INSTRUMENTATION AND EVALUATION OF DISTRICT 10 CALTRANS AUTOMATED WARNING SYSTEM (CAWS)

Evaluation of Traffic Safety Influence Based on Historical Collision Data

Prepared for the California Dept. of Transportation and California Office of Traffic Safety by Loragen Corporation, San Luis Obispo, California

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Evaluation of Traffic Safety Influence Based on Historical Collision Data

4.1 Introduction

This section of the final report examines historical traffic accident data in order to assess the safety benefits of the CAWS system. Safer conditions would generally be inferred from a reduction in the number and/or severity of accidents, both in general and when hazardous conditions are present. We consider all available archived accident, traffic, and environmental data, in addition to information on external influences and trends, before and after the system was activated and relative to equivalent control areas.

The observational nature of the problem, as opposed to a controlled experiment, presents a great challenge in isolating true cause-effect relationships amid a number of uncontrolled parameters and necessary assumptions. As discussed in Section 2, the very definition of “traffic safety” and methods for its measurement are the topic of considerable discussion in the literature. The data and results presented herein are therefore subject to multiple interpretations, and are best considered in conjunction with the findings of the other sections of this evaluation report.

We attempt to identify empirical relationships and influences on collisions by both a direct presentation of historical collision data normalized to various measures of exposure, and multivariate nonlinear modeling. Both approaches have their advantages and limitations, which will be discussed in context later.

The first and largest part of this section presents the results of an extensive study of collision frequencies and rates, considered in both broad and specialized classes, controlling in a linear sense for all relevant metrics of exposure. This analysis generally conforms to the guidelines of NCHRP Synthesis (1), and is comprehensive, possibly to the point of excessive detail. The primary measure of exposure to potential collisions is the amount of travel in vehicle-miles traveled, reported as millions of vehicle miles traveled or MVM. The opposite directions of each of the CAWS highways were used as the primary control area for comparison purposes. Two supplemental highways are also examined as additional points of comparison. The type and conditions associated with the collisions are also used as a measure of exposure in addition to MVM. Primary and secondary (caused by a previous collision) collisions are examined separately and together. Fatal and injury (F&I) collisions, property damage only (PDO) collisions, and collisions reported in the absence of road construction are isolated.

We then present results of collision rate estimation by a number of fitted exponential multivariate collision models. These models combine different highway descriptor variables in a variety of ways, in an attempt to isolate relative influences of each variable, in particular, the presence of non-presence of the CAWS.

Throughout this document, the terms collision, accident, and crash will be used synonymously.

4.2 Methodology

4.2.1 Evaluation Considerations

A very large body of published work is available on the topic of statistical methods for the utilization of accident data to evaluate traffic safety enhancements. It would be impossible to review even a fraction of the literature here. Key works that we found of particular value in formulating our approach were NCHRP Synthesis 205 (1), a compendium of papers in Transportation Research Record 1840 (2), and books and papers by Hauer (3,4) Hirst et. al., (5), Elvik (10), Evans (6) and early guidelines for evaluation of European safety projects (7). The hazards and complexities of statistical analysis methods in highway safety evaluations are well recognized, and have been documented in these works. Practical cautionary arguments common to most include the need for care in normalization to metrics of exposure, the need to isolate as best as possible the incremental effect of the safety enhancement from other effects, and the need to apply common sense to qualify numerical statistics with observable cause-and-effect relationships.

The use of collision (accident) records as the basis of a safety effects evaluation is highly prone to error. At the very start of the chain of possible error sources is the reporting of accidents. Hauer and Hakkert (8) reviewed 18 studies and concluded that police miss some 20% of injuries that require hospitalization, 50% that do not, and that perhaps 60% of reportable property-damage-only accidents are not reported.

Why are collisions so commonly used as an indicator of safety effectiveness? Because they are presumed to be a direct measure of the ultimate outcome that we seek to improve, because the are almost always available, they are quantitative, and because of the arsenal of statistical methods and computer packages that may be applied to their analysis (not always appropriately). By contrast, alternative indicators which address the precursors to accidents, such as driver behavior analyses, require specialized instrumentation and the careful design of field experiments.

Perhaps the greatest challenge in the CAWS evaluation is determine the effect of the CAWS on traffic safety (ultimately measurable in terms of accident rates, type or severity), isolated from, among other things, the natural or expected response in the absence of the CAWS. For this reason, and consistency with traditionally accepted practice, the basic structure we employ in our analysis of accident data is that of an observational before-after study with multiple comparison groups in which we attempt to isolate the incremental effect of the CAWS, controlling for all other factors and influences. We employ traditional as well as model-based statistical methods.

4.2.2 Control Methods

The overall period of observation, 1992 through 2003, is so long that a large number of ecological changes occurred, some with the potential to substantially affect collision frequencies. Risk exposure varies with many factors including roadside activity, environmental conditions, traffic characteristics, and more. At the very least, traffic volumes in both the study and control areas increased substantially over the years.

The dependency of collisions on traffic flow are well established. In all data presentations, we follow the standard practice of controlling in a linear way for these changes by normalizing raw frequency data to 1 Million Vehicle Miles traveled (MVM). As discussed by Hauer (3) and others, this is less-than-ideal because of the generally parabolic relationship of accident frequencies to traffic volume. For example, in a study on French motorways, Martin (9) found that even after normalization to the kilometer equivalent of MVMT, accident rates followed a relationship with hourly traffic volume shown in Figure 4.2.2.1, which segregates also between 2- and 3-lane highways.

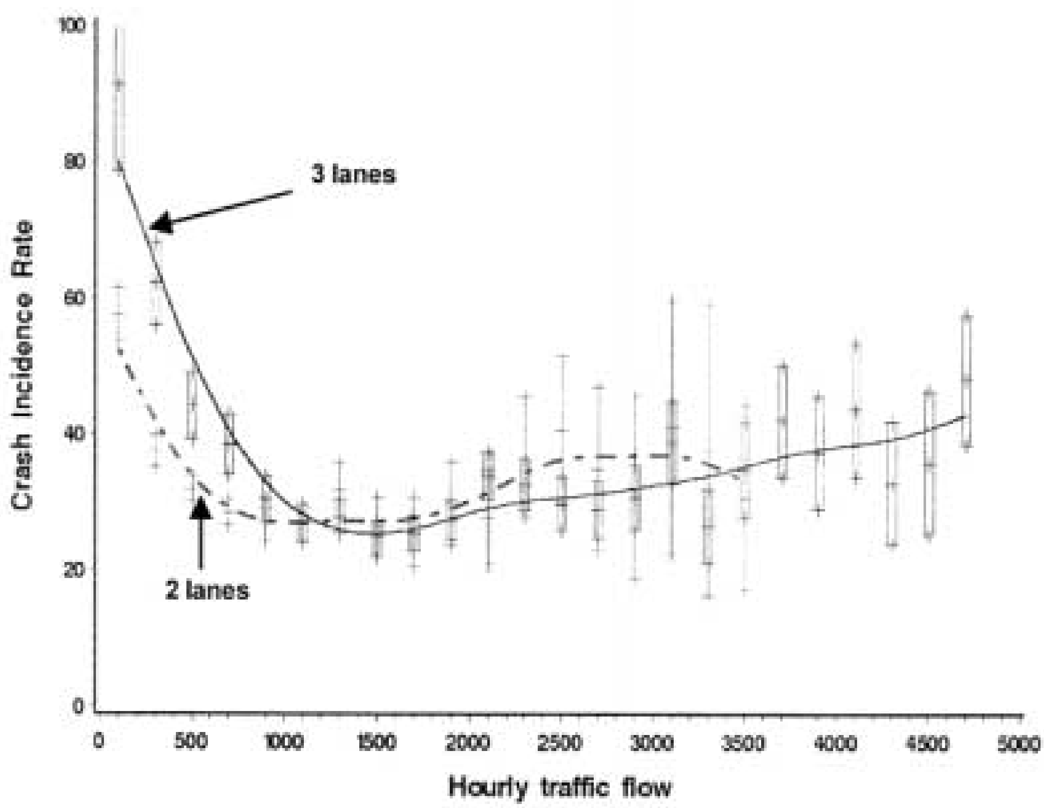

Figure 4.2.2.1. Crash incidence rates (crashes per 100 million vehicles - km) and hourly traffic flow, copied directly from (9) p. 623.

By the utilization a primary control area with nearly identical traffic volume, we attempt to minimize the nonlinear effect of normalization to MVM. We also attempt to control for each of the other factors to the extent that historical data could be obtained. For example, for accidents reported as occurring in fog conditions, the number of heavy fog days is also used as a measure of exposure in addition to a MVM calculated only for fog days. Separate rates were also developed by type of collision, e.g., fatal and injury (F&I) collisions, property damage only (PDO) collisions, and collisions reported in the absence of unusual road surface conditions, including road construction. The later was included to control for possible biases that might be introduced by having different amounts of road construction underway in the study and control sections in the years before and after the CAWS activation. Summarizing the comparison and control techniques:

- Normalize accident counts to measurable metrics of risk exposure, such as time, traffic volume, inclement weather days, and fog-days, non-construction days.
- Present data from the study area side-by-side with a control and two other comparison areas.
- Compare with an area of proximate roadways having similar weather patterns.
- Examine collisions by type and severity.
- Examine collisions as isolated, primary or secondary (related to primary).
- Fit accident data to a multivariate regression model, and infer relative influence of the CAWS from the regression coefficient.
- Verify results of statistical analyses by examination of the elements of the causal chain by which the CAWS can potentially affect traffic accidents.

Regarding the last bulleted item: Simple statistics based on historical accident data can often be misleading because they ignore the basis from which these statistics arise. Once reduced to numbers, the assumptions of the analysis or modeling process are easily forgotten, and the causal chains responsible for the results cannot be questioned. For this reason, it is important that the results of the various statistical analyses we present in this section be viewed in parallel with the observations presented in the other sections of this report. The importance of an identifiable causal chain supporting any statistical traffic safety conclusions was emphasized recently by Elvik (10), who presented a number of cases in which otherwise-valid statistical results were contradicted by flaws in the casual chains. In particular, this approach helps to isolate the phenomena we seek to observe from uncontrolled confounding factors which can easily lead to incorrect conclusions. In our evaluation of the CAWS system, we have attempted to be cognizant of this important means for qualification of our results by linking a detailed driver response analysis (Section 2), an examination of exactly with the system was doing (Section 3), and the present analysis of collision data.

The operable causal chain is:

> Hazardous condition detected by CAWS → CMS(s) activated with appropriate advisory message → driver observation to this message → driver response in some safety-enhancing way (reduced speed, increased separation, increased attentiveness) → reduced risk and severity of collision

A physical connection or valid statistical correlation between each successive points in the chain is required to validate any conclusions inferred from purely numeric accident data. In this causal chain we allow the possibility of an externally non-measurable driver response, e.g., increased attentiveness, which would largely manifest as reduced driver reaction time. We caution, though, that this is a weak link: e.g., even a substantial reduction in driver reaction time due to improved attentiveness can have no little positive safety effect if the driver exhibits high risk-taking behavior (11), such as following too closely for their speed, or conversely, excessive speed for the visibility conditions.

4.3 Area and Period of Observation

4.3.1 Study, Control and Comparison Areas

Figure 4.3.1.1 is the Caltrans as-built project plan map for the CAWS. A physical map of the area is shown in Figure 4.3.1.2. The CAWS study area, in which the CAWS is operative, includes the westbound direction of State Route 120 between State Route 99 and Interstate 5 (6.4 miles), and the southbound direction of Interstate 5 between French Camp and Interstate 205 (9.9 miles), converging at the San Joaquin River in an area locally known as the Mossdale Y. The CAWS serves just one direction of travel of each highway, owing to its genesis as a means to reduce fog-related accidents at and near the merge point of these two freeways, and area known for recurrent fog and traffic congestion. As detailed in Section 3, strategically spaced throughout this area are the CAWS sensing and control elements: 9 remote weather stations used for fog and wind detection, 36 traffic monitoring stations used to detect traffic conditions, and 9 changeable message signs (CMSs) used to notify drivers of these conditions. The identical but opposite directions of both highways are employed for comparison purposes as a control area, used for both direct comparison and normalization purposes.

In many of the data presentations, an 8.01-mile portion of State Route 99 between State Routes 120 and 219 and a 12.74 portion of Interstate 205 between Interstate 5 and the Alameda County line, were included in the analysis as supplemental control areas. These highways were selected because they include heavy commute directions and because of the inclusion of the SR-120/SR-99 interchange and the I-5/I-205 interchange, features associated with high traffic turbulence. The selected section of SR-99 is a high-volume north-south truck route, which also serves local commuters and commerce in the central valley. It is an older state highway, dating to 1926, recently authorized as an interstate highway but not yet signed as such. A number of construction projects are planned for SR-99 under SAFETEA-LU for the immediate future to improve safety and capacity (12). The selected section of Interstate 205 is a high-

volume commuter and commercial route between the San Francisco Bay area and the Central Valley, which is scheduled in 2005 to be widened to six lanes under TCRP Project #107.

In the multivariate model-bases analysis conducted in §4.13, these additional highways will be used as the major part of the non-CAWS comparison area. Also for the model-based analysis only, an additional small comparison section is taken along 1.16 miles of Interstate 5 north of French Camp Turnpike, just upstream of where southbound drivers enter the CAWS influence area. The SR-99 and I-205 comparison highways are shown in the maps of Figure 4.3.1.3 and Figure 4.3.1.4.

Figure 4.3.1.1. Map of CAWS Deployment on I-5 and SR-120, from Caltrans As-built Plans.

Figure 4.3.1.2. Location of CAWS Study and Control Highways on I-5 and SR-120 converging at the Mossdale Y.

Figure 4.3.1.3. Supplemental control highway: I-205 between I-5 and Route 580 through Tracy, California.

Figure 4.3.1.4. Supplemental control highway, SR-99 between SR-120 in Manteca and SR-219 (Kiernan Ave.) in Salida.

Table 4.3.1.1 is a 2002 list of average annual and peak traffic totals at all traffic count stations located in the study, control and comparison areas, from (13). Units are Average Annual Daily Traffic (AADT) measured either over the entire year or extrapolated to an equivalent annual total. Our particular concern in examining these data is the relative traffic volumes in each area, since volume is known to be a strong but nonlinear (parabolic) predictor of collision rates. This qualification is critical to the fair comparison of annual collision totals from different areas normalized to MVM (3). Areas of greatly dissimilar volume are generally considered questionable for comparison purposes, although of necessity, there is sometimes no choice.

Table 4.3.1.1. 2002 AADT comparison at count stations located on study, control and comparison highways, from (13).

			South and West			North and East		
Route	Mile	Description	Peak Hr	Peak Mo	AADT	Peak Hr	Peak Mo	AADT
5	14.83	MOSSDALE, JCT. RTE. 120 EAST	11500	152000	143000	9200	106000	101000
5	17.52	LATHROP, LATHROP ROAD	8600	81000	68000	9200	84000	71000
5	20.95	FRENCH CAMP OVERCROSSING/ EL DORADO	9500	87000	73000	8900	81000	68000
5	21.44	MATHEWS ROAD	8900	81000	68000	9000	83000	70000
5	22.51	FRENCH CAMP TURNPIKE	9000	83000	70000	9500	93000	84000
120	0.49	MOSSDALE, JCT. RTE. 5; BEGIN FREEWAY				5800	74000	70000
120	1.33	WEST YOSEMITE AVENUE	5800	74000	70000	5000	60000	58000
120	3.32	AIRPORT WAY	5000	60000	58000	4900	59000	56000
120	5.31	MANTECA, MANTECA ROAD/MAIN STREET	4900	59000	56000	4700	55000	48000
120	6.87	SOUTH JCT. RTE. 99	4700	55000	48000			
99	22.56	SALIDA, JCT. RTE. 219 EAST; BROADWAY	12100	111000	106000	12700	116000	110000
99	24.27	HAMMET ROAD	12700	116000	110000	12100	116000	108000
99	24.75	STANISLAUS COUNTY -SAN JOAQUIN COUNTY	12100	116000	108000	12100	116000	108000
99	0.89	RIPON, MAIN STREET	12100	116000	108000	13700	116000	115000
99	1.71	MILGEO AVENUE	13700	116000	115000	14100	125000	115000
99	2.37	JACKTONE ROAD	14100	125000	115000	13900	123000	119000
99	5.82	SOUTH JCT. RTE. 120	10900	112000	105000	10200	91000	86000
205		ALAMEDA COUNTY						
205	0.21	JCT. RTE. 580; BEGIN FREEWAY				7700	115000	106000
205	0.45	ALAMEDA-SAN JOAQUIN COUNTY LINE	7800	115000	110000			
205	0	ALAMEDA-SAN JOAQUIN COUNTY LINE				7800	115000	110000
205	1.38	PATTERSON PASS ROAD	7800	115000	110000	8600	119000	119000
205	3.37	OLD ROUTE 50	8600	119000	119000	9000	96000	91000
205	8.13	TRACY, MAC ARTHUR DRIVE	9000	97000	92000	6800	102000	92000
205	12.69	JCT. RTE. 5	6800	102000	92000			

In Table 4.3.1.1, ‘Mile’ is the post mile at which the count station is located. ‘Peak Hr’ is an estimate of the traffic count for the hour of peak traffic. ‘Peak Mo’ is an annualized estimate of AADT for the peak traffic month of the year. AADT (Annual average daily traffic) is the total volume for the year divided by 365 days. The traffic count year is actually from October 1st through September 30th.

And as can be seen in Table 4.3.1.2, with the exception of the Mossdale Y (I-5 junction with SR-120) section of the study area, the overall AADT values are roughly equivalent in the study and control directions of the I-5 and SR-120. However, the high volumes reported for the Mossdale Y section are due to the conjunction of I-5 and SR-120 into a common 5-lane highway for this one-mile section, combining the three southbound lanes of I-5 with the two west-bound lanes of SR-120. It therefore carries the traffic of both highways, until bifurcated again at the junction of I-205, after which I-5 again reverts to three southbound lanes. On a per-lane basis, traffic volume in the Mossdale Y section is

equivalent to the other (through) sections of I-5 and SR-120. AADT on the SR-99 and I-205 comparison highways in both directions are significantly higher than either the CAWS study or control directions.

Focusing on historic trends in the study and control directions of the CAWS, normalized travel volume viewed as MVM over the complete study and control directions of the CAWS highways have been historically well balanced, as indicated by Table 4.3.1.2. The physical characteristics of the study and control directions of the CAWS highways are almost identical in terms of length, number of lanes, speed limits, static signage, grade, number of on/offramps, and the commuter population.

Table 4.3.1.2. Traffic volume comparison, presented as MVM (Million Vehicle Miles) traveled, study v control directions of I-5 and SR-120.

	10^6 Vehicle-Miles, CAWs Study Direction	10^6 Vehicle Miles, CAWS Control Direction
1992	161.32	163.18
1993	164.72	161.55
1994	159.88	158.63
1995	160.53	157.93
Jan–Oct 96	159.43	155.24
1997	192.44	191.96
1998	187.23	197.63
1999	183.00	219.22
2000	187.32	224.63
2001	244.26	243.98

Although overall MVM are nearly identical between the study and control areas, the traffic patterns differ somewhat. The study direction is characterized by a morning commuter traffic peak, while the control direction experiences a corresponding PM commuter traffic peak. This is important to note since fog is a much more frequent phenomena in the early morning hours rather than during the afternoon[1]. Peaks occur in both directions in both the AM and PM. In the morning, the more heavily traveled direction is towards the San Francisco Bay Area. During the evening, the pattern reverses, with the control directions of the CAWS highways experiencing nearly identical volume profiles. The AM and PM peaks in each direction, dominated by commuters to the San Francisco Bay Area, are partially balanced by a population of commuters traveling north on I-5 from the central valley to the Sacramento area, less than an hour north. I-5 is also a primary north-south corridor of interstate truck commerce in California, which sustains a continuously high level of large-vehicle traffic at all hours.

[1] System was motivated by a legal action against the State of California related to problems with safety in heavy fog conditions. System is also capable of alerting drivers to hazardous conditions that are not unique to the AM commute, such as slow or stopped traffic ahead.

In the overall analysis, we examine the CAWS study and control directions, as well as the two external control areas, considering the entirety of each area.

We then examine and compare just the study and control directions of the CAWS by division into three areas of common characteristics: 1) SR-120, 2) I-5 north of SR-120, and 3) I-5 south of SR-120, and using the supplemental SR-99 and I-205 for comparison. Analyzing traffic data in this manner identifies those segments that might be problem areas.

Later, to support the multivariate model-based analysis, the supplemental control areas will be used as non-CAWS baseline segments in addition to the control direction of the CAWS. All segments will be subdivided into one to two mile-long directional segments, in a particular year and time period.

4.3.2 Periods of Observation and Data Sources

The CAWS automated warning system was activated in November 1996. This analysis of the long-term impact on traffic safety compares accident, volume, and environmental data for two study periods. All collision data were obtained from the Caltrans TASAS (14) and California Highway Patrol SWITRS (15) databases, statewide repositories of data including nearly all fatal and injury (F&I) motor vehicle traffic collisions, and a large portion of property-damage-only (PDO) collisions. It is recognized that a substantial number of property damage collisions go unreported, although logic suggests a higher reporting rate for collisions on freeways. The Caltrans TASAS Unit provided all coded collisions for the selected highway sections covering the before and after time periods in the form of a text file.

For both sources, data is generally retired after 10 years, which limited our starting point for the 'before' period to 1992. The before period is the 58-month period before system activation, January 01, 1992, through October 31, 1996. Except for the handling of the two-month period immediately after the CAWS was first activated in November 1996, the before period will remain constant in all data presentations and analyses. The 'after period' will vary slightly among the data presentations in this section. Accident data does not generally appear in complete form in these databases for a minimum of six months, and in some cases over a year afterwards. Data is not necessarily added in time order. SWITRS programmers enter high-severity accidents from CHP records first, then progressively add more routine data as time permits. All TASAS data are then derived from SWITRS data with the addition of post mile information, which must be manually researched for many accidents.

The two months November and December 1996 are considered transition months following the initial activation of the CAWS, a period of driver familiarization and system debugging which is not considered representative of the true capabilities of the system. In some cases it is excluded completely from the dataset, while in others these two months are treated as part of the "before" period simply as a matter of numeric convenience. These slight differences were the result of the development of this analysis by multiple authors at different times over a period of three years, including the response of the evaluators to

requests by agency reviewers following a preliminary (2002) release of this section to investigate specific attributes of the data. In all cases, a more-than-adequate after period is considered, a minimum of six years.

