficient.

The dependent variable Y represents the collision rate while the independent variables X_1, X_2, ... signify parameters such as operating speed, speed limit, ADT, Truck ADT, MVM, and Truck MVM. A detailed description of the models, which were used are included in Appendix G.

3.5.2 Limitation of Multivariate Regression Analysis

Operating speed was used as one of the independent variable. Consequently, sample sizes were much smaller than for the other analyses. This was due to the lack of operating speed data. The database for the 55-65 mph group included 33 observations with only eight of the observations being after the speed limit increase. Even worse was the 65-70 mph database, which included 21 observations with only three of the observations in the *after* period.

3.5.3 Application of the Multivariate Regression Analysis

The Multivariate Regression analysis was used to analyze all of the types of collision rates for the 55-65 mph and the 65-70 mph speed limit increases. The following is an example of the analysis using a model for the fatal collision rate for the 55-65 mph speed limit increase.

A backwards, stepwise regression procedure was used, which begins with all independent variables estimating the dependent variable. The model then removes each independent variable that is not statistically significant. To report an example, one begins with the dependent variable fatal collision rate; the relevant independent variables were speed limit, total vehicle traffic (MVM), truck traffic (Trk MVM), and 5+-axle truck traffic (Trk 5 MVM). The first variable to be excluded from the model was speed limit with a level of significance of a mere 54.8%. Next, the 5+-axle truck traffic was excluded because it had a level of significance of only 39%. After

3.6 LIMITATIONS OF ANALYSIS

This analysis focused on the trend of collisions on selected major California highways (mostly freeways) and did not give attention to the trend of collisions on other roadways. The speed limit change on the high-speed highways may have caused a slight change in the frequency of collisions on the nearby, parallel roadways; if some travel was diverted from these nearby roads onto the freeways. If this type of change did occur, this analysis would not detect such a change.

5. In no analysis was the Fatal+Injury collision experience found to change significantly.

6. The most significant result of the multivariate regression analyses was that findings of earlier work were confirmed because there was a positive association between collision rates and the amount of travel. This was consistent with other work and supported the use of the Hauer methodology that utilizes actual counts.

Table 10 Results of Analyses Based on 1996 Speed Limit Increase on State Highways

	Collisions Counts or Collision Rates using 3 yrs. before and 3 yrs. after				
Analysis Method	Total	Fatal	Dark	Wet	Fat+Inj
Frequentist					
55 - 55 highway segments - C	Does not apply				
55 - 65 highway segments - T	I	NS	NS	NS	NS
65 - 70 highway segments - T	Not used for 65 - 70 segments				
ANOVA					
55 - 55 highway segments - C	NS	D	NS	MD	NS
55 - 65 highway segments - T	I	I *	I	NS	NS
65 - 70 highway segments - T	I	MI *	NS	NS	NS
Observational (Hauer)					
55 - 55 highway segments - C	Does not apply				
55 - 65 highway segments - T	I	I	I	NS	NS
65 - 70 highway segments - T	MI	I	NS	NS	NS

C - Comparison group, T - Treatment group
NS - No statistically significant change
I - Statistically significant increase
D - Statistically significant decrease
MI - Marginally statistically significant increase
MD - Marginally statistically significant decrease
* - Found to increase collision rate using ratio of treatment fatal collision rate to comparison fatal collision rate

The results of the multivariate analysis are discussed below and are summarized in the composite Table 11 that combines the results for both groups of highway segments experiencing a speed limit increase. From this composite table, several generalizations that were made. Clearly, the variables relating to travel were positively correlated with all of the collision rates other than the fatal collision rate. In almost every case the significant travel variable was based supports the use of the Observational Before-After methodology that uses collision counts.