In addition to counts of annual total, injury, and fatal collisions within each highway segment during each time period, a variety of detailed collision characteristics were tabulated, including:

- Counts by type of collision,
- Counts by type of object hit (for hit-object collisions),
- Counts by weather at the time of collision (clear, cloudy, rain, fog,…),
- Counts by weather-related surface condition (dry, wet, slippery,..),
- Counts by number of parties involved (one, two, three or more),
- Counts by violations involved,
- Counts by unusual surface conditions (construction, reduced width, holes/ruts, loose material,…),
- Counts by lighting condition (day, dusk, dark).

In each case, total and F&I collisions were tabulated separately. Some of these detailed breakdowns were used in the data analysis; for example, relationships were developed excluding collisions occurring in the presence of unusual road surface conditions, such as construction, on the grounds that possible differences in collision rates under unusual road conditions should perhaps not be attributed to CAWS.

Traffic volumes reported as AADT in Table 4.3.1.1 were obtained from the Caltrans Traffic Data System on-line database http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/. This excellent resource provides online-data in html format for the years 2002-2005, and downloadable Excel ® format data starting in 1992. When required, daily and hourly traffic counts were obtained from the Traffic Operations, Electrical Systems Branch of the Caltrans District 10 office in Stockton, CA. This unit of Caltrans is responsible for the collection and dissemination of traffic counts on the State Highway System. In the CAWS study direction all traffic count stations were also, after 1996, components of the CAWS traffic monitoring station network (but not the inverse).

AADT is converted into total volume by multiplying by the number of days of exposure in a year (usually 365). Total volume is used to estimate total travel (MVM) by multiplying by the length of each section between the mile markers. Totals for the study, control and comparison areas are then generated by summation of MVM from each of these segments.

The collision data were reduced and analyzed using various software including the Minitab Statistical Software, SAS (Statistical Analysis System), and Excel. The full data set for all areas, spanning January

1992 through June 2003, contained 2321 “before” collisions of which 930 involve fatalities and injuries (F&Is) and 6086 “after” collisions, of which 2204 are F&Is.

4.4 All-Weather Accident Rates

Collision rates are compared in the study and control directions of the CAWS area, as well as the two external comparison areas, during the periods before and after implementation of CAWS, while controlling for the influence of many different highway, traffic, and environmental factors. In this analysis, the southbound direction of SR-99 and the westbound direction of I-205 are combined to serve as one supplemental control area, and the northbound direction of SR-99 and the eastbound direction of I-205 are combined to serve as another. Along with the primary CAWS control area, northbound I-5 and eastbound SR-120, these areas will be treated as control areas for comparison purposes.

4.4.1 Overall (All-weather) Collisions

Table 4.4.1.1 shows the total number of collisions reported in all types of weather in the study direction (westbound lanes of SR-120 and southbound lanes of I-5) and the control direction on those highways and in both directions on the two additional control freeways. The collision rates for each year are computed as the number of collisions divided by the number of vehicle miles traveled. Note that 1992 does not include data for SR 99 and I-205, and that only the first six months of 2003 are included.

Table 4.4.1.1. Total All-Weather Collisions and Collision Rates.

Year	Study Direction (5SB/120WB)		Control Direction (5NB/120EB)		Comparison Highway (99SB/205WB)		Comparison Highway (99NB/205EB)	
	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)
1992	79	0.48	100	0.51				
1993	84	0.5	101	0.51	147	0.59	160	0.65
1994	82	0.49	119	0.6	149	0.56	164	0.62
1995	96	0.56	152	0.75	165	0.62	199	0.75
1996	90	0.49	96	0.45	168	0.62	170	0.63
Ann Avg.	86.2	0.5	113.6	0.56	157.3	0.6	173.3	0.66
System Activation								
1997	119	0.64	147	0.67	224	0.8	271	0.96
1998	134	0.72	138	0.63	237	0.84	249	0.88
1999	144	0.77	157	0.71	206	0.71	331	1.09
2000	240	1.21	187	0.8	254	0.81	371	1.19
2001	203	0.99	179	0.75	269	0.72	428	1.15
2002	164	0.72	209	0.79	251	0.64	472	1.2
Jan-Jun 2003	68	0.58	104	0.76	136	0.7	194	1
Ann Avg.	162.9	0.8	175	0.73	244.7	0.75	358.6	1.07
Increase	89.0%	60.0%	54.0%	30.4%	55.6%	25.0%	106.9%	62.1%

Figure 4.4.1.1 summarizes and compares the annual collision rates from Table 4.4.1.1 for the study and control directions and the two supplemental control areas, for each year of data. The leftmost bar for each year indicates the study direction, served by the CAWS, while the other three bars indicate the control facilities.

In both the study and control directions of the study area, there is a noticeable increase between the before period (1992 - 1996) and the after period (1997 - 2003), both in the annual average collision total and the annual average collision rate (collisions normalized to MVM). However the increase was greater in the study direction, with the annual average collision rate (per MVM) increasing from 0.50 before CAWS to 0.80 after the CAWS, while in the control direction it increased from 0.56 before to 0.73 after.

Two major changes in traffic happened near the end of the before period which may have had an impact on collision rates in all areas. The first, and most significant, change is that in late 1995 (according to Stockton CHP) the speed limits on freeways were increased from 55 MPH to 65-70 MPH. The speed limit signage in the CAWS area was actually changed in January 1996. In a report to Congress, the National Highway Traffic Safety Administration (NHTSA) stated that California freeways where speed limits were increased from 65 MPH to 70 MPH suffered a 12.1% increase in fatal collisions and a 3.3% increase in injury collisions (16). All freeways that increased speed limits had an increase of 4.1% for all types of collisions.

In addition, the Dot-Com boom coincided with the after period of the study, bringing increased traffic and lengthening the commute distances of many travelers. Increasing numbers of Bay Area commuters moved to the Valley in search of reasonably priced housing, generally adding to the stress levels of commuting throughout the area. Although it is speculative, these changing conditions could have served to increase collision rates during the after period and may be reflected in the comparisons shown. It appears that the Dot-Com boom peaked around the year 2000, and began to ebb in the year 2001 (17). By 2002, many of the Dot-Com businesses that had sprung up in the Bay Area had succumbed to bankruptcy, and some of the related traffic load may have been alleviated.

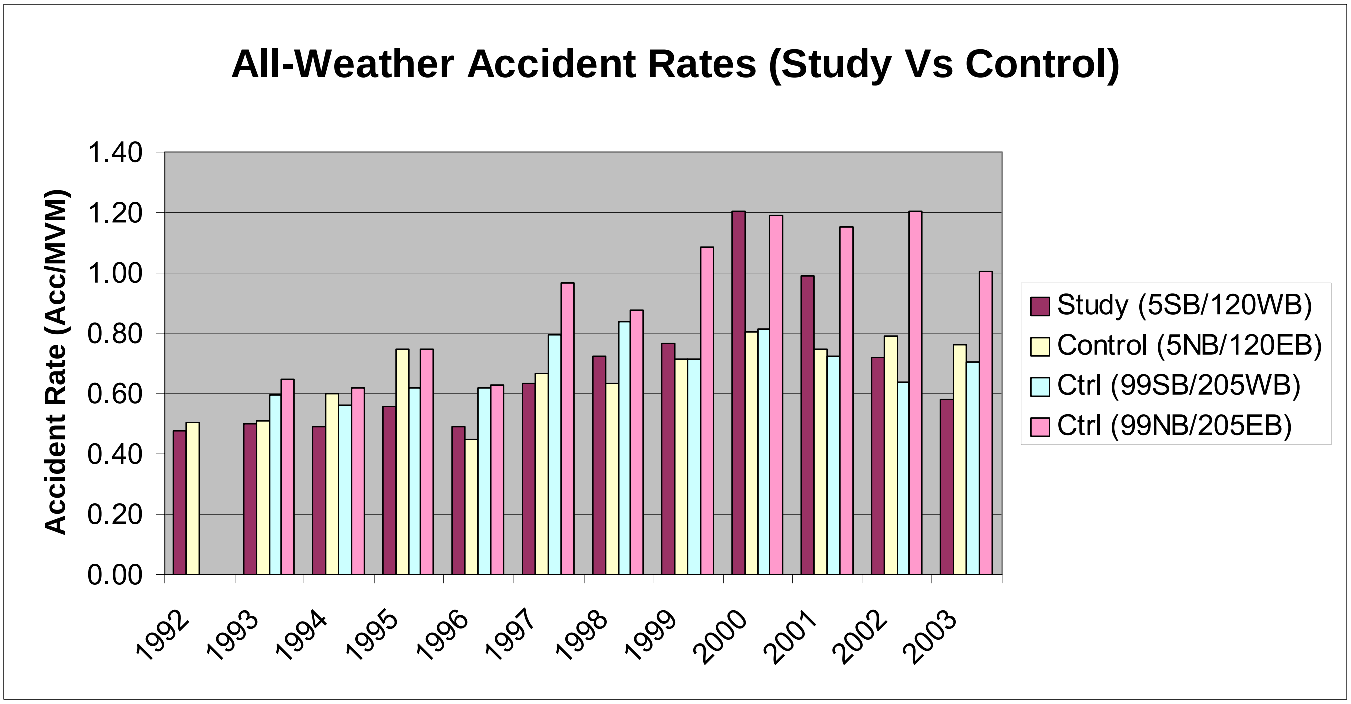

Figure 4.4.1.1. Annual All-Weather Collision Rates for Study and Control Facilities.

In any case, Table 4.4.1.1 and Figure 4.4.1.1 show that numbers of collisions and accident rates generally increased about the time of the CAWS activation. The largest increases occurred in the study direction (5SB/120WB) and in one direction of the control areas (99NB/205EB). The accident rate increase in the study direction is most pronounced in 2000 and 2001, falling back to below the other areas in the first six months of 2003 (the last available data).

A structural-repair construction project took place on I-5 affecting both the control and study direction of the CAWS intermittently over the course of 2 ½ years. This project was approved in May 1999, and completed in October of 2001. Construction activities included the installation of CMSs in the northbound (control) direction of I-5, and trenching for power for these facilities along the median from French Camp Road to just South of French Camp Slough. (The evaluation test site at French Camp Slough benefited from this power conduit). Additional construction took place in the northbound I-5 direction following the destruction in 2002 of one of the new northbound I-5 CMSs by a truck collision. This left the evaluation test site at French Camp Slough without power for a period of about six months, although it did not affect the operation of the CAWS. A brief period of construction affecting only the study direction of the CAWS occurred in late 2002, with the addition of a service lane to the median on southbound I-5 between Mathews Road and French Camp Slough. These events may have had an influence on accident rates in these areas during those years.

Referring to Table 4.3.1.1, high traffic volumes may have been a factor in the particularly high collision rates in the 99NB/205EB control area, especially during recent years. The scheduled upcoming lane additions and modifications to these highways were probably justified by these numbers.

The aggregate before-after affect in the total accident rates for the four sections is shown in Figure 4.4.1.2. This figure reinforces the conclusion that collision rates generally increased in all areas about the time of the CAWS activation. The study direction on 5SB/120WB has the second largest jump among the four areas, clearly dominated by 2000 and 2001.

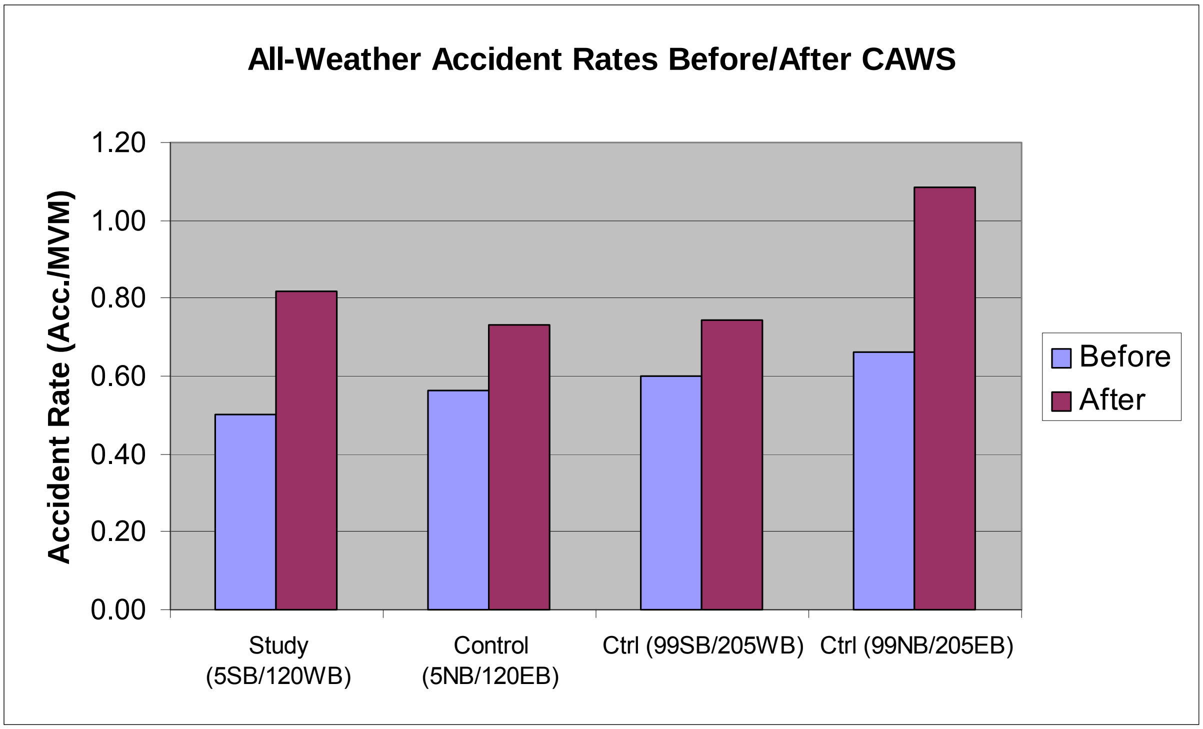

Figure 4.4.1.2. Before-After Comparisons for Total Accident Rates.

4.4.2 Accident Severity

Trends in collision severity are also of great concern. Table 4.4.2.1 summarizes the annual trends in fatal and injury collisions and collision rates for the study direction and the three control sections.

Table 4.4.2.1. All-Weather Fatal and Injury Collisions and Collision Rates

Year	Study Direction (5SB/120WB)		Control Direction (5NB/120EB)		Comparison Highway (99SB/205WB)		Comparison Highway (99NB/205EB)	
	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)
1992	30	0.18	44	0.22				
1993	31	0.18	38	0.19	56	0.23	68	0.27
1994	24	0.14	53	0.27	64	0.24	59	0.22
1995	40	0.23	58	0.29	64	0.24	91	0.34
1996	29	0.16	39	0.18	69	0.25	73	0.27
Ann Avg.	30.8	0.178	46.4	0.23	63.25	0.24	72.75	0.275
System Activation								
1997	52	0.28	55	0.25	95	0.34	94	0.33
1998	39	0.21	54	0.25	77	0.27	87	0.31
1999	54	0.29	53	0.24	68	0.24	126	0.41
2000	76	0.38	78	0.33	89	0.29	143	0.46
2001	67	0.33	75	0.31	98	0.26	158	0.43
2002	66	0.29	85	0.32	87	0.22	161	0.41
Jan-Jun 2003	25	0.21	37	0.27	44	0.23	61	0.32
Ann Avg.	57.7	0.314	67.7	0.32	86	0.297	127.3	0.427
% Increase	87.38%	76.57%	45.94%	39.13%	35.97%	23.81%	74.96%	55.32%

Figure 4.4.2.1 shows the trends in annual collision rates based on the data from Table 4.4.2.1. Comparing the complete after and before periods, F&I collision rates increased 77% in the CAWS study direction, compared with 39% in the control direction, and 24% and 55% on the each direction respectively of the comparison highway. The trends are similar to those for total collisions shown in Table 4.4.1.1, except that the jumps in the collisions rates in the study direction for 2000 and 2001 are not as pronounced as for total collisions.

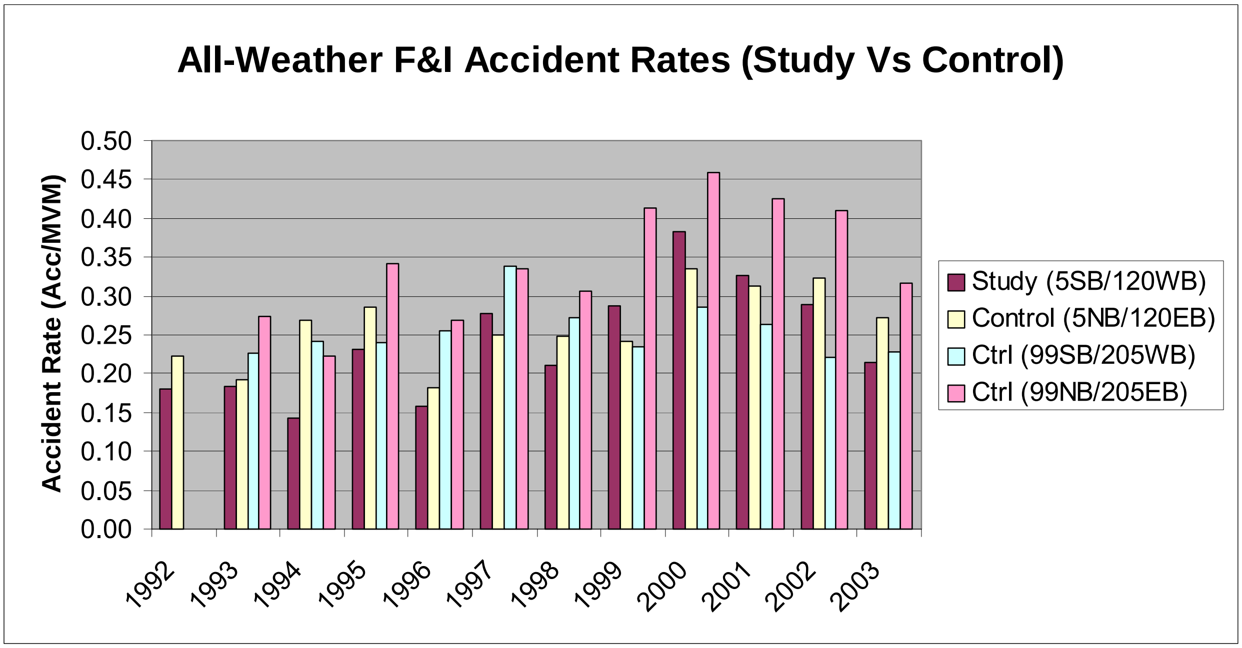

Figure 4.4.2.1. Annual Fatal and Injury Collision Rates for Study and Control Areas.

The corresponding before-after comparisons for the aggregate fatal and injury collision rate appear in Figure 4.4.2.2. These generally appear similar to the previously shown comparisons for total collisions.

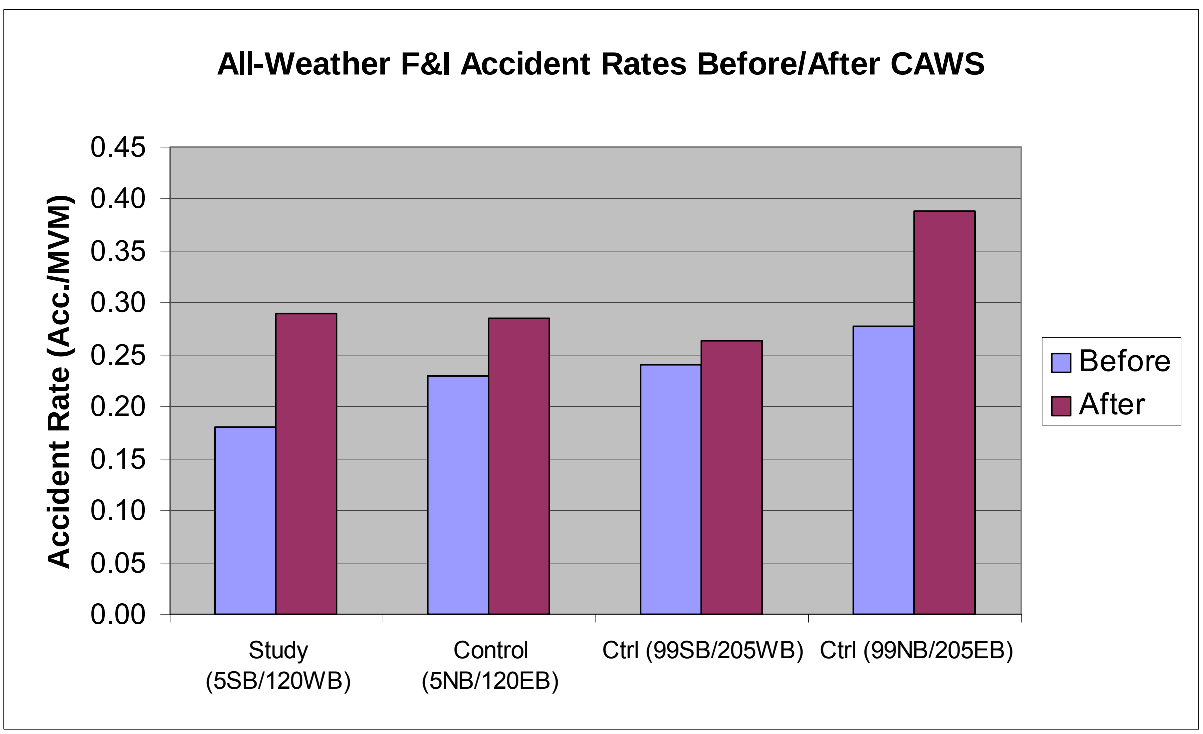

Figure 4.4.2.2. Before-After Comparisons for F&I Accident Rates.

4.5 Localized Observations

Where are the collisions occurring? Some sections of both the study and control directions of the CAWS generate much higher accident frequencies and rates than others.

4.5.1 A Close-up View of Accident Density

In the following graphics, we subdivide the study and control directions of the CAWS into very small sections, each approximately 0.25 miles in length, in an effort to identify the ‘problem’ areas.

Figure 4.5.1.1 (a) is map of the study directions of the CAWS highways color-coded for accident frequency during the 58-month before period January 1992 – October 1996 inclusive. Figure 4.5.1.1 (b) shows the corresponding color-coded map for the control directions of these highways. Figure 4.5.1.2 (a) and (b) show equivalent information for an equal time period immediately after the CAWS, November 1996 – August 2001 inclusive. Locations of fatal accidents are indicated on all maps by red stars.

These maps reveal clearly the problem areas. Prominently featured is the southbound Mossdale Y of the study area, especially immediately after the merge point of traffic from westbound SR-120. The figures show that this area was problematic before the CAWS, but became much more so in the years immediately after the CAWS. This junction is also a problem in the control direction, but to a lesser extent and approximately the same before and after the CAWS. Fatal accidents increased from four to fourteen in the study directions, while in the control directions, fatal accident increased from eleven to twelve.