3. Future speed limit increases should continue to follow the Caltrans Traffic Manual because of the important guidance it provides when speed limit changes are being considered.
4. Another aspect, which is beyond the scope of this project, is the assessment of the impact of truck-involved collisions associated with the speed limit change. The multivariate analysis implied that an increase in truck travel would likely contribute to an increase in collision experience.
5. Based on the findings of this research study, it would seem appropriate to review the collision experience of other state departments of transportation since the speed limit changes resulting from the repeal of the NMSL in November 28, 1995. This may be an area where more research could be conducted.

11. Hanley, Kevin E., Ferarra, Thomas C., Gibby, A. Reed. *The Evaluation of Accident Reduction Factors on California State Highways.* Report No. FHWA/CA-TE-96-01.

12. Caltrans "1997 Accident Data on California State Highways", Sacramento.

13. Mendenhall, William; Sincich, Terry. *Statistics for the Engineering and Computer Sciences.* Dellen Publishing Company, San Fransisco, California, 1988.

Table A-1 Highway Segments which Experienced a Speed Limit Increase from 65-70 mph

Segment #	Route	Begin Post Mile	End Post Mile
1	5	TEH R 0.000	TEH R023.999
2	5	SIS R 23.300	SIS R045.099
3	5	SAC 0.018	SAC 14.099
4	5	YOL 2.800	GLE R028.820
5	505	YOL 0.000	YOL R022.355
6	505	SOL R 0.000	SOL R010.625
7	580	ALA 0.092	ALA 0.392
8	101	SLO 67.230	SLO R069.319
9	5	KER 10.500	FRE 066.158
10	99	KER L 0.748	KER 019.499
11	99	KER 27.900	TUL R038.967
12	99	FRE 28.400	MAD 10.199
13	99	TUL 41.200	FRE 017.644
14	10	RIV R 0.000	RIV R 156.491
15	15	RIV R 0.000	RIV 036.777
16	15	SBD 8.826	SBD 186.237
17	40	SBD 0.000	SBD R154.642
18	215	RIV R 8.430	RIV 0.26.109
19	215	SBD 14.104	SBD 017.752
20	5	MER 0.000	SJ 024.249
21	5	SJ 33.600	SJ 049.818
22	120	SJ R 0.493	SJ T006.879
23	205	SJ R 8.500	SJ R012.699
24	580	SJ 0.000	SJ 015.339
25	8	IMP R 10.300	IMP R096.899
26	8	SD R 21.815	SD R076.499
27	15	SD R 36.700	SD R054.257

Segment #	Route	Begin Post Mile	End Post Mile
48	101	SB R 35.983	SB 038.459
49	101	SLO 37.325	SLO 059.366
50	101	MON 51.160	MON 055.839
51	101	SB R 56.463	SB 057.946
52	101	MON 58.589	MON 077.789
53	101	SB 69.835	SB 071.789
54	101	SB 77.295	SLO 030.535
55	101	MON 84.520	MON 085.623
56	156	MON R 0.167	MON R001.349
57	217	SB 1.014	SB 002.988
58	5	KER R 0.000	KER 010.499
59	14	KER R 0.000	KER R012.564
60	41	FRE R 22.105	FRE R032.299
61	58	KER R 52.400	KER 074.906
62	58	KER 78.651	KER R101.883
63	58	KER R127.826	KER R143.859
64	65	TUL 17.700	TUL 021.829
65	99	FRE 17.645	FRE 028.399
66	99	KER 19.500	KER 027.899
67	99	MAD 19.900	MAD 029.358
68	99	TUL R 38.968	TUL 041.199
69	178	KER R 1.702	KER R006.229
70	2	LA 14.104	LA R023.390
71	5	LA 0.000	LA 001.209
72	14	LA R 24.788	LA R077.007
73	33	VEN 0.000	VEN R005.599
74	57	LA R 0.000	LA R007.718
75	60	LA L 0.000	LA R030.455
76	101	LA 25.300	VEN R043.621
77	110	LA 0.700	LA 021.399
78	126	VEN 0.000	VEN R012.899
79	134	LA 0.000	LA R013.340
80	210	LA R 0.000	LA R048.499
81	405	LA 29.540	LA 048.599
82	605	LA R 0.000	LA 025.759
83	10	SBD 0.000	RIV R000.299
84	15	RIV 36.778	SBD 008.825
85	60	SBD R 0.000	RIV 027.789
86	91	RIV R 0.000	RIV 021.658
87	111	RIV R 62.540	RIV R063.377
88	215	RIV R 20.500	RIV 022.549
89	215	RIV 23.195	RIV 027.557
90	259	SBD L 0.000	SBD 001.514
91	5	SJ R 22.508	SJ 033.599
92	99	MER T 12.700	MER 024.299
93	99	SJ 22.200	SJ 038.779
94	99	MER T 36.343	SJ 016.399
95	120	SJ R 0.500	SJ T006.799