A smaller concentration of accidents appears to be clustered between the first and second CMS of the CAWS system in the study direction, and slightly north of this in the control direction. On and offramps for French Camp Road are located in this area affecting both the study and control directions. A small truck stop is located near this undercrossing. Trucks enter traffic on I-5 by accelerating slowly up elevated onramps contributing to a greater local speed differential in both directions at this location.

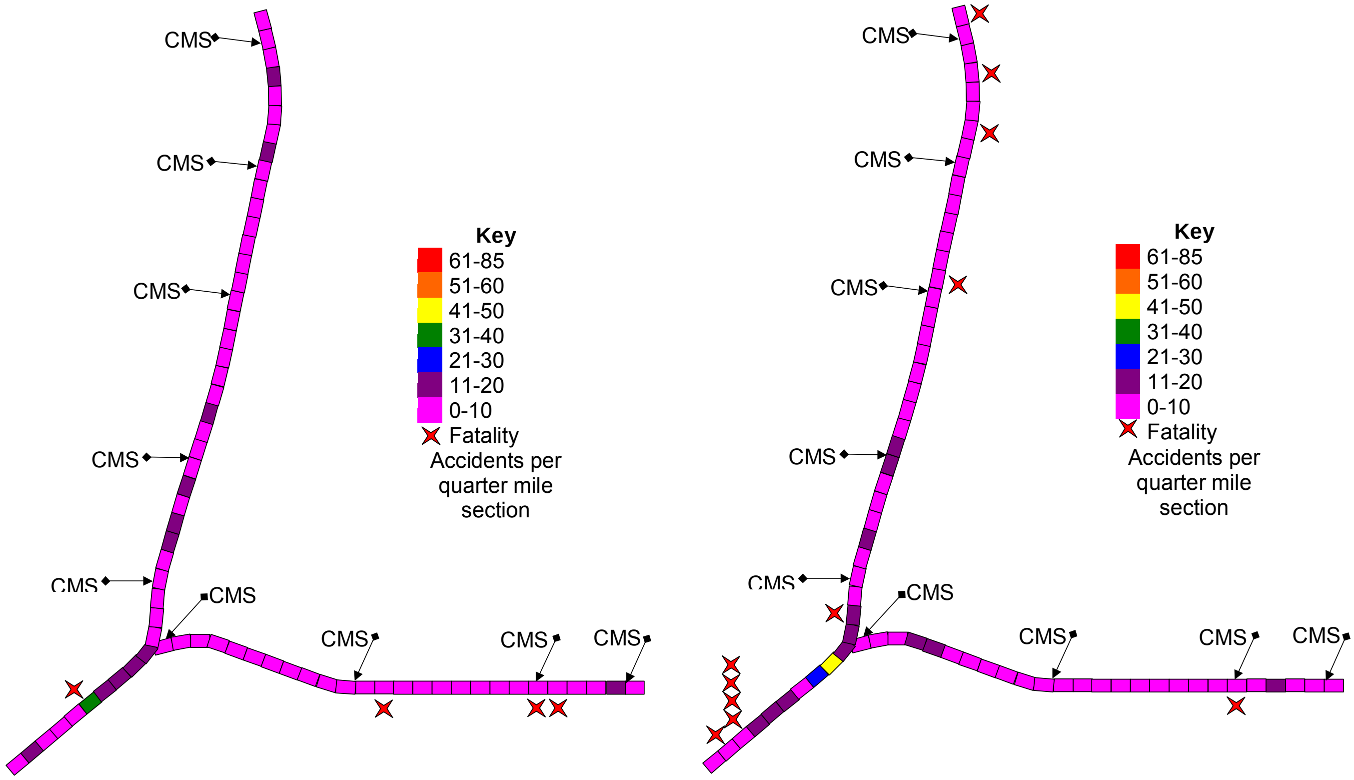

Figure 4.5.1.1. Overall accidents, before period. (a) study direction, left; (b) control direction, right.

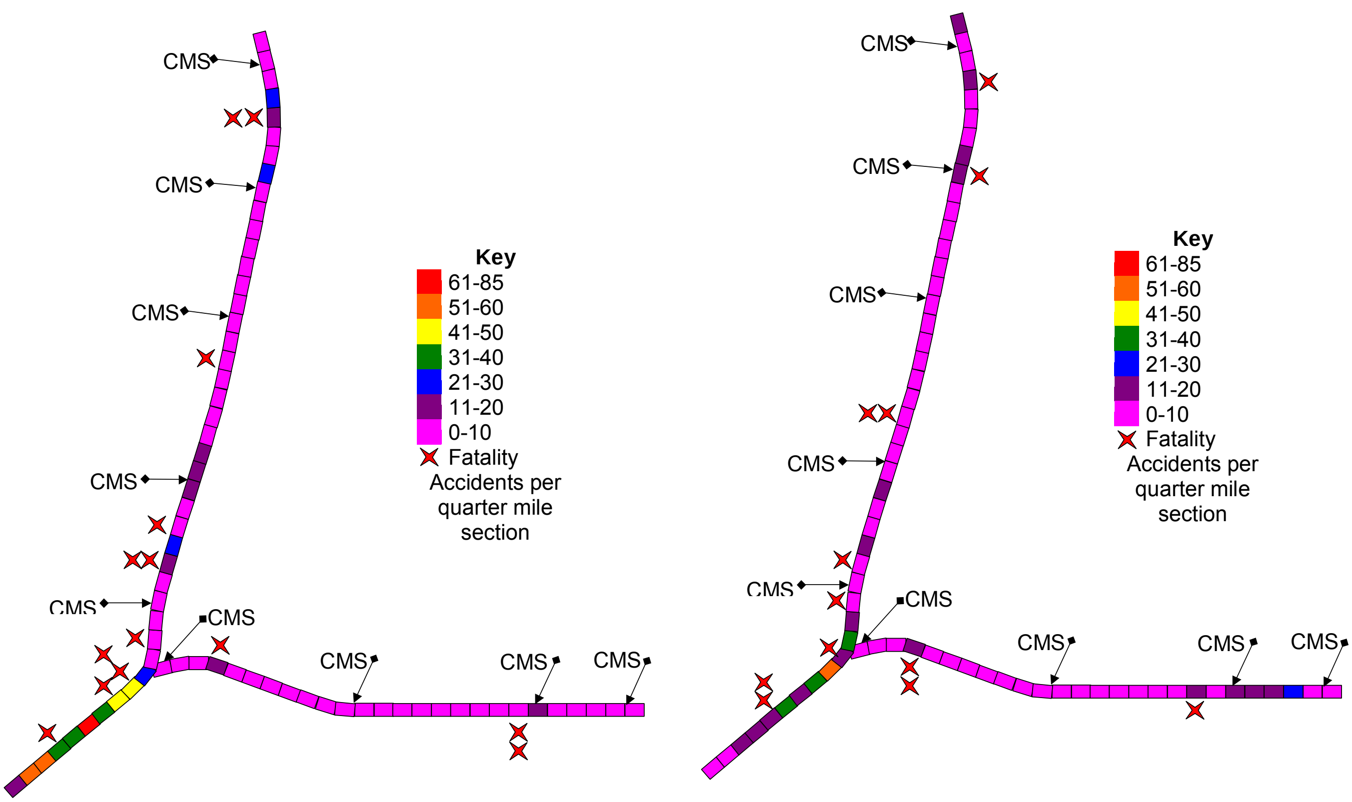

Figure 4.5.1.2. Overall accidents, after period. (a) study direction, left; (b) control direction, right.

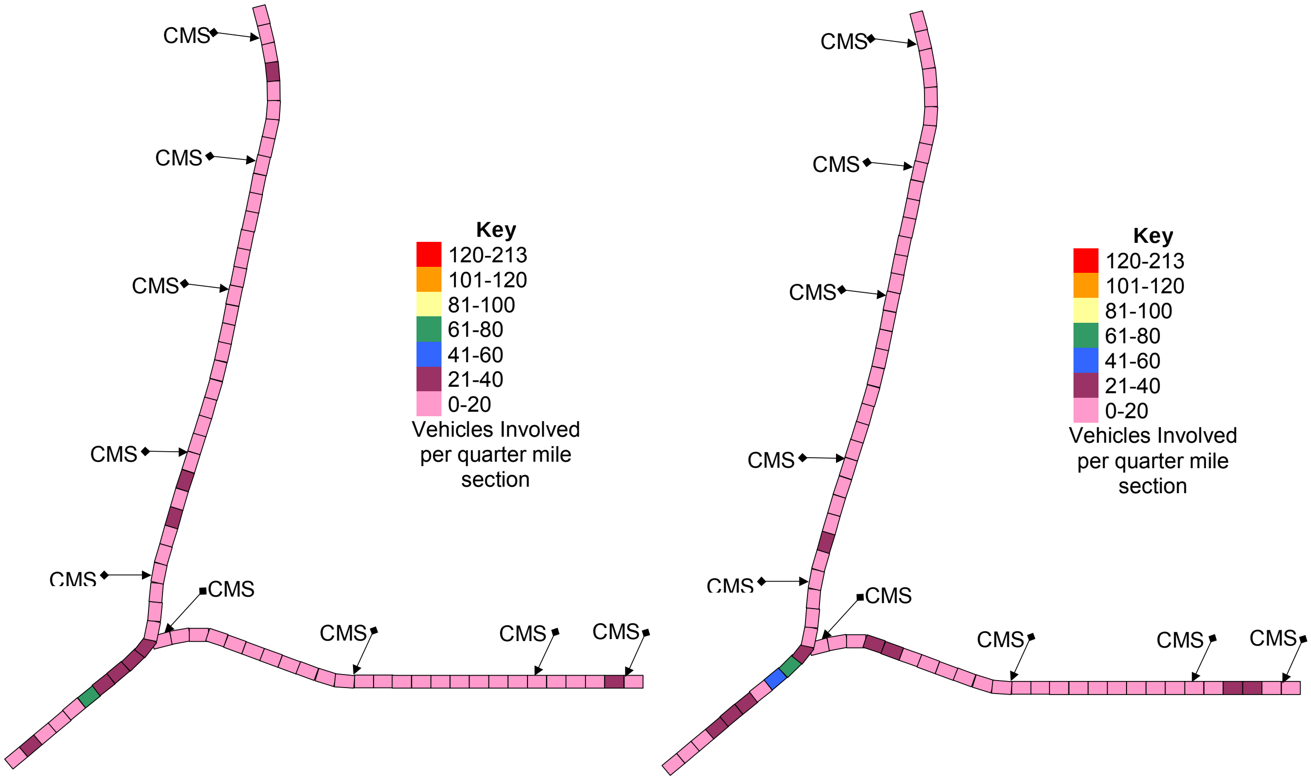

Figure 4.5.1.3. Vehicles involved in accidents, before period. (a) study direction, left; (b) control direction, right.

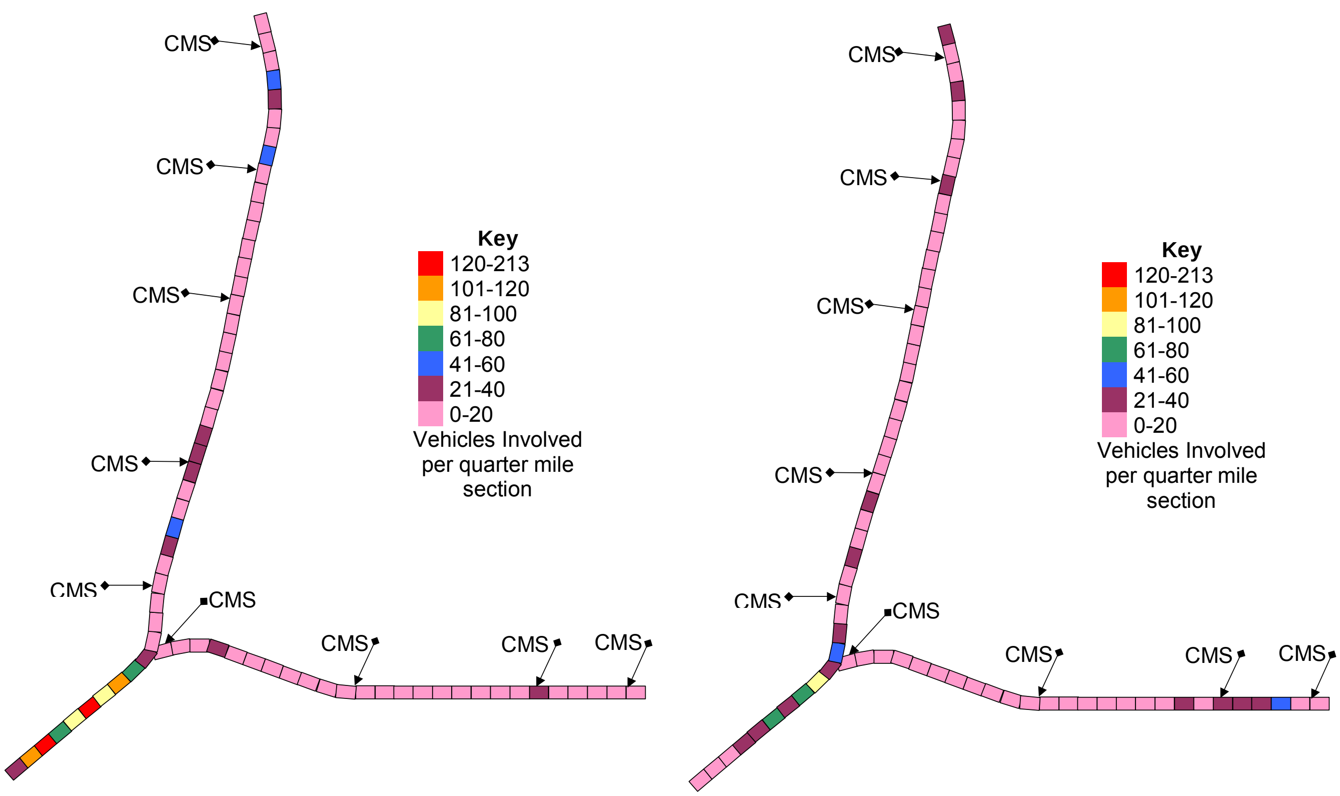

Figure 4.5.1.4. Vehicles involved in accidents, after period. (a) study direction, left; (b) control direction, right.

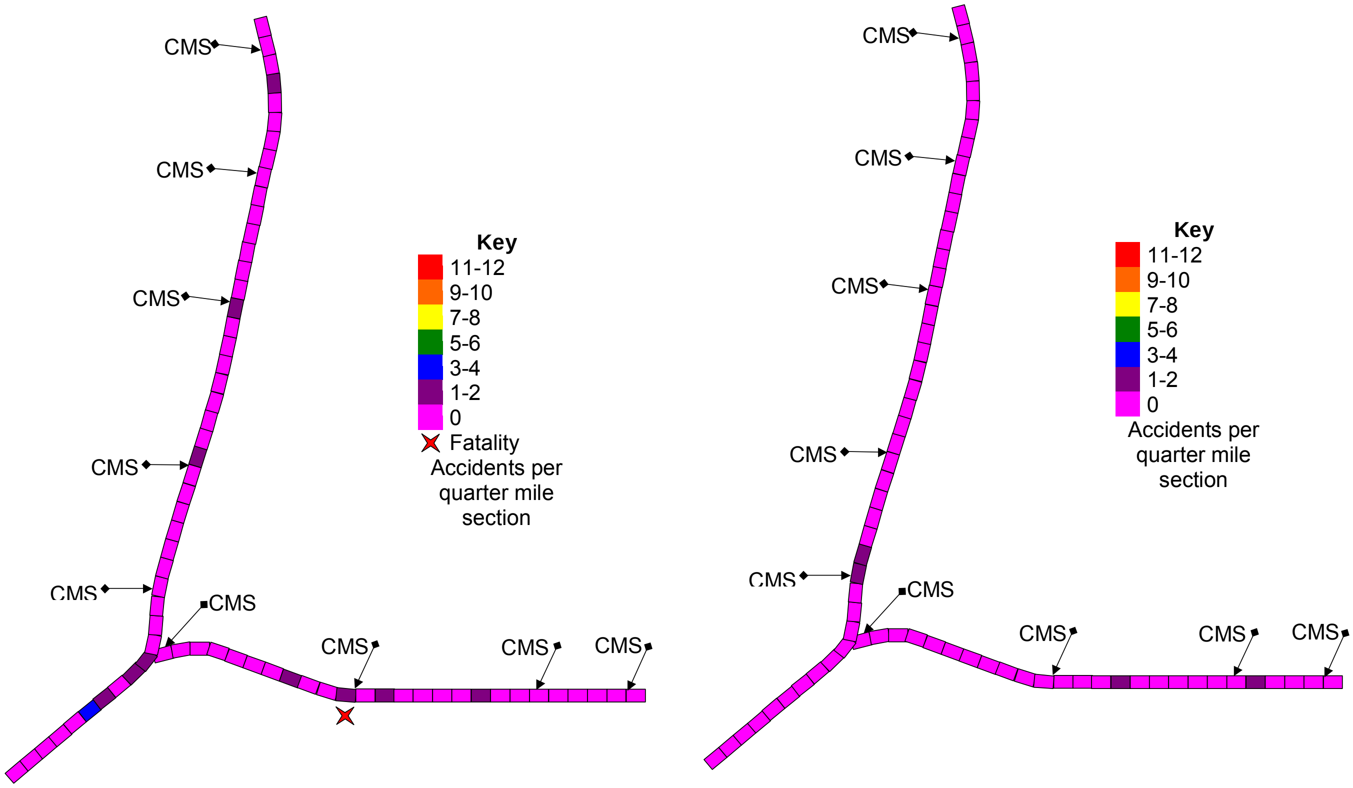

Figure 4.5.1.5. Accidents in fog, before period. (a) study direction, left; (b) control direction, right.

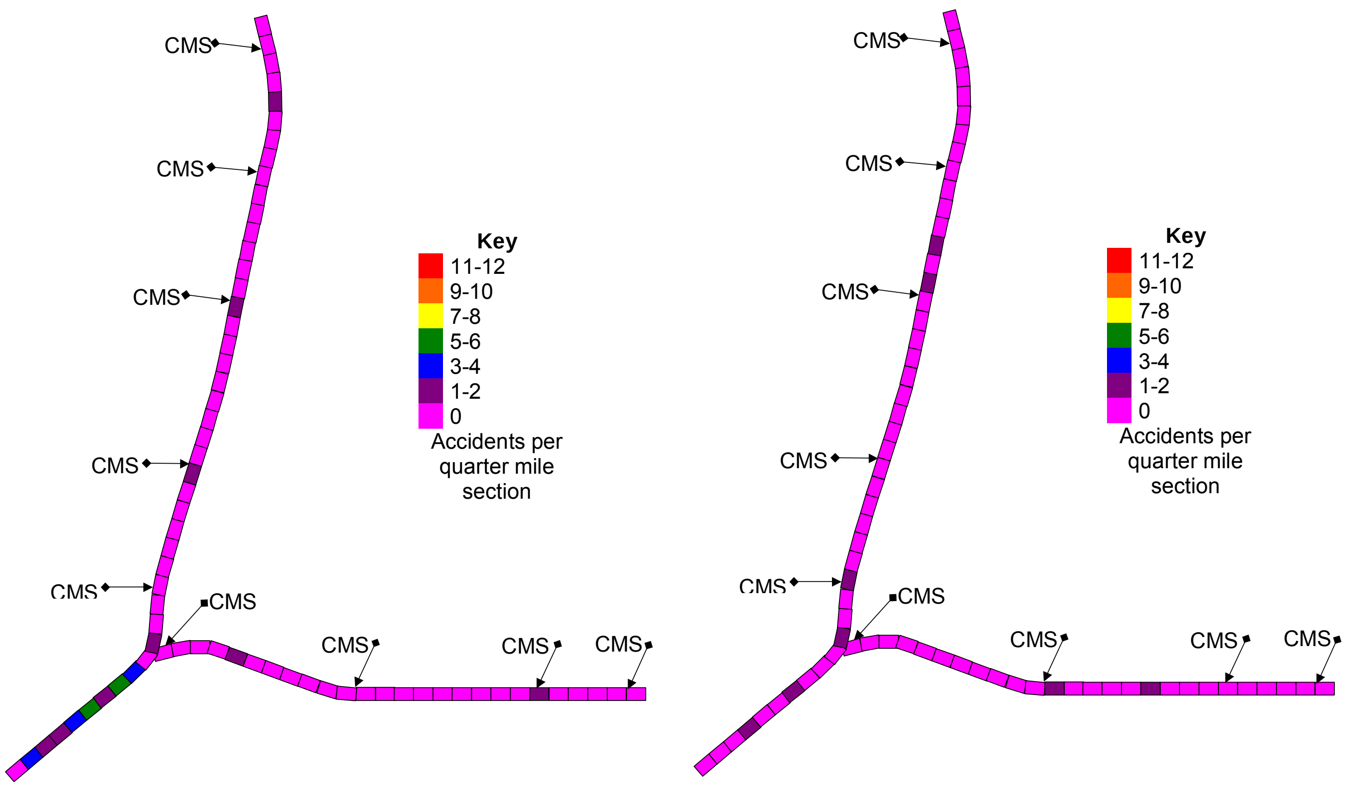

Figure 4.5.1.6. Accidents in fog, after period. (a) study direction, left; (b) control direction, right.