Table A-3 Highway Segments which were Retained with a Speed Limit of 55 mph

Segment #	Route	Begin Post Mile	End Post Mile
1	20	NEV R12.302	NEV R16.479
2	49	NEV 13.060	NEV R14.474
3	50	ED 18.760	ED 20.529
4	51	SAC 0.000	SAC 8.859
5	160	SAC R44.620	SAC 47.049
6	80	ALA 2.720	ALA 4.579
7	80	ALA 4.580	ALA 8.029
8	80	CC 0.000	CC 12.749
9	80	CC 12.750	CC 14.129
10	92	SM R7.300	SM R18.799
11	101	MRN L0.000	MRN 12.519
12	237	SCL R0.290	SCL R1.069
13	5	LA 9.45	LA 19.899
14	10	LA 14.840	LA 18.389
15	90	LA R1.033	LA 2.649
16	101	LA S0.000	LA S1.328
17	101	LA 0.000	LA 1.569
18	101	LA 4.400	LA 11.749
19	110	LA 20.000	LA 31.909

Table B-4 Example Data Table for Highway Segments which Experienced a Speed Limit Increase from 65-70 mph

HIGHWAY SEGMENT	TOT	FAT	INJ	F+I	WET	DARK	ACC RT	FT RT	Dark RT	Wet RT	F+I RT	MVM	ADT
0005 TEH R 0.000 THRU TEH R023.999	69	2	32	34	3	21	0.3696	1.0713	0.11249	0.0161	0.162	186.691	21321
0005 SIS R 23.300 THRU SIS R045.099	50	3	25	28	2	21	0.47828	2.8697	0.20088	0.0191	0.268	104.541	13139
0005 SAC 0.018 THRU SAC 014.099	37	5	18	23	6	21	0.21517	2.9076	0.12212	0.0349	0.134	171.961	33463
0005 YOL 2.800 THRU GLE R028.820	258	9	119	128	14	115	0.41732	1.4558	0.18601	0.0226	0.207	618.233	18966
0505 YOL 0.000 THRU YOL R022.355	19	0	12	12	0	6	0.2217	0	0.07001	0	0.14	85.7013	10501
0505 SOL R 0.000 THRU SOL R010.625	31	1	17	18	3	14	0.50387	1.6254	0.22755	0.0488	0.293	61.5244	15857
0580 ALA 0.092 THRU ALA 000.392	3	0	1	1	1	2	1.36187	0	0.90792	0.454	0.454	2.20285	18400
0101 SLO 67.230 THRU SLO R069.319	10	0	4	4	0	6	0.84613	0	0.50768	0	0.338	11.8185	15500
0005 KER 10.500 THRU FRE 066.158	712	23	351	374	26	320	0.66598	2.1514	0.29932	0.0243	0.35	1069.09	17333
0099 KER L 0.748 THRU KER 019.499	116	7	50	57	4	65	0.56098	3.3852	0.26598	0.0193	0.276	206.779	30216
0099 KER 27.900 THRU TUL R038.967	456	10	186	196	30	167	0.59971	1.3152	0.21963	0.0395	0.258	760.366	30341
0099 FRE 28.400 THRU MAD 010.199	142	5	67	72	12	58	0.71003	2.5001	0.29001	0.06	0.36	199.991	40865
0099 TUL 41.200 THRU FRE 017.644	252	5	98	103	34	96	0.58839	1.1674	0.22415	0.0794	0.24	428.29	38620
0010 RIV R 0.000 THRU RIV R156.491	765	29	326	355	44	346	0.48735	1.8475	0.22042	0.028	0.226	1569.71	27481
0015 RIV R 0.000 THRU RIV 036.777	230	13	106	119	10	97	0.34245	1.9356	0.14442	0.0149	0.177	671.629	50138
0015 SBD 8.826 THRU SBD 186.237	963	63	483	546	22	391	0.48202	3.1534	0.19571	0.011	0.273	1997.85	30745
0040 SBD 0.000 THRU SBD R154.642	294	16	153	169	2	119	0.52737	2.87	0.21346	0.0036	0.303	557.487	9876.9
0215 RIV R 8.430 THRU RIV 026.109	95	3	48	51	5	39	0.44924	1.4186	0.18442	0.0236	0.241	211.47	33470
0215 SBD 14.104 THRU SBD 017.752	42	0	18	18	4	23	0.77841	0	0.42627	0.0741	0.334	53.9561	40500
0005 MER 0.000 THRU SJ 024.249	505	21	230	251	40	221	0.613	2.5491	0.26826	0.0486	0.305	823.821	26622
0005 SJ 33.600 THRU SJ 049.818	93	8	49	67	7	48	0.48753	4.1938	0.24114	0.0367	0.299	190.759	32225
0120 SJ R 0.493 THRU SJ T006.879	34	2	17	19	6	12	0.44398	2.6117	0.1567	0.0784	0.248	76.5793	32885
0205 SJ R 8.500 THRU SJ R012.699	31	0	14	14	2	8	0.4054	0	0.10462	0.0262	0.183	76.4675	50000
0580 SJ 0.000 THRU SJ 015.339	49	3	28	31	2	22	0.50682	3.103	0.22755	0.0207	0.321	96.6803	17268
0008 IMP R 10.300 THRU IMP R096.899	165	6	77	83	1	85	0.57555	2.0929	0.2965	0.0035	0.29	286.682	9069.7
0008 SD R 21.815 THRU SD R076.499	187	10	95	105	15	58	0.60997	3.2619	0.18919	0.0489	0.342	306.572	16034
0015 SD R 36.700 THRU SD R054.257	119	5	64	69	9	57	0.35037	1.4721	0.16782	0.0265	0.203	339.64	53000

Table B-6 Example Data Table for Highway Segments which Remained with a Speed Limit of 55 mph