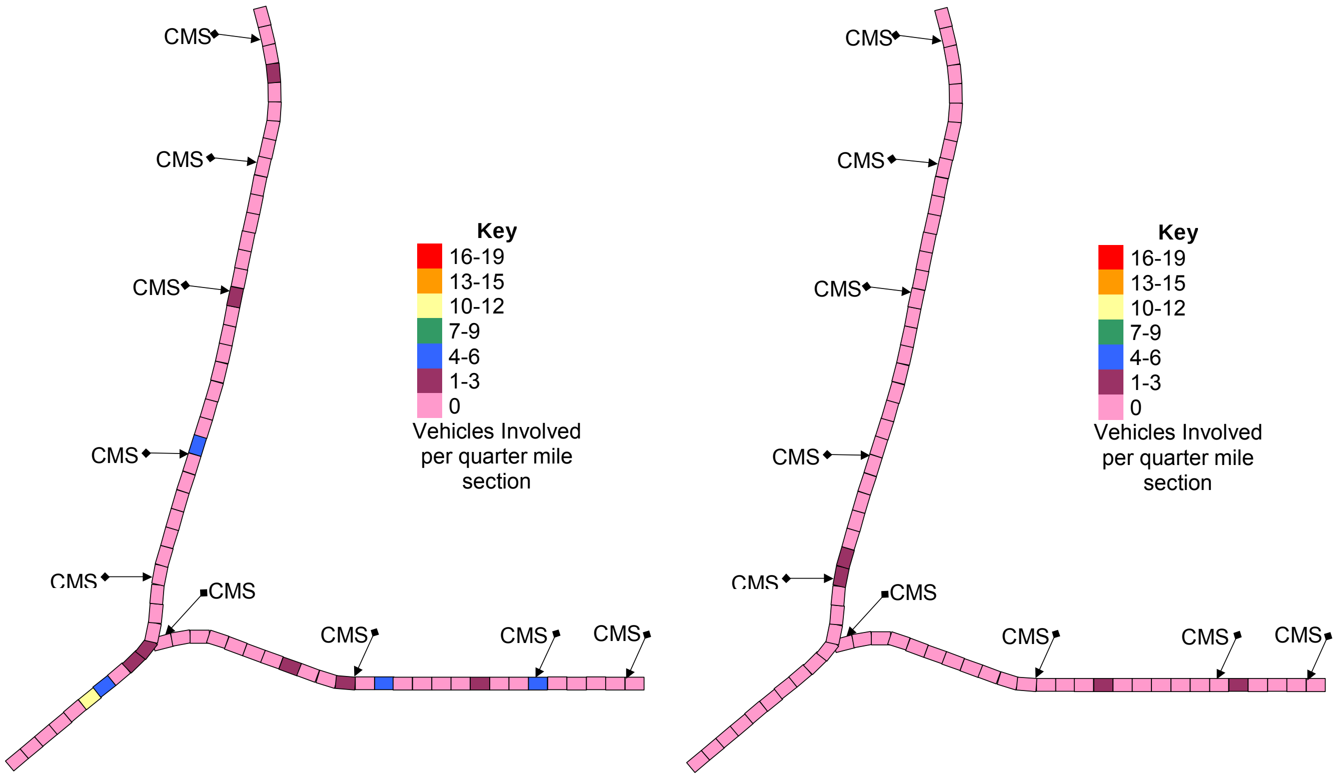

Figure 4.5.1.7. Vehicles involved in fog accidents, before period. (a) study direction, left; (b) control direction, right.

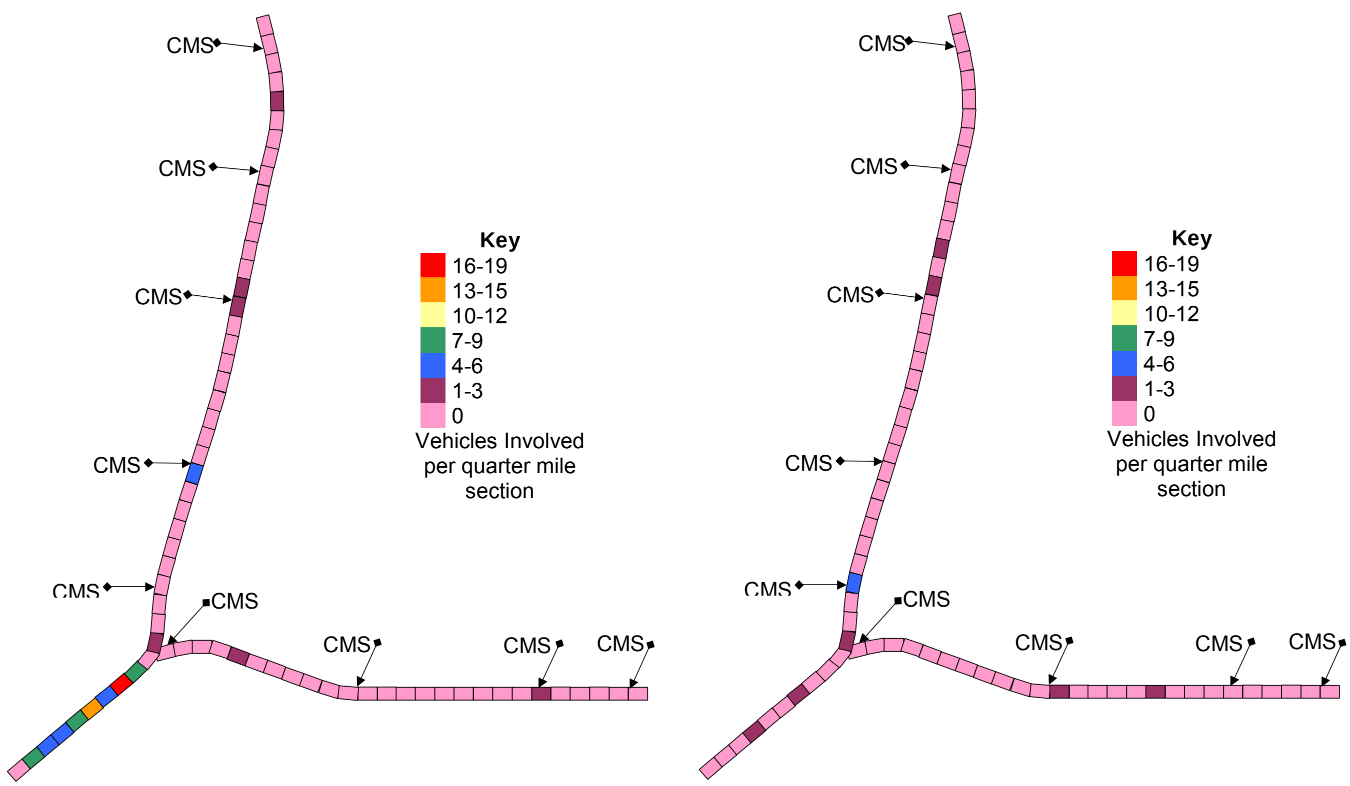

Figure 4.5.1.8. Vehicles involved in fog accidents, after period. (a) study direction, left; (b) control direction, right.

Since one accident contributes only one count to the data set but may involve multiple vehicles, we also investigated the number of vehicles involved in accidents, and presented these in the color coded maps of Figure 4.5.1.3 and Figure 4.5.1.4, which are otherwise equivalent to Figure 4.5.1.1 and Figure 4.5.1.2. This view of the local accident frequencies amplifies the prior observations; a significant number of multiple vehicle collisions occurred concentrated in the Mossdale Y, especially at the merge point of I-5 with SR-120, although a less pronounced trend is also observed in the control direction of this junction.

We then repeat the presentation of the last four figures with equivalent local data for accidents coded in TASAS as having fog as a contributing factor. Figure 4.5.1.5, , Figure 4.5.1.7 and

Figure 4.5.1.8 mirror the trend of the all-weather accidents, particularly with regard to the concentration of vehicles involved in accidents in the Mossdale Y, indicating an elevated number of multiple-vehicle accidents in the southbound merge area. In the control directions, fog accidents were fairly evenly distributed throughout the area, and a relatively small increase occurred from the before to the after period.

4.5.2 Segmented by Areas of Similar Characteristics

For a slightly broader perspective, the CAWS area can be subdivided into three distinct areas of reasonably consistent characteristics: 1) SR-120, 2) I-5 north of SR-120, and 3) I-5 south of SR-120. Analyzing collision rates in each of these segments helps to identify those segments that might be more or less responsible for the overall aggregated results. For comparison, one of the supplemental control highways (SR-99 and I-205) in the corresponding directions of travel will be used as a reference.

4.5.2.1 All-weather Accidents by Segment and Year

Figure 4.5.2.1 presents the annual all-weather collision rates in the study direction for the three different segments of the study area, and the selected control area. The annual trends show that collision rates on southbound I-5, southbound SR-99 and westbound I-205 are generally higher after 1996, however rates on westbound SR-120 are lower or about the same. As anticipated from the previous local area maps, the section of southbound I-5, south of SR-120 is very noticeable with respect to the spikes in collision rates especially in 2000 and 2001, and to a lesser extent throughout the post-1996 period.

Figure 4.5.2.2 compares the corresponding annual all-weather collision rates in the opposite directions for the same highway segments (the CAWS control direction and the opposite directions of the supplemental control area). The same vertical scale is used to facilitate direct comparison. Here, after a spike in rates in all segments in 1995, a lesser peak is observed in 2000, followed by a generally decreasing trend in the most recent years. The noticeable spike in southbound collision rates for I-5 south of SR-120 does not appear in the northbound control direction.

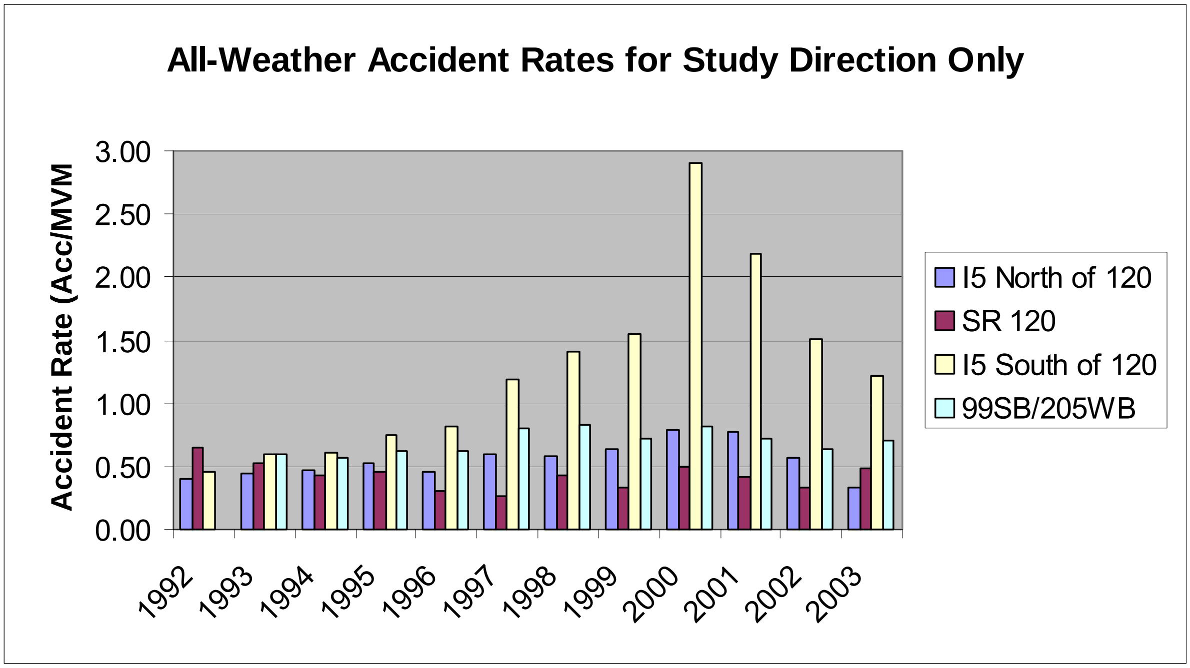

Figure 4.5.2.1. Annual Collision Rates for Study Direction on Highway Segments and Control.

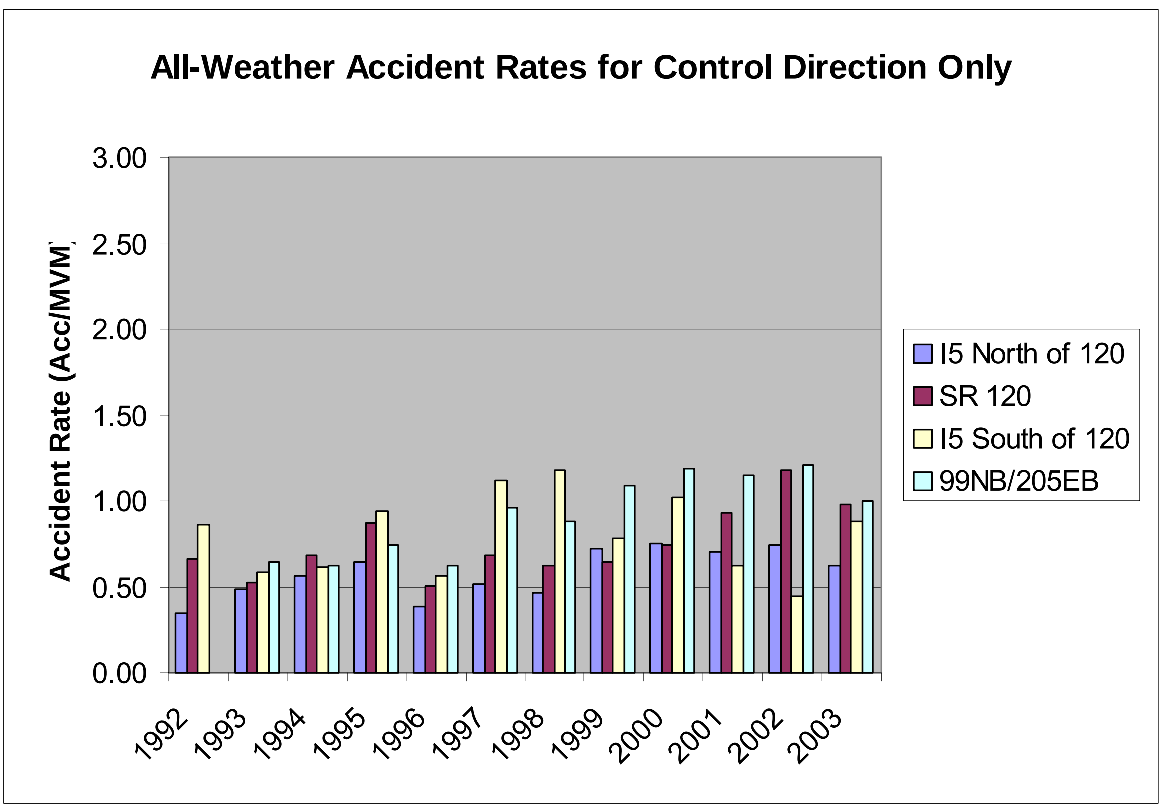

Figure 4.5.2.2. Annual Collision Rates for Control Direction on Highway Segments and Control.

4.5.2.2 Fatal and Injury Accidents by Segment and Year

The corresponding annual fatal and injury collision rates in these same areas are shown in Figure 4.5.2.3 and Figure 4.5.2.4. The trends for the study direction appear to show a pattern similar to the total collision rates in the study direction for I-5, however the apparent decline in rates for SR-120 is not evident, and there is no apparent trend at all for the control areas (SR-99 and I-205). For the opposite directions (CAWS control directions and the opposite directions of the supplemental control area) shown in Figure 4.5.2.4, there are no evident trends at all. This is in part due to the exposure base in MVM being fairly small for these annual graphs, in some cases on the order of 50 MVM, which can produce fairly erratic rate estimates.

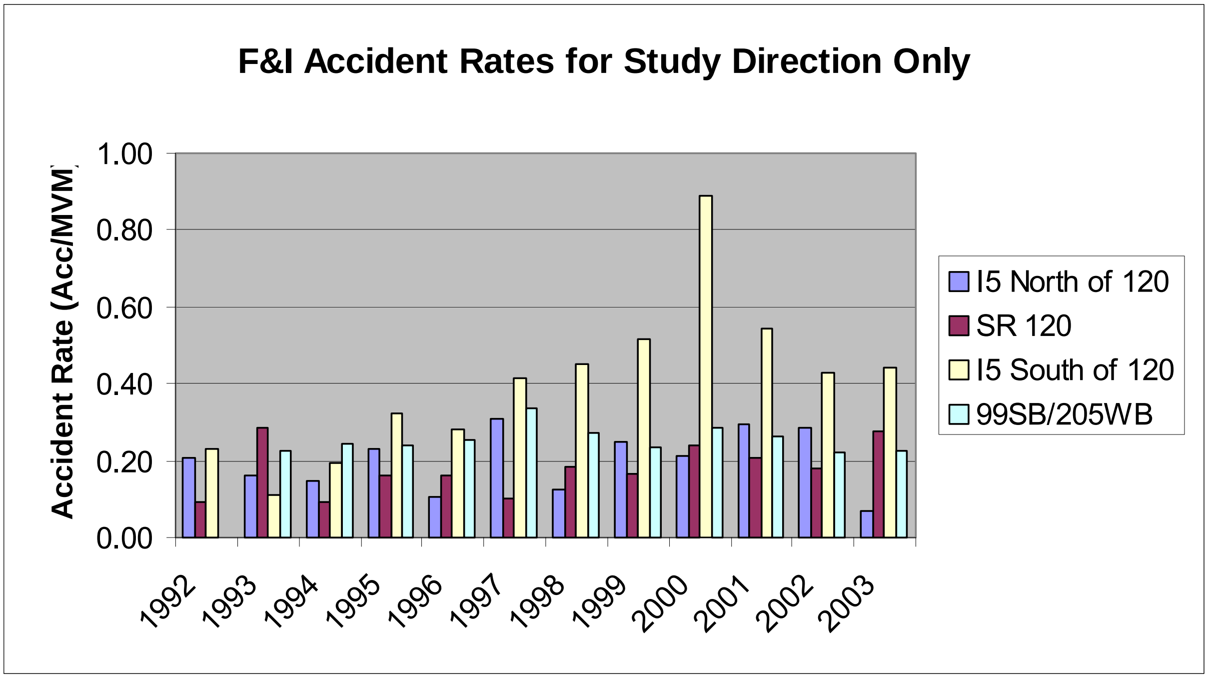

Figure 4.5.2.3. Annual F&I Collision Rates for Study Direction on Highway Segments and Control.

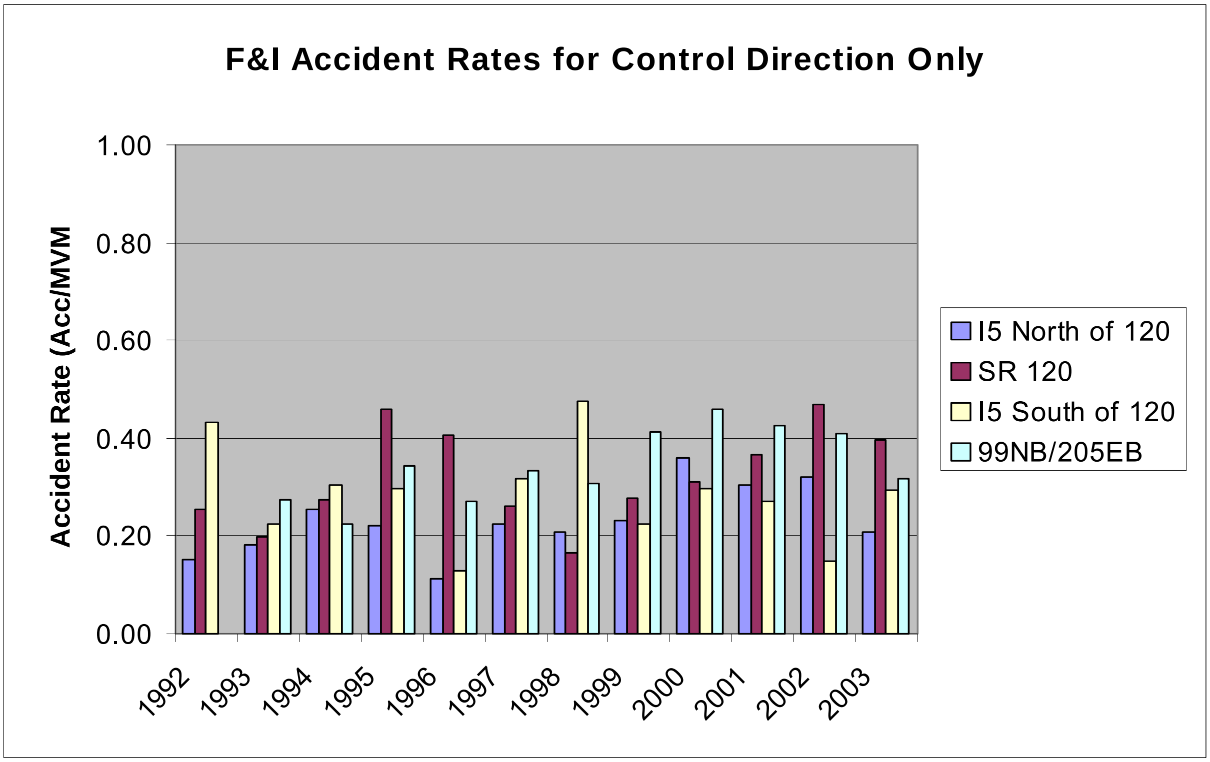

Figure 4.5.2.4. Annual F&I Collision Rates for Control Direction on Highway Segments and Control.

4.5.2.3 Accident Severity Composition, Period-total by Segment

As an alternative to viewing volume-normalized accident rates, we examined briefly the composition of the accident mix, since this may provide some insight into changes in accident severity not necessary evident in separately stated rates. We focused just on the study and control directions of the I-5 and SR-120, and used as the indicator the percentage of all accidents classified as property-damage-only (PDO) accidents. For this analysis, the after period extended from January 1997 through March 2002. The findings for all-weather accidents are shown in Figure 4.5.2.5 and the findings for inclement weather accidents are shown in Figure 4.5.2.6.

For all-weather accidents, the PDO percentage was nearly invariant between the study and control directions, as indicated by Figure 4.5.2.5. One of the more interesting cased which could be isolated was the percentage of PDO accidents occurring in inclement weather, shown as a percentage of all accidents (thus the low percentages). This view of the data is shown in Figure 4.5.2.6. PDO accidents became a larger percentage of the accident mix in the study direction of the segment of I-5 south of 120. In the study direction of 120 and the study direction of the segment of I-5 north of 120, the PDO accident percentage decreased. This suggests that for accidents occurring in inclement weather in the study direction of the Mossdale Y, the severities were reduced somewhat. Curiously, in every control segment, the opposite trend occurred compared with its corresponding study segment.