HIGHWAY SEGMENT	TOT	FAT	INJ	F+I	WET	DARK	ACC RT	FT RT	F+I RT	Wet RT	Dark RT	MVM	ADT
0020 NEV R 12.302 THRU NEV R016.479	32	0	16	16	3	4	0.76511	0	0.383	0.07173	0.0956	41.824	27432.6
0049 NEV 13.060 THRU NEV R014.474	3	0	2	2	1	1	0.21883	0	0.146	0.07294	0.0729	13.709	26562.9
0050 ED 18.760 THRU ED 020.529	16	0	1	1	2	11	0.96469	0	0.06	0.12059	0.6632	16.586	25686.9
0051 SAC 0.000 THRU SAC 008.859	473	1	185	186	75	124	1.16388	0.2461	0.458	0.18455	0.3051	406.4	125683
0160 SAC R 44.620 THRU SAC 047.049	27	0	17	17	2	6	0.93773	0	0.59	0.06946	0.2778	29.793	40247.4
0080 ALA 2.720 THRU ALA 004.579	411	0	117	117	40	133	2.31122	0	0.658	0.22494	0.7479	177.83	262076
0080 ALA 4.580 THRU ALA 008.029	320	0	102	102	20	98	1.16294	0	0.371	0.07268	0.3561	275.17	218578
0080 CC 0.000 THRU CC 012.749	647	2	270	272	84	220	1.01561	0.3139	0.427	0.13186	0.3453	637.05	136901
0080 CC 12.750 THRU CC 014.129	59	3	21	24	3	16	1.10507	5.619	0.45	0.05619	0.2997	53.39	106073
0092 SM R 7.300 THRU SM R018.799	304	0	143	143	53	100	1.01858	0	0.479	0.17758	0.3351	298.45	71164.8
0101 MRN L 0.000 THRU MRN 012.519	532	3	203	206	68	163	0.82276	0.464	0.319	0.10516	0.2521	646.61	141507
0237 SCL R 0.290 THRU SCL R001.069	15	0	7	7	1	4	1.21055	0	0.565	0.0807	0.3228	12.391	43578.9
0005 LA 9.450 THRU LA 019.899	1660	9	470	479	111	535	1.78121	0.9657	0.514	0.11911	0.5741	931.95	244357
0010 LA 14.840 THRU LA 018.389	424	2	123	125	31	155	1.2195	0.5752	0.36	0.08916	0.4458	347.68	268401
0090 LA R 1.033 THRU LA 002.649	25	0	15	15	3	13	0.56796	0	0.341	0.06816	0.2953	44.017	74625
0101 LA S 0.000 THRU LA S001.328	71	0	21	21	7	31	1.08875	0	0.322	0.10734	0.4754	65.212	134536
0101 LA 0.000 THRU LA 001.569	335	4	102	106	24	139	2.62167	3.1303	0.83	0.18782	1.0878	127.78	223127
0101 LA 4.400 THRU LA 011.749	775	5	278	283	74	358	1.2799	0.8257	0.467	0.12221	0.5912	605.52	225738
0110 LA 20.000 THRU LA 031.909	1785	6	503	509	92	715	2.50864	0.8432	0.715	0.1293	1.0049	711.54	163694

Table C-7 Weight in Motion Sites on Highway Segments Which Experienced a Speed Limit Increase from 65-70 mph

Traffic Station	County	Route	Post Mile	Leg	Years of Data
903	SOL	505	3.058	B	1
851	FRE	5	48.99	A	1
808	RIV	10	19.4	A	5
809	SBD	15	20.011	B	5
855	SBD	40	28.481	B	1
340	SJ	5	22.512	A	2
284	MER	5	17.578	A	3
82	SJ	5	6.467	A	1
24	SJ	5	44.712	B	2
624	IMP	8	23.48	A	1

Legend

A - After post mile

B - Before post mile

Appendix D

Complete Results for the Frequentist Methods

Appendix D includes tables that were generated while doing the Frequentist analysis. These tables also report the results of the analysis in the form of a Z-value. For statistical significance ($p < 0.05$), Z must be greater than or equal to 1.96. For marginal significance ($0.05 < p < 0.10$), the Z-value must be between 1.65 and 1.96.

The Frequentist analysis was done using annual average data and highway segment data. The annual average data consists of average collision rates for each year for **all of the highway segments combined.** This data set consists of seven observations *before* the speed limit increase and three *after* (one observation for each year). The highway segment data consists of the data for each and **every highway segment individually** for each year. For example, the data set for the 55 to 65 mph speed limit increase consists of 784 observations before the speed limit increase and 336 *after* the increase (one observation for each segment for each year).

The only statistically significant change was that the slope of the slope of the collision rate increased after the speed limit increase when the annual average data was used without a comparison group.

Table D-11 Frequentist Analysis Results for 55-65 mph Speed Limit Increase, Using Annual Average Data with Comparison Group

	Before Speed Limit Increase (Yr. 1-7)				After Speed Limit Increase (Yr. 8-10)				
Type	Slope	Y-int.	Y11,21 at yr 4		Slope	Y-int.	Y12,22 at yr 9		Z - Value
Col Rt	-0.0011	0.759	0.754		0.035	0.547	0.864		-0.004
Col Rt-55	0.0134	1.474	1.527		0.082	0.905	1.639		
Ft Rt	-0.0707	0.949	0.666		-0.034	0.837	0.535		0.380
Ft Rt-55	0.0131	0.679	0.731		0.009	0.415	0.496		
Dark Rt	-0.0036	0.26	0.246		0.003	0.233	0.262		0.064
Dark Rt-55	-0.003	0.533	0.521		0.017	0.368	0.522		
Wet Rt	0.01	0.0563	0.096		0.022	-0.067	0.135		-0.330
Wet Rt-55	0.0201	0.129	0.209		0.049	-0.135	0.304		
F+I Rt	-0.0046	0.303	0.285		0.003	0.249	0.273		0.038
F+I Rt-55	-0.0135	0.514	0.460		0.014	0.317	0.440		

n11	112	Observations in before period of treatment group
n12	112	Observations in before period of comparison group
n21	19	Observations in after period of treatment group
n22	19	Observations in after period of comparison group

Note: No increase was statistically significant

Appendix E

Sample Calculation for the Analysis of Variance Method where definitions of T_1 and T_2 can be found in any statistical text. Using the above results, we can calculate SSE by the following equation.

$$SSE = SStotal - SST = 0.0302 - 0.0256 = 0.0046$$

Using the value for SSE, we can determine the values for MST and MSE as follows:

$$MST = \frac{SST}{p-1} = \frac{0.0256}{2-1} = 0.0256 \qquad MSE = \frac{SSE}{n-p} = \frac{0.0046}{10-2} = 0.000576$$

Now we determine the F statistic by the following equation:

$$F = \frac{MST}{MSE} = \frac{0.025585}{0.000576} = 44.41655$$

Using this F statistic, a value of 3.36 is needed for a p value of 0.10 and an F value of 5.12 is needed for a p value of 0.05. The F value for the collision rate is 44.42 so the increase in the collision rate for the 55-65 mph speed limit increase is statistically significant with a p value of about 0.001.

Analysis was completed for all of the data using the Hauer analysis method explained previously. The following illustration is the Hauer analysis of the data set of the 55-65 mph speed limit increase. The notation used in this illustration is defined in Appendix H.

To complete the Hauer analysis method for the 55-65 mph data, the following data was used:

Year	Comparison Collision Count	Treatment Collision Count
1993	8284	41730
1994	8477	43394
1995	8502	45108
1996	8320	49314
1997	8342	52102
1998	9226	56071

The comparison group is composed of road segments which were retained at 55 mph and the treatment group is composed of road segments which experienced a speed limit change from 55 to 65 mph beginning in December 1995.

Using the data in the preceding table, the following values can be calculated:

- $K = 41730 + 43394 + 45108 = 130{,}232$
- $L = 49314 + 52102 + 56071 = 157{,}487$
- $M = 8284 + 8477 + 8502 = 25{,}263$
- $N = 8320 + 8342 + 9226 = 25{,}888$

Using these values, we calculate r_c as follows:

$$r_c = \frac{N}{M} = \frac{25{,}888}{25{,}263} = 1.0247$$

We now calculate the amount of collisions that we expect in the *after* period of the treatment group.

Year	Comparison	Treatment	O	O - Avg O	(O - Avg O)^2
1990	7914	42800			
1991	8585	41024	0.883	-0.133	0.0177
1992	8230	40979	1.042	0.025	0.0006
1993	8284	41730	1.012	-0.005	0.0000
1994	8477	43394	1.016	-0.001	0.0000
1995	8502	45108	1.036	0.020	0.0004
1996	8320	49314	1.117	0.100	0.0101
1997	8342	52102	1.054	0.037	0.0014
1998	9226	56071	0.973	-0.044	0.0019
Averages:	8431	45836	1.017		
				Sum =	0.0321

Consequently, $s^2(O) = (0.0321)/(8-1) = 0.000459$.