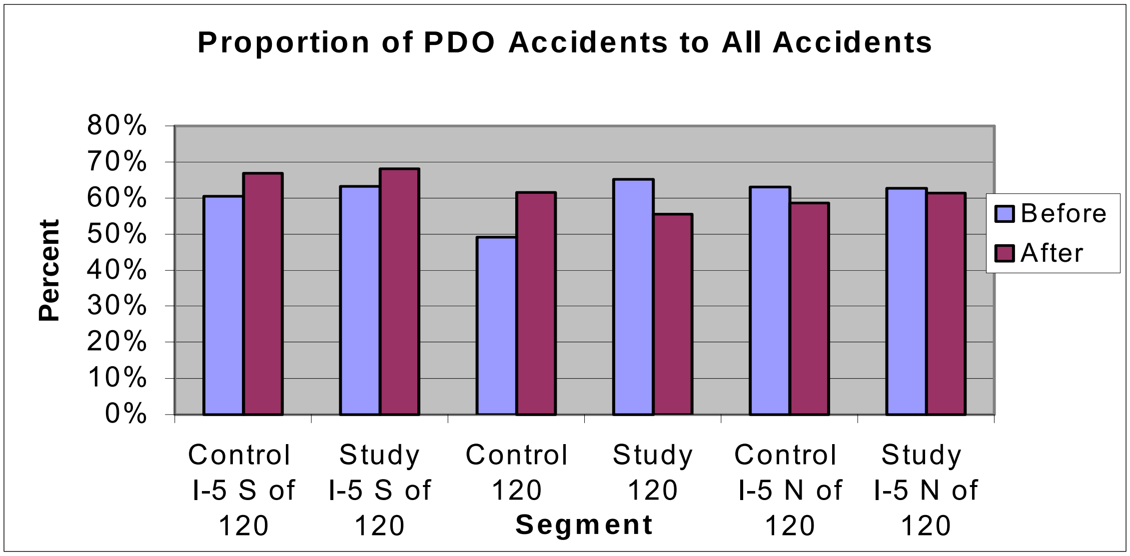

Figure 4.5.2.5. Property damage only accidents as a percentage of all accidents.

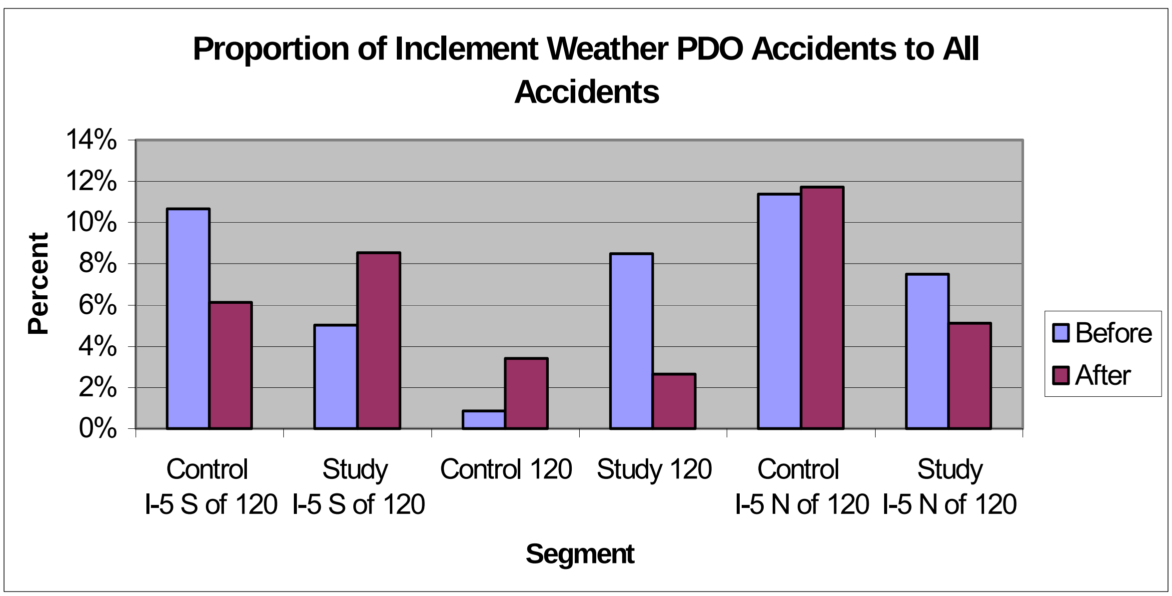

Figure 4.5.2.6. Property damage only accidents occurring in inclement weather, as a percentage of all accidents.

4.5.2.4 Period-total Accident Rates by Segment

In order to reduce the erratic variation in the calculated rates seen in some of the previous graphs, the same data were aggregated to produce simple before-after comparisons. Figure 4.5.2.7 shows the comparisons for total collision rates for the various highway sections in both directions. With the exception of SR-120 in the study direction, rates are generally higher after 1996 for both the study

sections and the selected control area. As previously noted, the rates for southbound I-5 south of SR-120 jumped dramatically, driven especially by the high numbers in 2000 and 2001. Figure 4.5.2.8 illustrates the corresponding comparisons for fatal and injury collision rates, which show roughly the same pattern, except for a small increase (rather than decrease) in the collision rate for westbound SR-120.

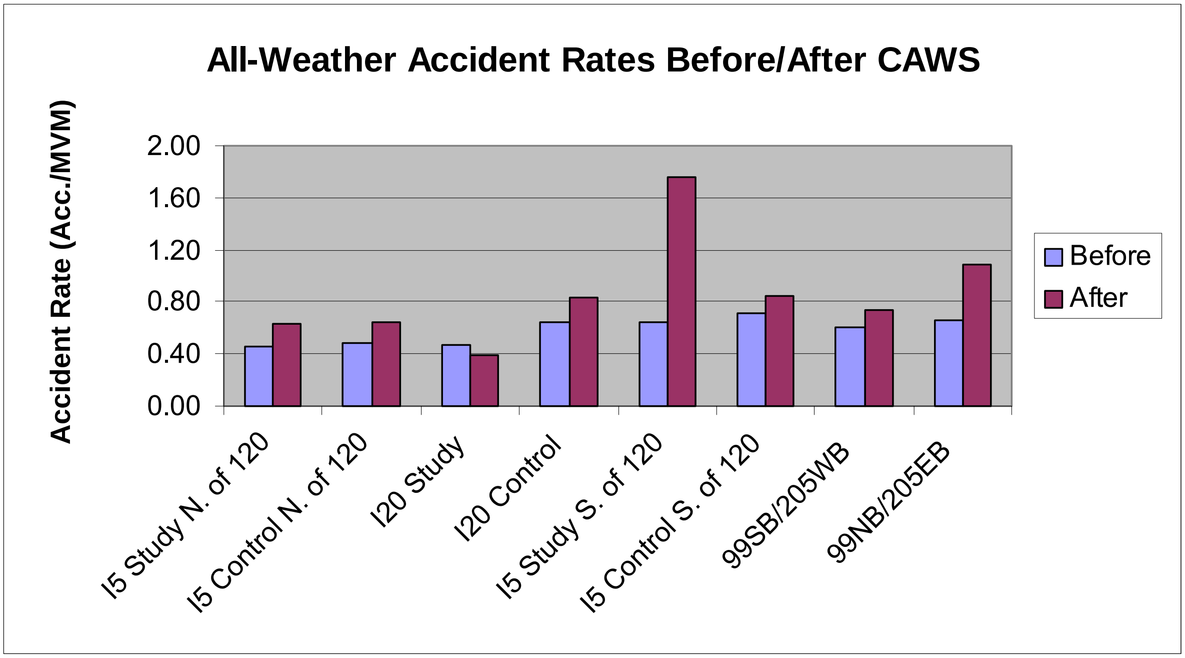

Figure 4.5.2.7. Before-After Collision Rates on Highway Segments and Control.

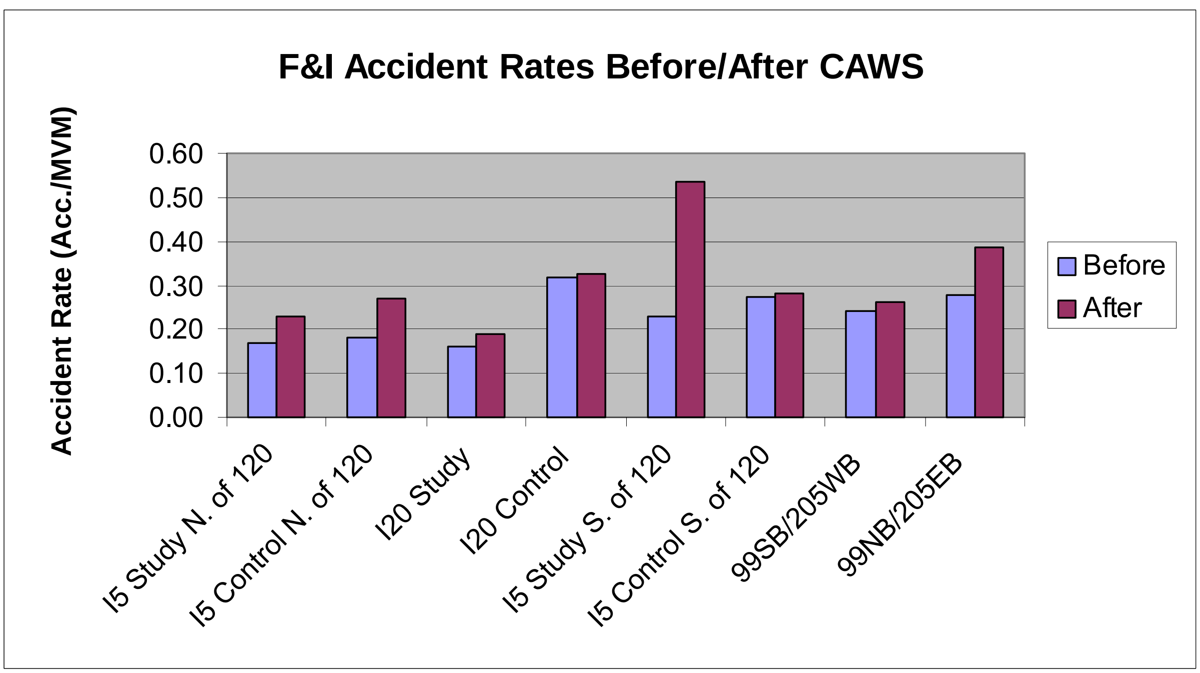

Figure 4.5.2.8. Before-After F&I Collision Rates on Highway Segments and Control.

It is appropriate to take a closer look at trends in the severity of collisions before and after system activation. The TASAS database classifies each collision as one of three types: fatal, injury, or property damage only (PDO). A decrease in the proportion of fatal and injury collisions would suggest an improvement in traffic safety, even if collision rates generally are increasing. The findings for all weather conditions are shown in Figure 4.5.2.5.

The figure shows both pluses and minuses. For I-5 north of SR-120, the proportion of F&I collisions in the study (southbound) direction remains the same, while the proportion increases for the opposite control direction. However, the opposite occurs in the case of SR-120, which shows a comparatively large increase in the proportion of F&I collisions in the study (westbound) direction, with a decrease eastbound. For I-5 south of SR-120, the proportions of F&I collisions decrease by about the same amounts in both directions. The proportions of F&I collisions also decrease by about the same amount for the SR-99 and I-205 control areas. There is no ready explanation for the dramatic (and unpleasant) changes on SR-120, which are so different in the two directions. It is true that about 1995 this highway was widened to a full four-lane freeway, from a mixed facility with some two-lane sections. However, as far as we know, this construction affected both directions similarly.

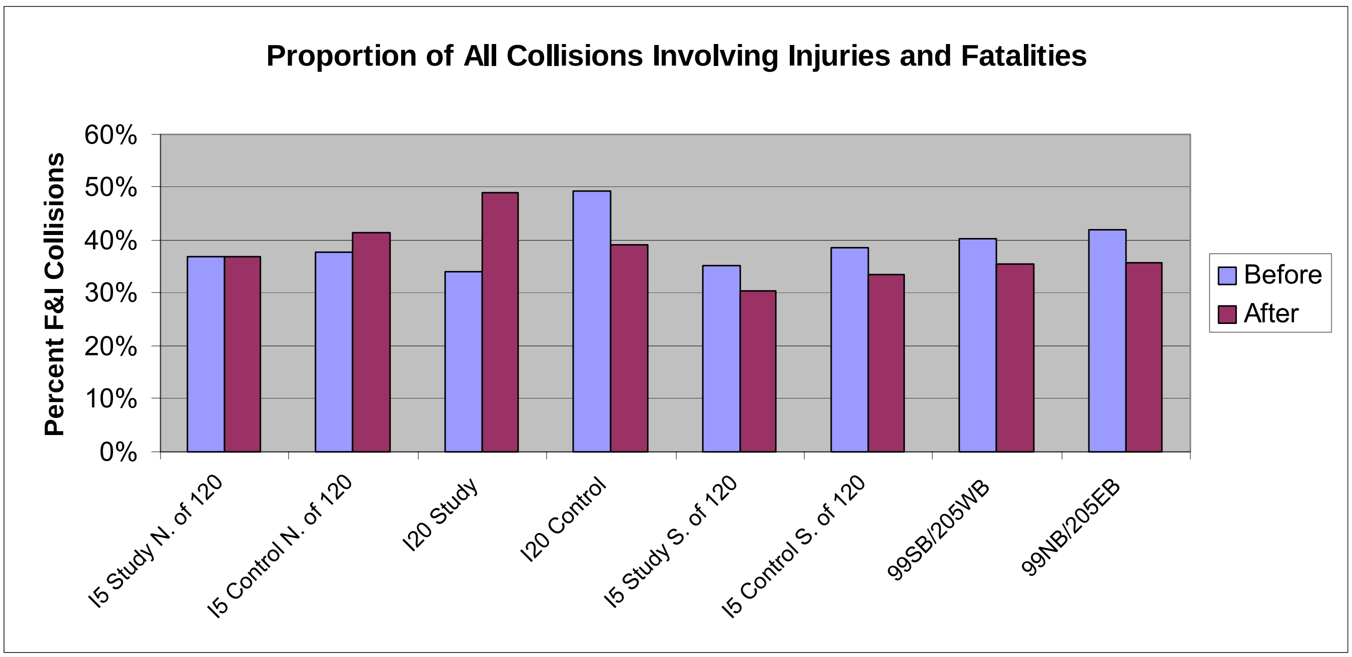

Figure 4.5.2.9. Before-After Proportions of F&I Collisions for Highway Segments and Control.

A map view of the merge section of southbound I-5 and westbound SR-120 in the Mossdale Y is shown in Figure 4.5.2.10. The two-lane feeder road from westbound SR120 creates two new lanes in the merge zone, after a left-hand bend with limited sight distance. The CAWS was intended to be of particular value in this zone, by providing advanced warning to drivers entering from SR-120 of obstructions in the merge

zone. As with any turbulent mixing section, increased collision rates are reasonably expected. Because of its unique geometry, normalized comparisons before and after in this same section are much more relevant than comparisons with the equivalent control direction, or the SR-99 or I-205 control highways.

Figure 4.5.2.10. Detailed View of the Mossdale Y Merge Section, from http://maps.google.com .

4.6 Peak v. Off-Peak

The CAWS study area experiences morning (AM) and afternoon (PM) directional traffic peaks associated with the primary commute direction, toward the San Francisco Bay Area. However, unlike most suburban areas, the peaks are moderated by a flow of commuters in the opposite direction, toward Sacramento, and by a relatively stable component of heavy truck traffic on I-5, a major north-south commerce route. It is well known that driving conditions during different periods of the day lead to differences in the number

and nature of collisions. Lighting and the proportion of drivers with impairment differ with time of day, and heavy congestion typically experienced during weekday peak periods is known to be associated with higher collision rates.

This section presents a collection of collision rate comparisons for different periods of the day, and for different levels of congestion.

4.6.1 Selection of Time Periods

As described in Section 4.13.1, the data set for this analysis defined six time periods, chosen to match approximately the peaking characteristics of traffic in the area, and to ensure that collisions would be spread fairly evenly among the different periods. We decided to define three 5-hour weekday daytime periods, one 15-hour weekend daytime period, and two different 9-hour nighttime periods for weekdays and weekends. The specific period definitions are:

- Weekday AM Peak (4 AM to 9 AM),
- Weekday Midday (9 AM to 2 PM),
- Weekday PM Peak (2 PM to 7 PM),
- Weekday Nighttime (7 PM to 4 AM),
- Weekend Daytime (4 AM to 7 PM),
- Weekend Nighttime (7 PM to 4 AM).

These definitions are generally consistent with information provided by CHP Officer Montez of the Public Affairs Office in Stockton who advised that peak period traffic occurs between 4:30 AM and 10:00 AM Monday through Friday in the study direction, and between 2:00 and 7:00 PM in the opposite direction.

4.6.2 Cross-period and Same-period Comparisons

A variety of same- and cross-period collision rate comparisons were generated from the data. Figure 4.6.2.1 and Figure 4.6.2.2 present a variety of comparisons surrounding the before-after collision rates for the study direction (I-5 southbound and SR-120 westbound), which appear both graphs. The weekday AM and PM peak traffic periods are of greatest interest. In addition to the control and study directions of the CAWS, we also show in the figures to follow the corresponding directions of external control areas on SR-99 and I-205.

In an effort to most directly compare volumes and common groups of drivers in Figure 4.6.2.1, we first compare the AM study direction with the PM control direction, and the two directions of the external control areas. It should be noted that the AM period, however, is much more prone to fog, which could skew the cross-period data for fog days.

In this comparison, the collision rate for the after-CAWS period stands out as more than twice the pre-1996 level. As before, the spike in collision rates within the I-5 section south of SR-120 clearly has a great influence on this outcome. It can be seen that PM peak collision rates for the control direction also increase post-1996 but by a lower factor, and collision increased by almost twice the before period during the PM peak of SR 99 and I-205 control area in the opposite direction of travel.

Figure 4.6.2.2 compares the same AM peak study direction rates to the AM peak rates on the control sections, with roughly similar results. This observation diminishes the perceived effect of the respective peak periods and their corresponding weather on accident rates in the CAWS and surrounding areas, at least for accidents overall. The same trend is observed as for the cross-peak comparison, with after-to-before ratios somewhat less in all control areas for the AM peak period.

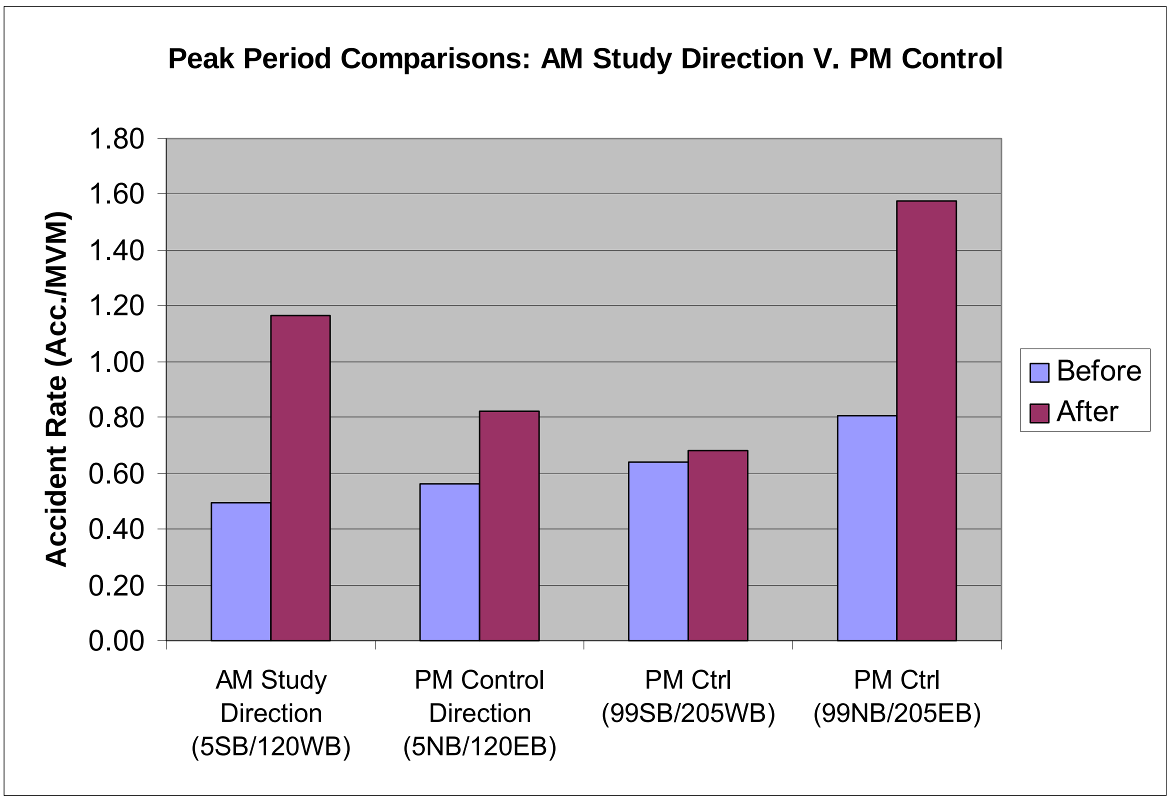

Figure 4.6.2.1. Peak Collision Rate Comparisons: AM Study Direction V. PM Control.

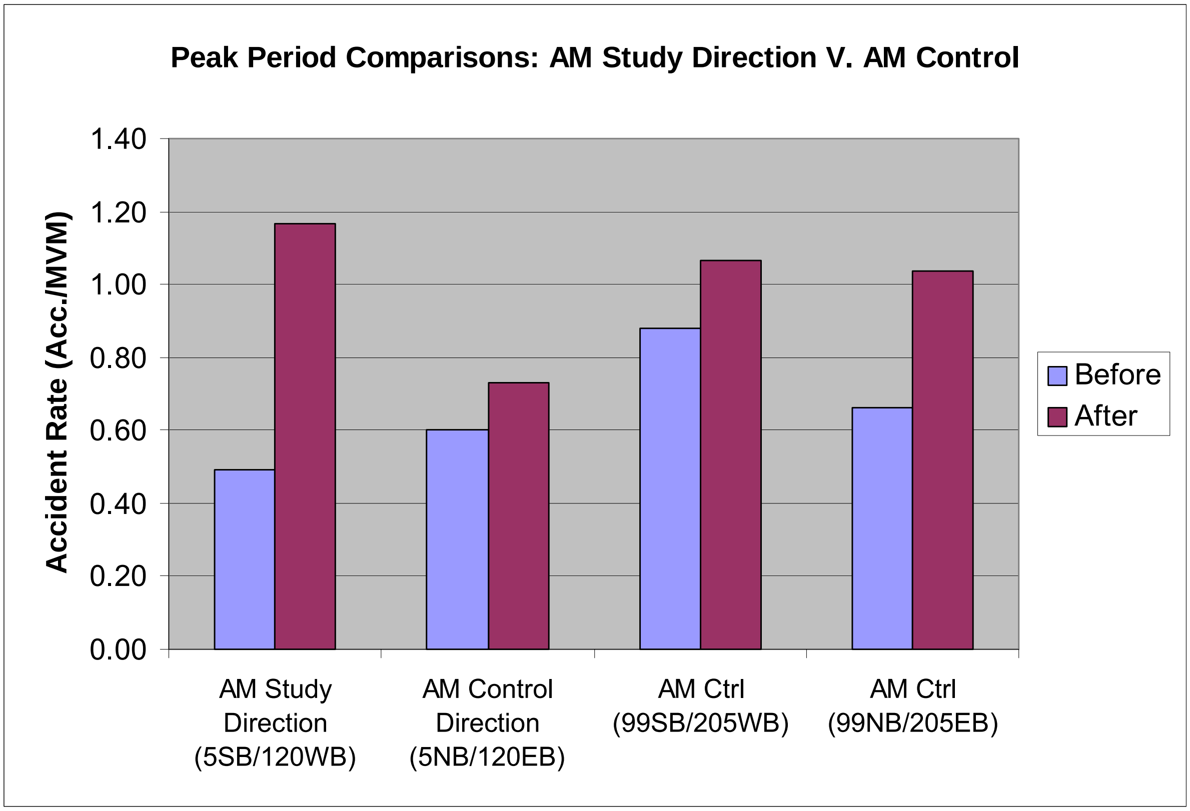

Figure 4.6.2.2. Peak Collision Rate Comparisons: AM Study Direction V. AM Control.

Another way to examine the numbers is view the AM peak and PM peak comparisons for I-5 and SR-120 side by side. This is done in Figure 4.6.2.3. The large jump in the AM peak collision rate that appears in the southbound southern direction is not reflected in the PM peak, when southbound traffic volumes are lower, or in the northbound direction for either period.

The corresponding fatal and injury peak period comparisons appear in Figure 4.6.2.4 and Figure 4.6.2.5. A fairly similar pattern exists in the case of peak F&I collisions, although the collision rate increase in the AM peak in the southbound direction is proportionally less than the increase in all collisions.

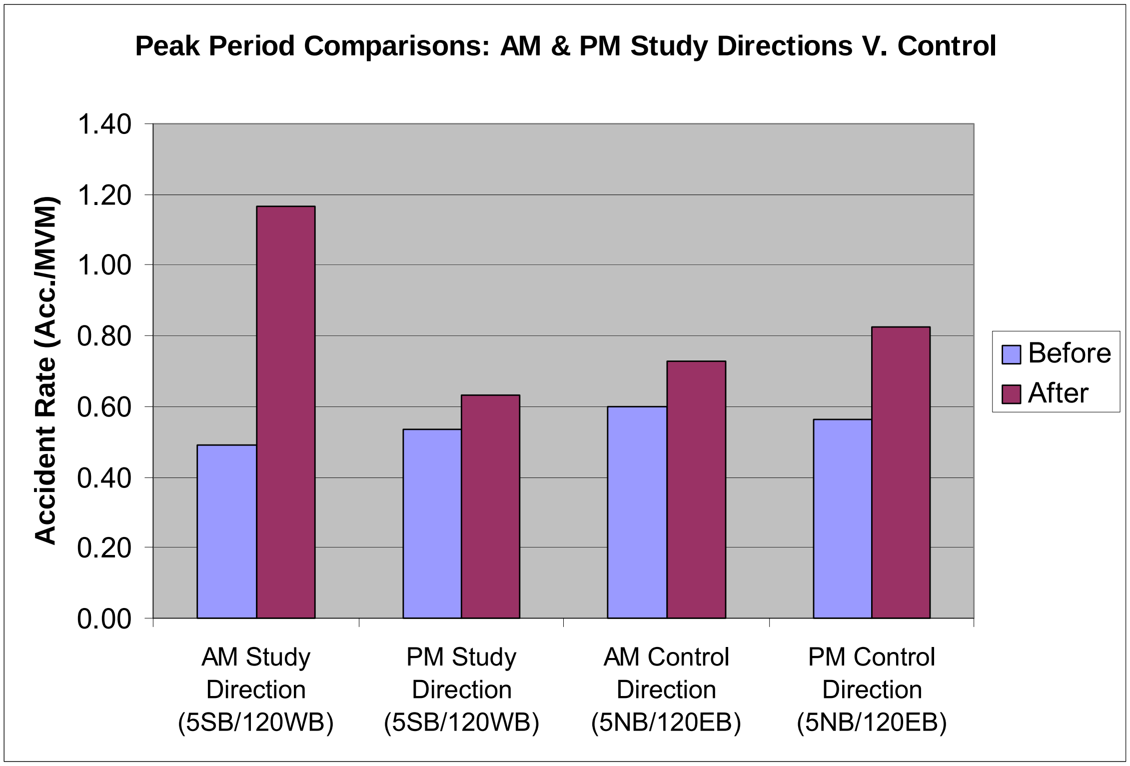

Figure 4.6.2.3. Peak Collision Rate Comparisons: AM and PM on I-5 and SR-120.

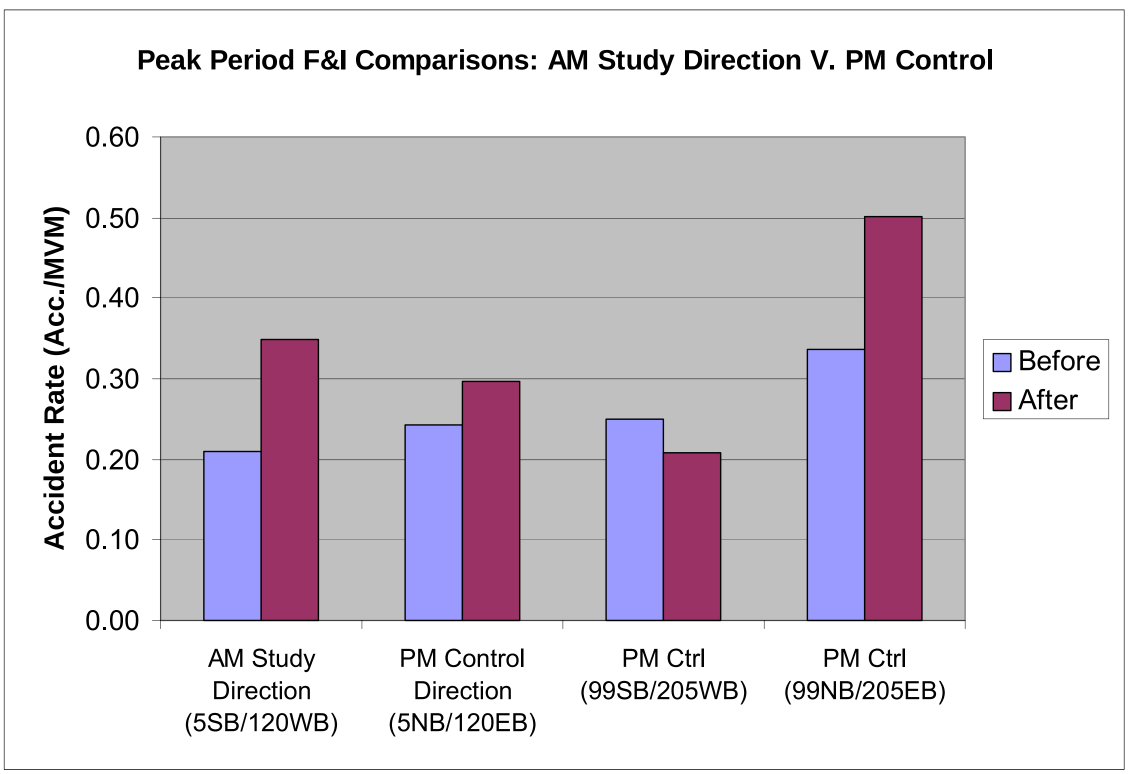

Figure 4.6.2.4. Peak F&I Collision Rate Comparisons: AM Study Direction V. PM Control.

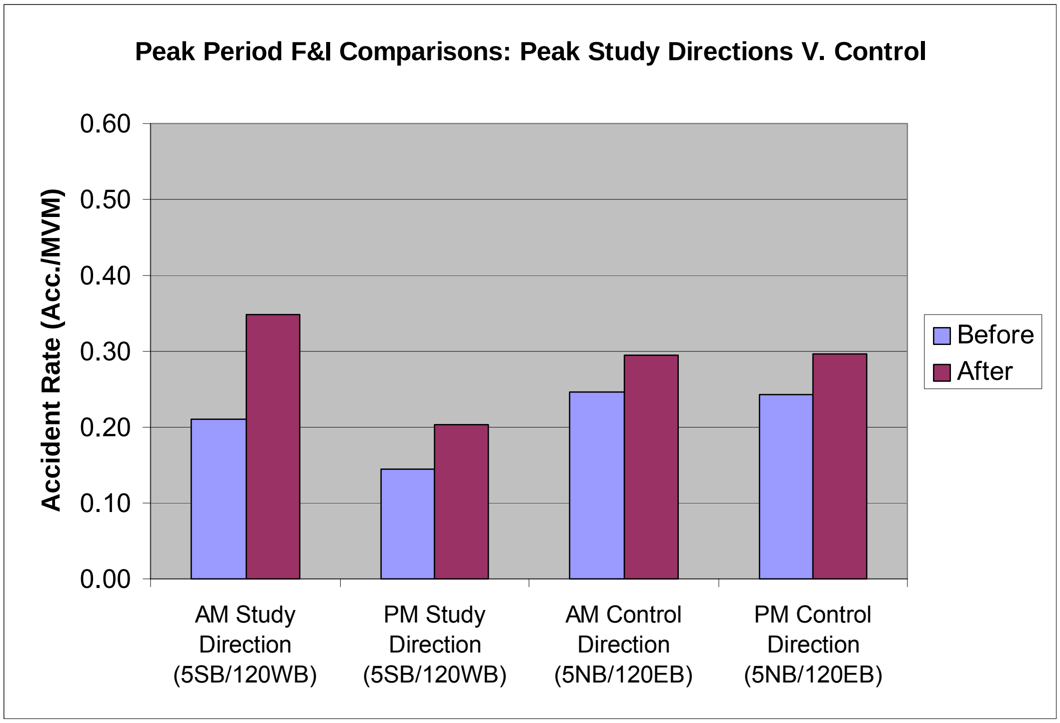

Figure 4.6.2.5. Peak F&I Collision Rate Comparisons: AM and PM on I-5 and SR 120.

Figure 4.6.2.6 shows analogous comparisons for the weekday midday period. It appears that in midday, the increase in collisions rates post-1996 compared to pre-1996 is about the same across the board.

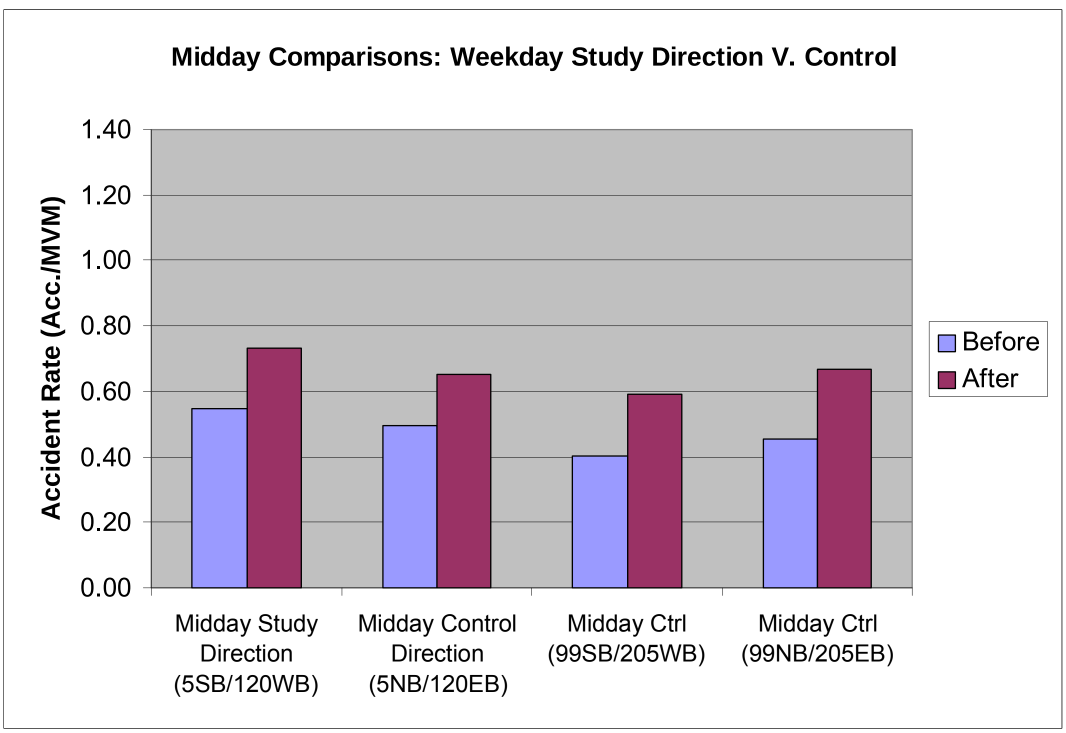

Figure 4.6.2.6. Midday Collision Rate Comparisons: Study Direction V. Controls.

4.6.3 Nights and Weekends

Comparable weekend collision rate comparisons appear in Figure 4.6.3.1 for day and Figure 4.6.3.2 for night. Curiously, while the weekday daytime pre-1996 and post-1996 comparisons seem similar across the board, the weekend nighttime again shows an unusually large increase in the southbound study direction. These periods are usually characterized by a much greater percentage of drivers unfamiliar with the area. If, for example, daily commuters tended to disregard the CAWS warning messages, drivers during weekend evening periods might be more likely to comply with them. Also, under the circumstances, it is less likely that active construction was occurring on the highway. It should be noted that there is a Sunday night recreational traffic peak in this area that might be associated with this finding. The weekday nighttime comparisons, which are not included, do not show the same effect.

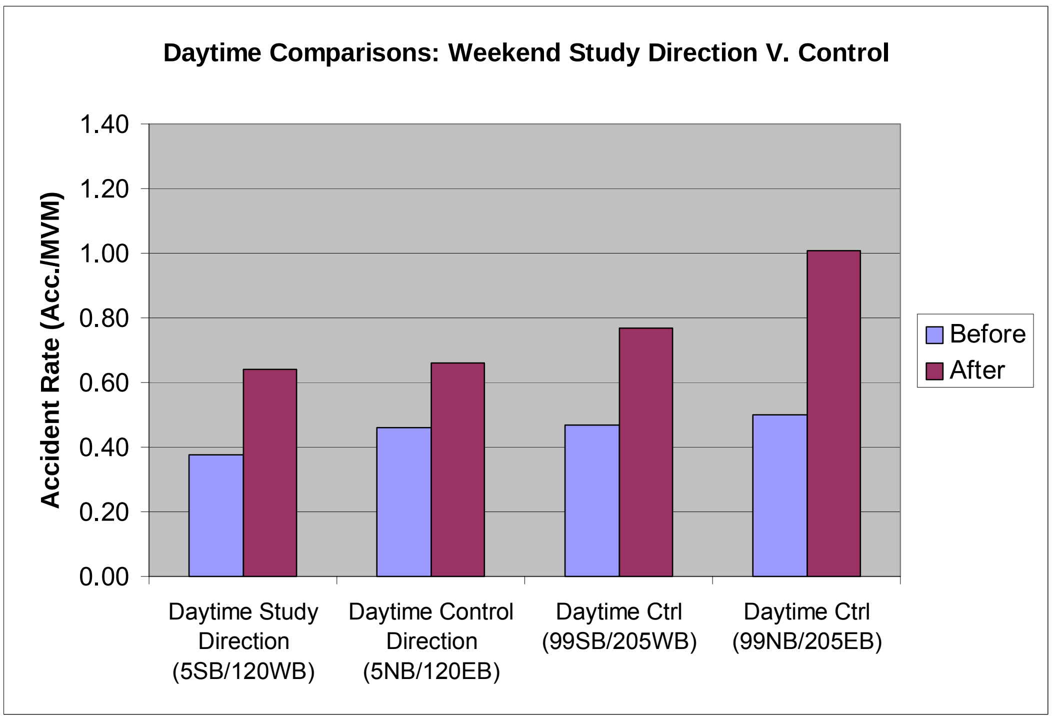

Figure 4.6.3.1. Weekend Daytime Collision Rate Comparisons: Study Direction V. Controls.

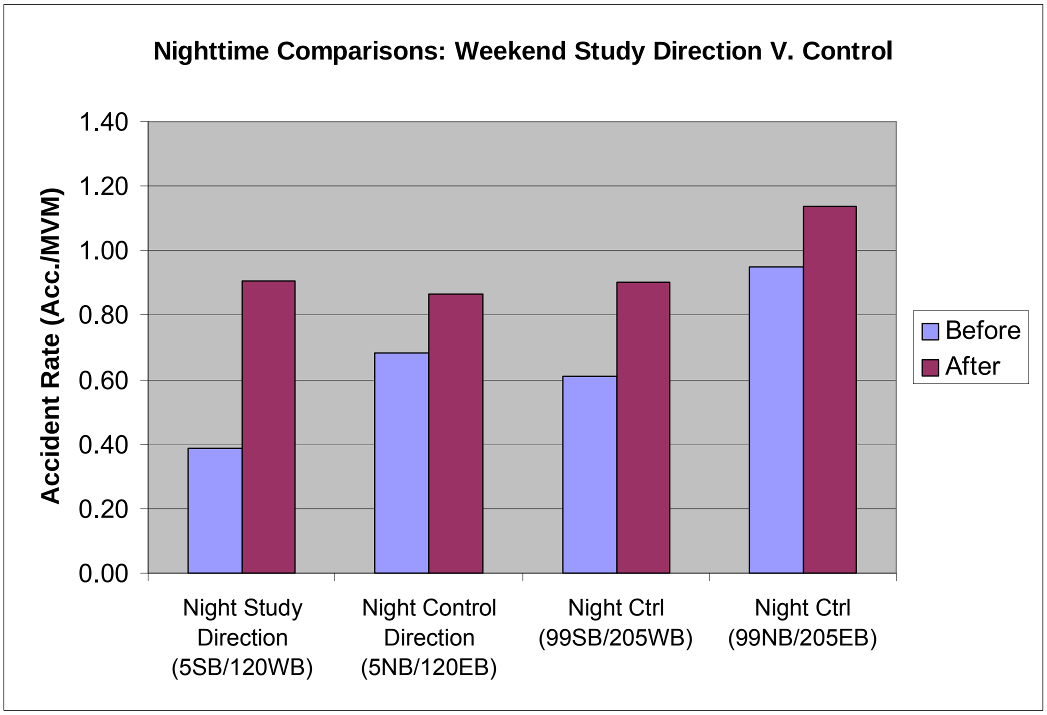

Figure 4.6.3.2. Weekend Nighttime Collision Rate Comparisons: Study Direction V. Controls.

Finally, to explore the weekend nighttime phenomenon in a bit more detail, we include the corresponding comparisons for fatal and injury collisions. These appear in Figure 4.6.3.3. Basically the same pattern is evident, although the proportional increase for the southbound study direction on I-5 and SR 120 does not stand out as noticeably greater than for the control sections.

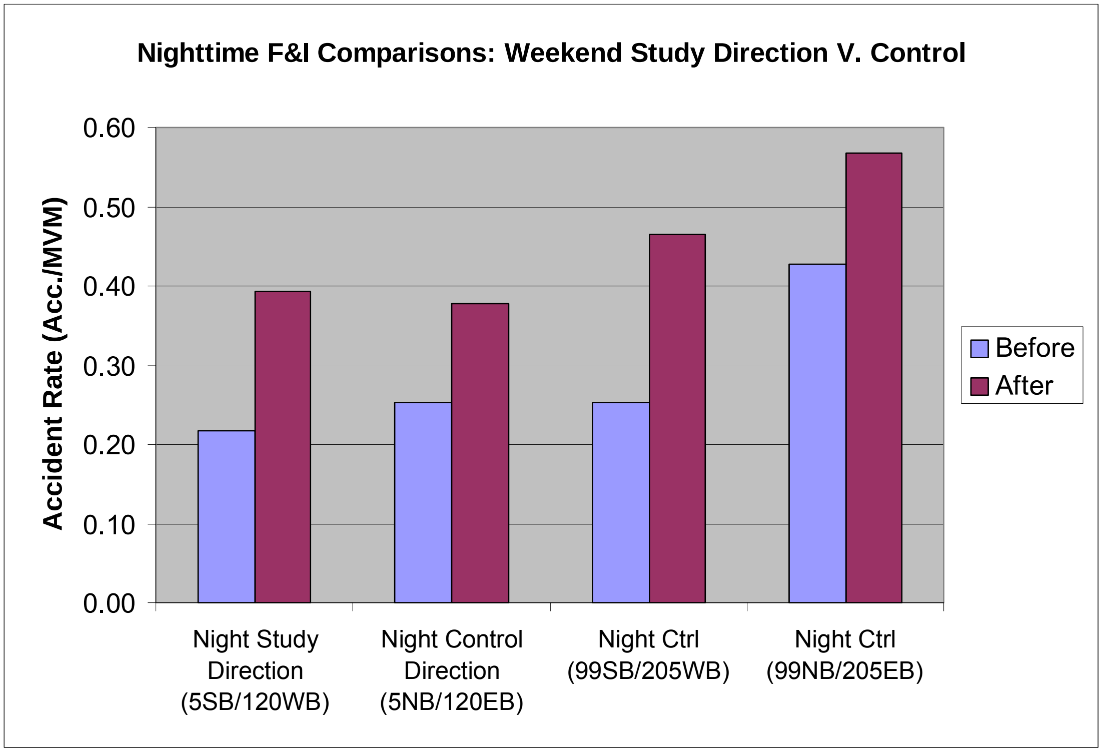

Figure 4.6.3.3. Weekend Nighttime F&I Collision Rate Comparisons: Study Direction V. Controls.

So what does all this mean? First, it certainly appears that there was an across-the-board increase in collision rates throughout area freeways that occurred around the end of 1996, the time the CAWS was activated. Obviously the CAWS could have had nothing to do with the rate increases observed on SR-99 and I-205, so there must be other important factors at work. The speed limit increase, growth and possible other changes in traffic, highway construction projects, and even systematic changes in the weather all appear as possible explanations.

At the same time, there appears to have been an unusually large increase in collision rates in the study direction, at least on I-5 in the southbound direction, in the major weaving section between SR-120 and I-205. Curiously, this does not appear in all time periods, but certainly shows up in the AM peak, and in the weekend nighttime period. The increase is especially noticeable for total collisions, and although present is somewhat less when only fatal and injury collisions are considered.

Peak period analyses will also be presented for collisions in inclement weather in §4.8, collisions in fog in §4.9, related (secondary) collisions in §4.10, and for construction in §4.11.4

4.7 Congestion

4.7.1 Level of Service Estimation

In this subsection, the levels of service (LOS) estimated for each highway segment in each time period and year are used to stratify collision rates. It was expected that higher collision rates would be seen in the presence of congestion, such as for LOS E and F, and perhaps D, compared to uncongested conditions in LOS A, B, and C.