Using this value of the sample variance, Var(w) can be calculated.

$$Var(w) = s^2(o) - [\frac{1}{\overline{K}} + \frac{1}{\overline{L}} + \frac{1}{\overline{M}} + \frac{1}{\overline{N}}] = 0.000459 - [\frac{2}{8431.11} + \frac{2}{45835.78}] = 0.00431$$

The values used for $\overline{K}$, $\overline{L}$, $\overline{M}$, and $\overline{N}$ are the average collision counts for the treatment and comparison groups for all years of data.

Now that a value for Var(w) has been obtained, the previous equation can compute Var[E(L)]. For this illustration we see that Var[E(L)] = 78,272,114.

The next step is to determine IE (the index of effectiveness) and the threshold value for that index. These values can be calculated using the following two equations. The values which are display below have been calculated using all of the values that were previously calculated.

$$IE = \frac{\frac{L}{E(L)}}{1 + \frac{Var[E(L)]}{[E(L)]^2}} = \frac{\frac{157,487}{133,448}}{1 + \frac{78,272,114}{[133,448]^2}} = 1.175$$

$$IE_{INC\_5\%} = \frac{E(L) + 2 \cdot \sigma[E(L)]}{E(L)} = \frac{133,448 + 2 \cdot 8,847}{133,448} = 1.133$$

Appendix G

Multivariate Regression Analysis

Appendix G includes the following:

- **Simple statistics of the database used for the Multivariate Regression analysis –** These statistics were included so the reader can have a better idea of what the database consisted of (i.e. number of observations, average values, etc.).

- **Multivariate Regression Models** – These models were included so the reader can see the details of the Multivariate Regression analysis that was done to better understand how the results were obtained.

- Model 4: Col Rt = $\beta_{15} + \beta_{16}$(Op Spd) + β_{17}(ADT) + β_{18}(Trk ADT) + β_{19}(Trk 5 ADT)

Where the variables are defined as follows:

β_0, β_5, β_{10}, β_{15} – regression constants

β_i – regression coefficient

ADT – average daily traffic

Col Rt – collision rate

MVM – million vehicle miles of travel

Op Spd – operating speed

Spd Lm – speed limit

Trk 5 ADT – average daily 5+ axle truck traffic

Trk 5 MVM – million vehicle miles of 5+ axle truck travel

Trk ADT – average daily truck traffic

Trk MVM – million vehicle miles of truck travel

Appendix H

Notation

I - Interstate

IE - index of effectiveness

$IE_{DEC\_5\%}$ - threshold value for index of effectiveness for a p value of 0.05 testing for a significant decrease in the *after* period

$IE_{INC\_5\%}$ - threshold value for index of effectiveness for a p value of 0.05 testing for a significant increase in the *after* period

INJ – injury collision count

K – number of collisions in treatment group *before* speed increase

L – number of collisions in treatment group *after* speed increase

m – meter(s)

M – number of collisions in comparison group *before* speed increase

Max – the maximum value of all observations

Mean – sum of observations divided by the number of observations

Min – the minimum value of all observations

mph – miles per hour

MSI – Marginally Significant Increase

MVM – vehicular travel [(miles of travel)*(number of vehicles)/(1 million)]

n – number of data points

N – number of collisions in comparison group after speed increase

NMSL – National Maximum Speed Limit

NSC – No Significant Change

O – refers to road sections *after and behind* the post-mile

O - the sample odds ratio (Hauer Method)

Y_{22} - collision rate of the comparison group *after* the speed limit increase

Yr – Year (1,2,3,…10)

Z – test statistic (frequentist methodology)