To prepare for this analysis, traffic count data were processed in order to estimate the peak hour directional traffic volume in each highway segment, during each of the six time periods considered in the analysis. In addition, the average hourly on-ramp volumes were determined. This data preparation is described in Section 4.13.1 of the report.

Based on these hourly traffic volumes, the methodology of the 2000 *Highway Capacity Manual* (HCM) was used to estimate the level of service that would be expected in each directional highway segment. Usually this involved applying the basic ramp junction analysis procedure, on the grounds that the critical location in each highway segment is likely to be the 1500 feet just downstream of the on-ramp junction. (Note that our highway segments were defined each to include just one on-ramp junction.) The HCM ramp junction methodology is essentially a slightly conservative extension of the basic freeway segment methodology. Some of the assumptions made in applying the HCM methodology are the following:

Peak Hour Factor = 0.92 (HCM default for urban areas)

Acceleration lane length = 600 ft. (180 m.) (per Caltrans *Highway Design Manual,* Fig. 504.2A)

Distance from on-ramp junction to next downstream off-ramp = 2500 feet

% trucks on on-ramps = 10% (mainline % trucks varied based on Caltrans traffic count data)

In addition, a special queuing analysis was applied to two highway segments, where congestion was thought to be significantly influenced by backups from bottlenecks located downstream in adjacent segments. These are the southbound segment of I-5 just north of the I-205 junction and the last eastbound segment of SR 120, adjacent to the junction with SR 99. In these cases, a portion of the segment mainline flow was compared to the downstream capacity and, if capacity was exceeded, the segment was assumed to contain a queue, thereby level of service F. Otherwise, the normal level of

service method was used. Some additional assumptions, based on available traffic counts, were made in this special queuing analysis:

62.5% of the I-5 southbound traffic in the southernmost study segment is destined to I-205

60% of the eastbound SR 120 traffic in the easternmost segment enters a connector ramp with SR 99 which has capacity = 1900 vph

On this basis, the worst-case (highest one hour) level of service (LOS) was estimated for each highway segment and time period in the data set. Segments and time periods were stratified into two groups corresponding to level of service A-C and level of service D-F conditions, respectively.

4.7.2 Collision Rate Comparison

The collision rate comparisons for the two groups appear in Figure 4.7.2.1 and Figure 4.7.2.2. As expected, collision rates for LOS D-F are generally higher than for LOS A-C. Under both conditions, collision rates increase across the board in the post-1996 period. For LOS A-C conditions, there is not much difference in the increases among the study and control sections. For LOS D-F, some peculiarities are evident. The proportional collision rate increase for the study direction (I-5 southbound and SR 120 westbound) appears huge, about a factor of five. At the same time, there is almost no before-after increase for one of the control section groups (SR 99 southbound and I-205 westbound).

The seemingly huge jump in the collision rate for the study direction under LOS D-E conditions may partly be discounted by the fact that these rates are based on an abnormally small level of exposure, especially in the before period, which is just under 50 MVM, too small to give statistically stable collision rates. The collision rate for the SR 99SB/I-205WB control section in the before period is based on about 100 MVM of exposure, which is better, but also fairly small and subject to unusually high random variation.

The corresponding comparisons for fatal and injury collisions were also examined, and generally gave the same results seen in the analysis of total collisions. The detailed F&I results are not shown here. It should be noted that some of the numbers are very small and therefore subject to considerable random variation. For example, there are only eight F&I collisions in the study direction for I-5 and SR 120 during the before period, associated with slightly less than 50 MVM of travel. Although these numbers can be used to calculate a collision rate, it would be subject to an unacceptably large standard error.

The examination of the influence of congestion level on collision rates, as expected, clearly shows that this factor is extremely important in explaining why collision rates vary from place to place and time to time. Certainly LOS is a critical factor to control for in attempting to discern the nature of the impacts on collision experience associated with activating the CAWS.

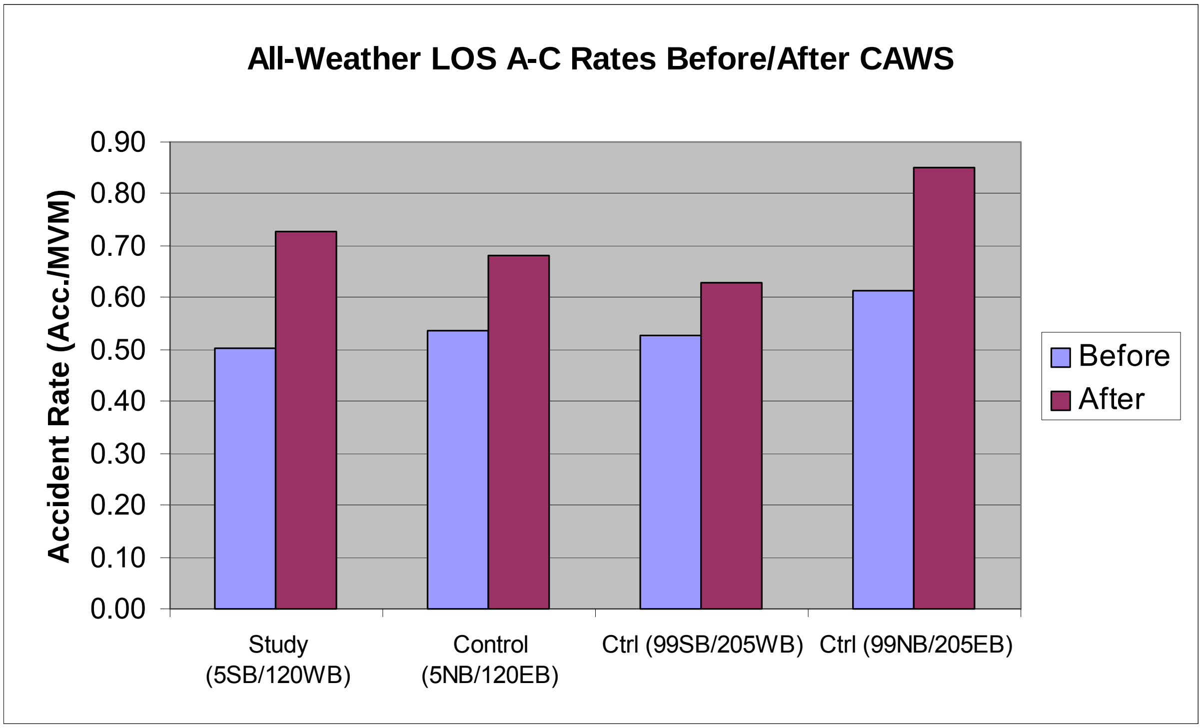

Figure 4.7.2.1. Collision Rate Comparisons for Level of Service A-C Conditions.

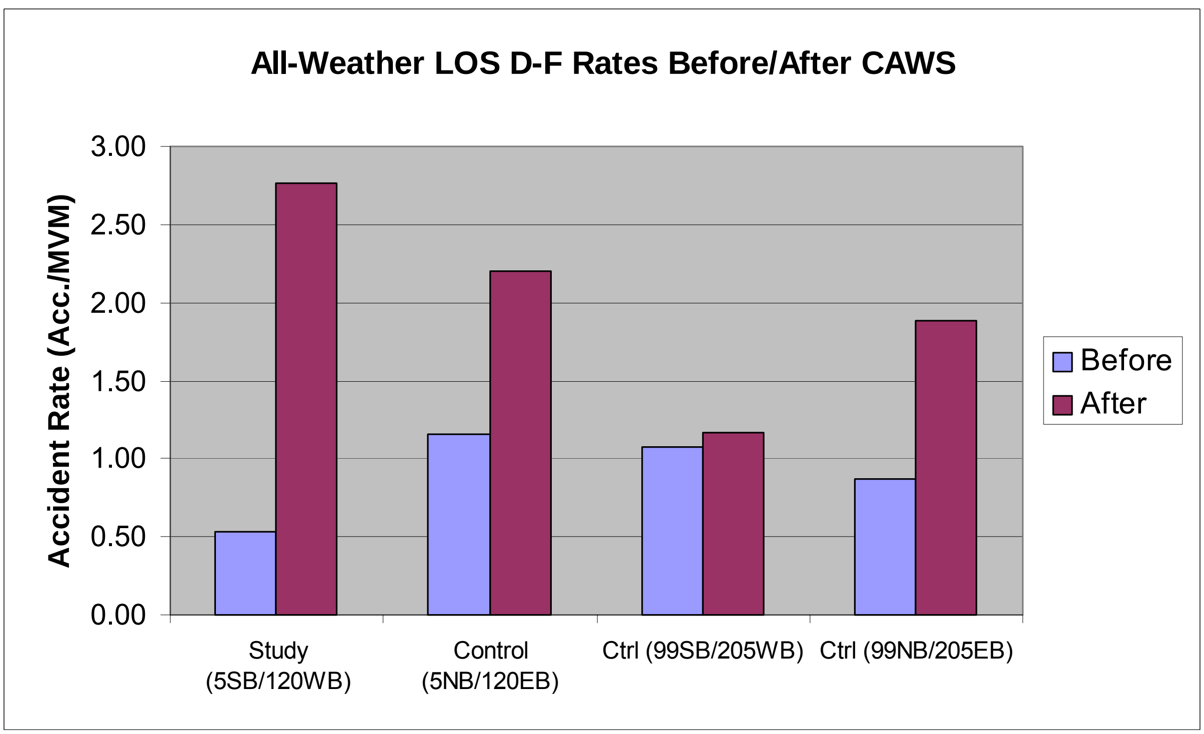

Figure 4.7.2.2. Collision Rate Comparisons for Level of Service D-F Conditions.

4.8 Inclement Weather

4.8.1 Collision Rate Comparison

Table 4.8.1.1 shows the total number of collisions that occurred in inclement weather (defined as rain or fog) in both the study direction and control directions. While the CAWS system does not warn drivers of rain or wet conditions, rain has an impact on visibility, and some police reports indicate limited visibility from heavy rain as a causal factor in collisions.

In this part of the investigation, no effort was made to estimate true inclement weather collisions rates, which would have required trying to estimate the number of vehicle-miles driven during inclement weather, to be divided into the inclement weather accident counts. Inclement weather collisions were simply identified as those which had either rain or fog coded in the weather field of the applicable TASAS data record.

Figure 4.8.1.1 visually compares the annual collision rates from Table 4.8.1.1. The 'inclement weather' collision rate for each year before and after system activation is computed as the number of inclement weather collisions divided by the total number of vehicle miles traveled. Thus, the inclement weather collision rates are much smaller in magnitude than the corresponding all-weather collision rates based on the same MVM measure of exposure.

Table 4.8.1.1. Inclement Weather Collisions and Collision Rates on Study and Control Sections.

Year	Study Direction (5SB/120WB)		Control Direction (5NB/120EB)		Control Highway (99SB/205WB)		Control Highway (99NB/205EB)	
	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)	Number of Collisions	Collision Rate (Acc/MVM)
1992	14	0.08	12	0.06				
1993	7	0.04	15	0.08	6	0.02	12	0.05
1994	8	0.05	10	0.05	10	0.04	10	0.04
1995	12	0.07	20	0.10	11	0.04	6	0.02
1996	10	0.05	15	0.07	16	0.06	11	0.04
	System Activation							
1997	20	0.11	11	0.05	11	0.04	12	0.04
1998	29	0.16	19	0.09	16	0.06	17	0.06
1999	17	0.09	13	0.06	19	0.07	10	0.03
2000	17	0.09	27	0.12	12	0.04	28	0.09
2001	13	0.06	21	0.09	20	0.05	30	0.08
2002	17	0.07	14	0.05	13	0.03	16	0.04
2003	5	0.04	3	0.02	10	0.05	9	0.05

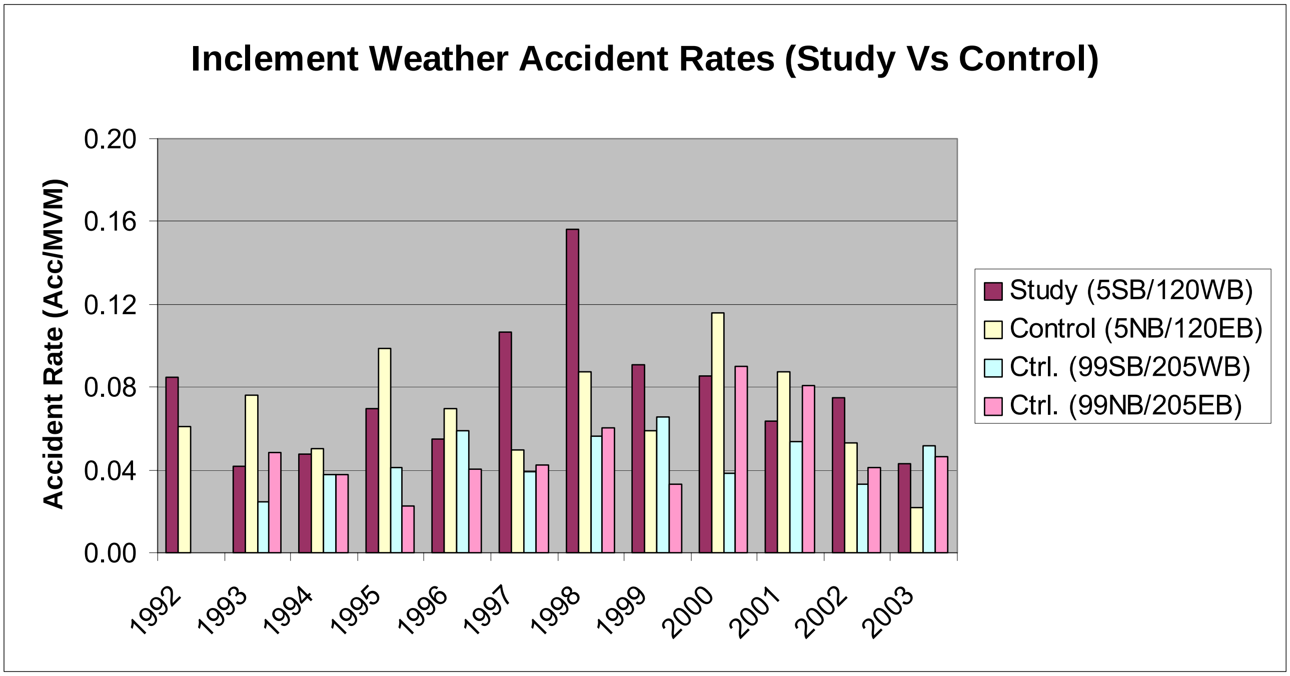

Figure 4.8.1.1. Inclement Weather Annual Collision Rates for Study Direction and Controls.

Since it may be difficult to extract comparisons from Figure 4.8.1.1, we provide Figure 4.8.1.2 presenting the same data with pre-1997 and post-1996 collisions combined. The patterns in Figure 4.8.1.2 are similar to some seen previously. An increase in inclement weather collision rates is evident for the study direction and for one of the control facility directions (99NB/205EB). The before-after collision rate comparisons for the other control sections show little difference for inclement weather conditions.

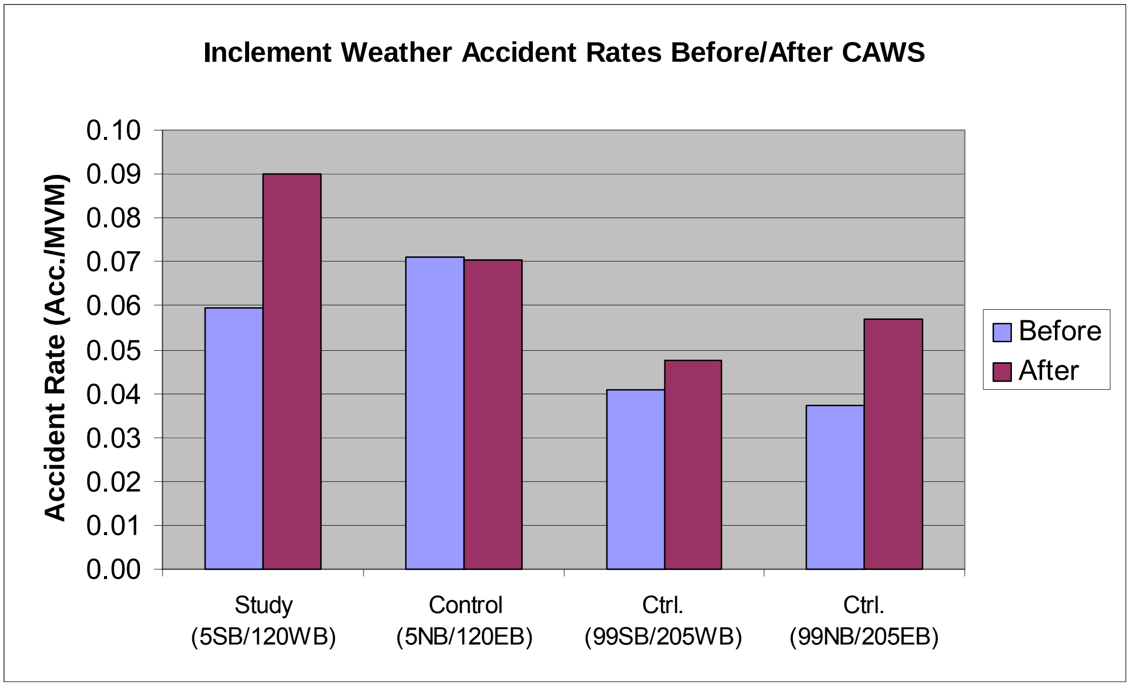

Figure 4.8.1.2. Inclement Weather Before-After Collision Rates for Study Direction and Controls.

Figure 4.8.1.3 shows the corresponding inclement weather collision rates calculated for only fatal and injury collisions. The comparisons are quite similar to those in Figure 4.8.1.2, although in this case the differences for all control sections show little difference.

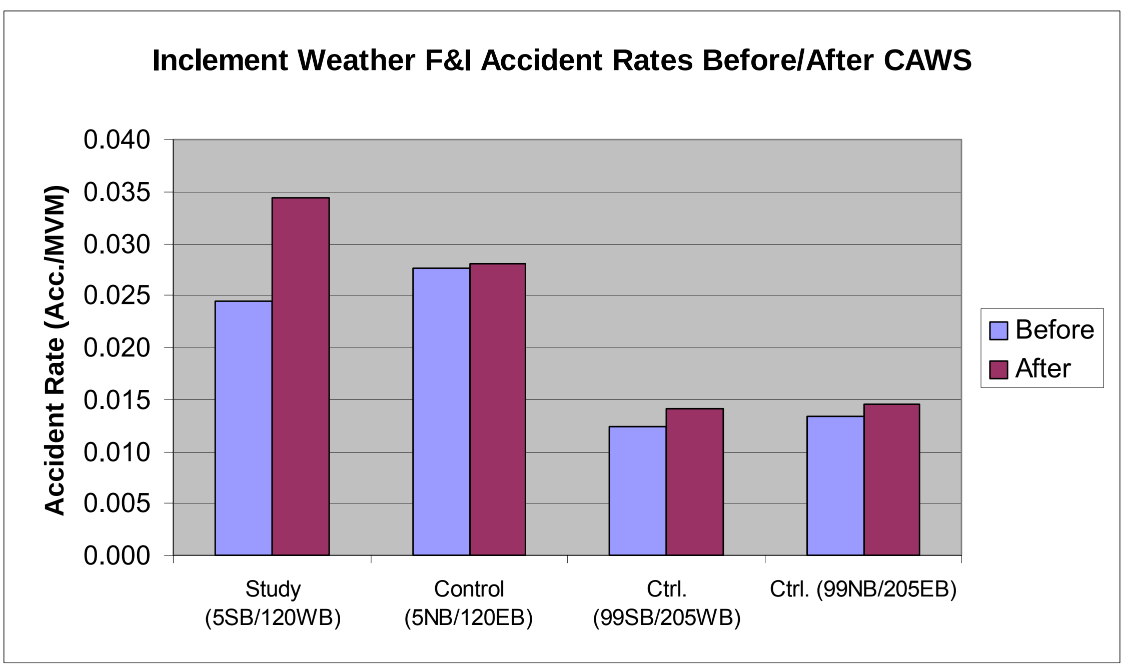

Figure 4.8.1.3. Inclement Weather Before-After F&I Rates for Study Direction and Controls.

4.8.2 By Highway Sub-sections

Figure 4.8.2.1 shows the same information for collisions disaggregated to key sub-sections of the study direction, and the supplemental control area. Figure 4.8.2.2 shows the same comparisons but for only fatal and injury collisions. Both graphs reveal basically the same patterns. Both the total and F&I collision rates increase substantially in the portion of southbound I-5 between SR-120 and I-205. Curiously, the opposite effect, a substantial collision rate decrease, occurs on the same sub-section in the opposite direction. The before-after comparisons in other areas are mixed. The inclement weather collision rates decrease in the SR-120 study direction, although they increase a little in the I-5 study direction north of SR-120.

Finally, it was of interest to examine whether or not we could see any relative effect on inclement weather conditions in the study direction relative to collisions overall. Since one of the main goals of CAWS is to help drivers in difficult weather, especially fog, perhaps the proportion of inclement weather collisions would relatively decline on the sub-sections served by cause, in relation to the other highway sections examined. Figure 4.8.2.3 compares the study direction and the control sections in terms of the proportion of inclement weather collisions, before and after system activation. Indeed, comparing this figure carefully to Figure 4.8.2.1 one sees that, while inclement weather collisions increased in the study direction following the activation of CAWS, they did not increase as much as collisions generally, thus the proportions of inclement weather collisions on these sections relatively declined. On the other hand, the same effect can be seen for some of the control sections, so it is difficult to conclude that the phenomenon being observed is actually associated with the CAWS. Although not depicted here, the patterns observed in the case of fatal and injury collisions are essentially the same.

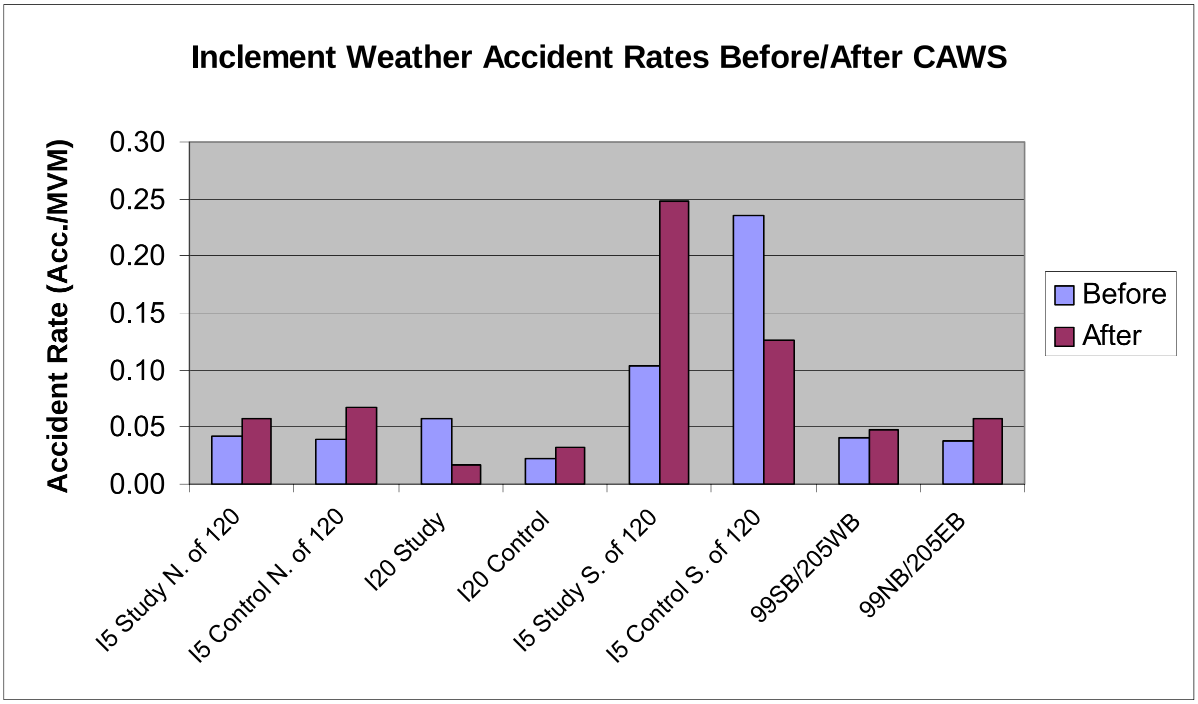

Figure 4.8.2.1. Inclement Weather Before-After Collision Rates for Study Sub-Sections.

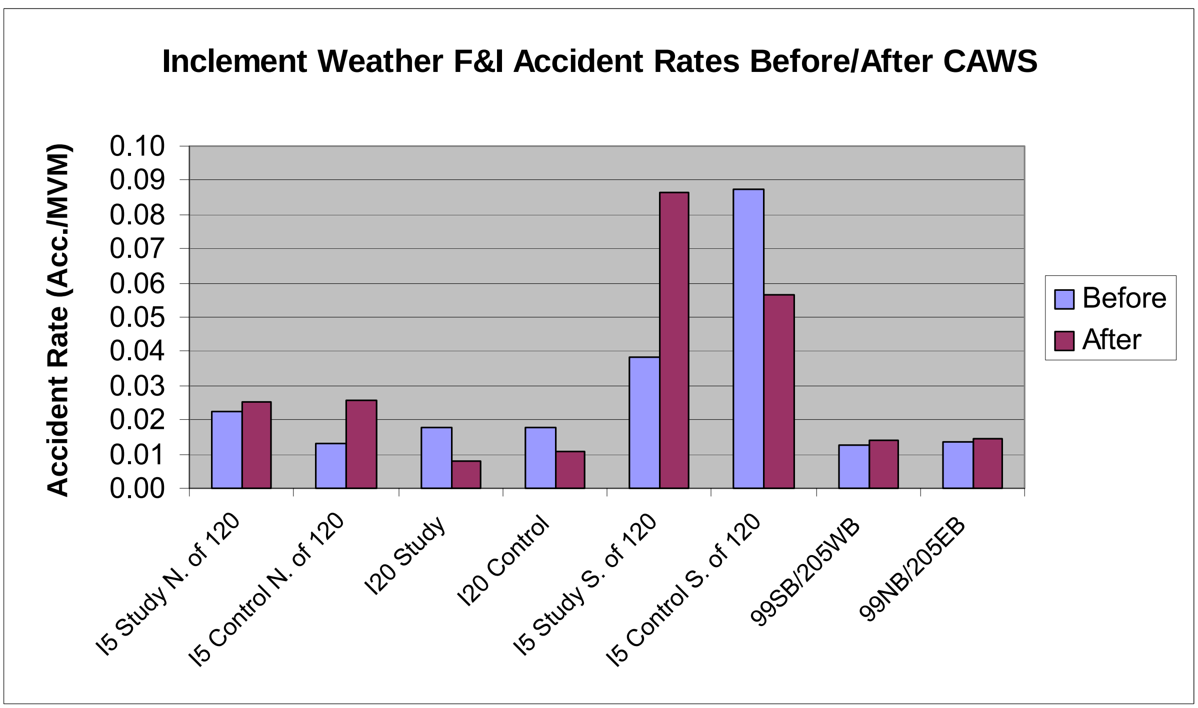

Figure 4.8.2.2. Inclement Weather Before-After F&I Rates for Study Sub-Sections.

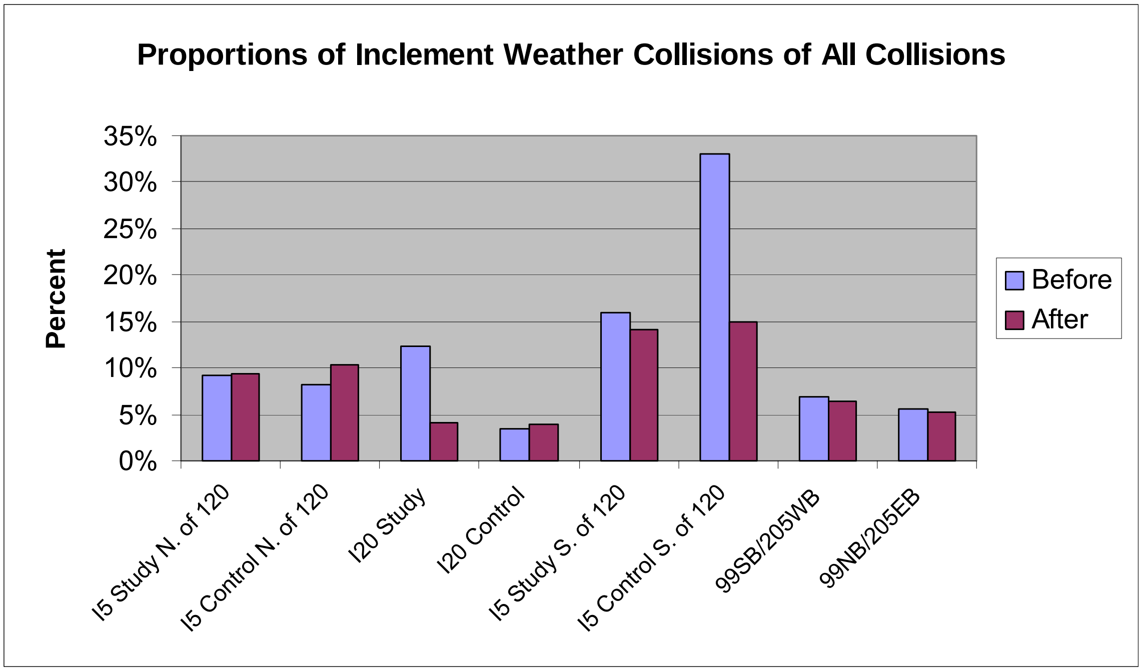

Figure 4.8.2.3. Proportion of Inclement Weather Collisions to All Collisions Before-After System Activation.

4.8.3 By Peak Traffic Period

Since the most concern regarding collisions in reduced visibility exists during the morning peak period, inclement weather collision rates were developed for collisions during that time period. Although the control direction on I-5 and SR-120 does not carry as much traffic in the AM peak, it does share the weather conditions, so those control directions are shown. The results for all AM peak, inclement weather collisions appear in Figure 4.8.3.1 and for the corresponding fatal and injury collision rates in Figure 4.8.3.2. These figures show some surprising comparisons for the AM peak study direction. While the overall collision rate increases post-1996, the F&I rate decreases, indicating a substantial decrease in collision severity. This effect is not evident in the control sections.

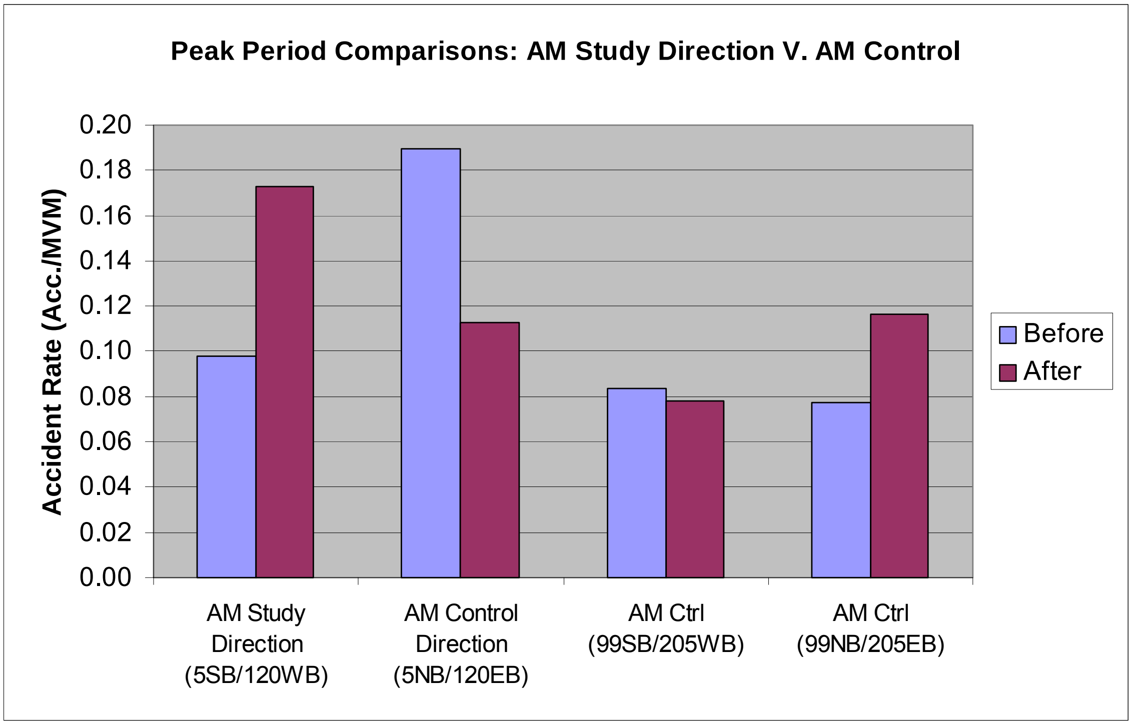

Figure 4.8.3.1. Inclement Weather Before-After Collision Rates for Weekday AM Peak Periods.

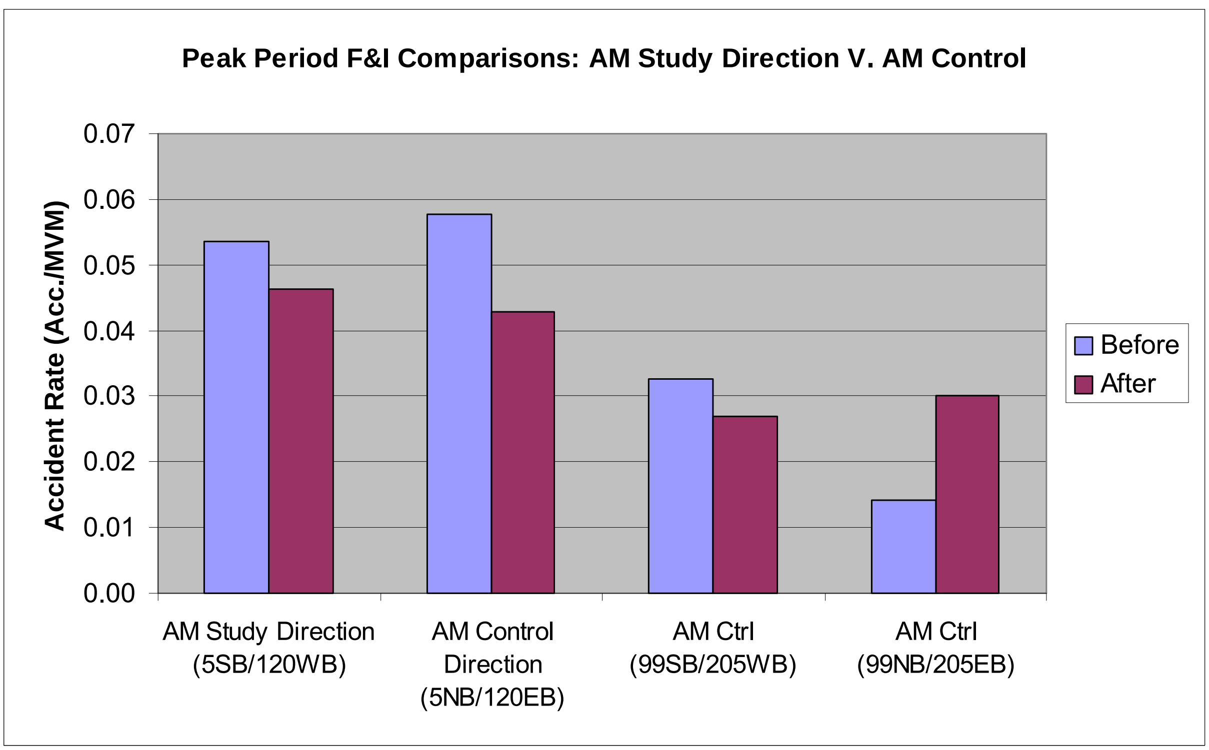

Figure 4.8.3.2. Inclement Weather Before-After F&I Rates for Weekday AM Peak Periods.

4.9 Fog

This phase of the analysis isolates the inclement weather collisions that occurred in the presence of fog. Collisions where fog was a factor were analyzed by using the number of heavy fog days as a measure of exposure to potential collisions instead of VMT.

4.9.1 Determination of Fog Days

For this investigation, environmental data were obtained from the National Climatic Data Center's National Virtual Data System (NVDS). The NVDS provides access to nationwide data from the National Oceanic & Atmospheric Administration (NOAA). The center reports the number of days of reported rain, fog, and other problematic atmospheric conditions recorded at the Stockton Metropolitan Airport. This information was downloaded from the NVDS web site web site http://nndc.noaa.gov/. While the Stockton Metropolitan Airport is over a mile away from the study area, and even farther away from some of the control sections, these weather reports were assumed to be representative of the surrounding region. A comparison of NVDS data to the CAWS weather data found that the NVDS data is over 91% consistent with CAWS observations in cases of fog, which is the more difficult match. 'Heavy fog days' are defined in the NVDS as any day where visibility drops to ¼ mile or less.

The NOAA data shows 122 heavy fog days during 1992-1996 and 257 heavy fog days during 1997-June, 2003. (14 of these heavy fog days occurred in November and December 1996, and therefore are misclassified as occurring in the pre-activation period.)

4.9.2 Collision Rates Normalized to Fog Exposure

Clearly, there is enough difference in before-after fog incidence that simple comparison of before and after fog collisions totals would be misleading. Therefore, collisions in fog were normalized to the number of collisions per 100 heavy fog days before and after system activation. This is shown in Table 4.9.2.1 for all collisions in fog and in Table 4.9.2.2 for fatal and injury fog collisions. Note that in these tables, the "study" and "control" designations for the supplemental control highway SR99/I-205 are irrelevant, since both these directions are both being used as control comparison areas.

The change in the 'fog-day collision rate' for the study direction is compared with the change in the fog-day collision rate for the control directions. A positive change indicates an increase in fog–related collisions whereas a negative change represents a decrease. Note that these tables are based on a total of 48 fog collisions through 1996, including 20 F&I collisions, and 117 fog collisions after 1996, including 39 F&I collisions. Approximately half of these collisions in fog occurred in the SR-99 and I-205 control areas.

Table 4.9.2.1. Fog Collisions per 100 Heavy Fog Days.

	Study Direction			Control Direction		
	Before	After	% Change	Before	After	% Change
SR-120	4.92	0.78	-84%	1.64	1.17	-29%
I-5 N. of SR 120	3.28	2.33	-29%	2.46	3.50	42%
I-5 S. of SR 120	4.10	14.01	242%	0.00	1.17	NA
SR99/I-205	10.66	10.12	-5%	12.30	12.45	1%
Total	22.95	27.24	19%	16.39	18.29	12%

Table 4.9.2.2. F&I Fog Collisions per 100 Heavy Fog Days.

	Study Direction			Control Direction		
	Before	After	% Change	Before	After	% Change
SR-120	2.46	0.00	-100%	1.64	0.78	-53%
I-5 N. of SR 120	0.82	0.78	-5%	0.00	1.56	NA
I-5 S. of SR 120	2.46	5.06	106%	0.00	0.00	NA
SR99/I-205	4.10	2.72	-34%	4.92	4.28	-13%
Total	9.84	8.56	-13%	6.56	6.61	1%

The data presented in Table 4.9.2.1 and Table 4.9.2.2 show quite a mixed picture. There appear to be desirable outcomes for the study directions on SR-120 and I-5 north of SR-120, compared to control sections, however the normalized number of collisions in fog increased substantially on southbound I-5 south of SR 120. This occurred both for all fog collisions and the more serious F&I collisions, although not to the same extent for the F&Is. This is, of course, consistent with other patterns seen previously for that sub-section.

Due to the small number of F&I collisions that occurred in the presence of fog, it was not reasonable to develop comparisons of collision rates for these accident types. The rates would be far too subject to random variation.

However, in order to make some further comparison, Figure 4.9.2.1 shows the proportions of fog collisions to all collisions in the before and after periods. The comparison is made for the subsections of interest.

Fog collisions will also be considered in conjunction with the classification of accidents in §4.12.2.

Figure 4.9.2.1 shows a mixed result. For the study directions on I-5 north of SR 120 and along SR 120, there is clearly a drop in the fog-day-normalized rate of fog collisions after 1996. However, the opposite occurs on southbound I-5 south of SR-120, with a large increase. This is in marked contrast to the

decrease in the proportion of all inclement weather collisions, previously shown in Figure 4.8.2.3. The control sections vary, although most also show a decrease in the proportion of fog collisions after 1996.

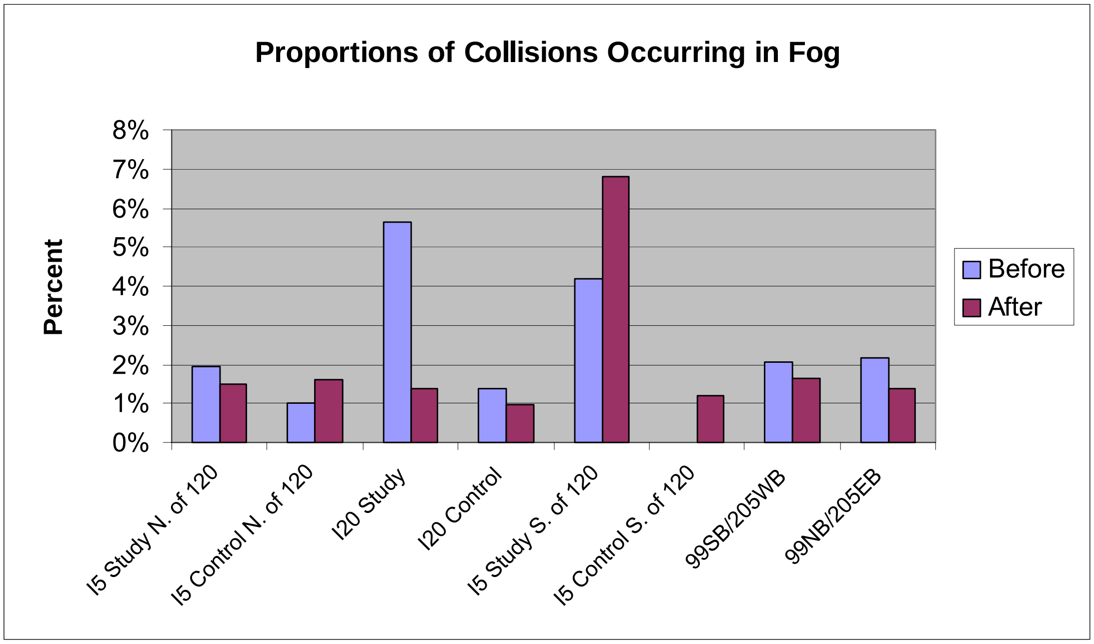

Figure 4.9.2.1. Proportion of Fog Collisions to All Collisions Before and After System Activation.

4.9.3 Fog Collisions in the AM Peak Traffic Period

Table 4.9.3.1examines fog-related collisions during the AM peak traffic period in the control and study directions of the CAWS. Since fog was very rare during the evening traffic peak, no purpose would be served by a cross-peak examination. Due to our lack of time-reliable fog data (to be sure that fog had indeed occurred in during the peak period), we were unable to normalize to just the set of peak periods in which fog was present, as we previously did for fog-day-MVM. We therefore normalized the peak period fog accidents to AM peak period MVM for both the study and control directions. In 1992 there were no peak period fog collisions in either direction, and in 1994 there were no peak period collisions in the control direction. Figure 4.9.3.1 represents the peak period fog collision rate for both directions normalized to peak period MVM.

Since the numbers are so small, the significance of these results are questionable. 1994 through 2000 the fog collision rate during the AM peak was consistently higher in the study direction compared with the control direction of the CAWS. Only one fog collision occurred in each of the directions in 2001. In early 2002, the collision rate relatively soared in both directions, a slightly higher rate in the control direction. It should be noted, however, that there were more an average of 24 fog days per year during the before period, and an average of 37 fog days per year during the after period, so that fog during peak periods was more likely in the after period. If these results are to be considered significant, they would indicate

an overall increase in the fog collision rates in the CAWS study direction during the matching AM peak traffic periods.

Table 4.9.3.1. Fog Peak Period Collision Rate AM Study Vs Am Control.

Year	Total Peak Period Fog Accidents Study direction only	Total Peak Period Travel (MVM)	Peak Period Fog Accident Rate (Accidents/ MVM)	Total 'Inclement Weather' Accidents Control direction only	Total Peak Period Travel Control (MVM)	Control Peak Period Fog Accident Rate (Accidents/ MVM)
1992	0	46.1	-	0	23.38	-
1993	2	46.65	0.043	2	26.53	0.08
1994	2	43.921	0.046	0	23.51	-
1995	3	46.99	0.064	1	26.34	0.04
Jan–Oct 96	3	41.393	0.072	0	21.9	-
Ann. Avg.	2.12	46.67	0.06	0.60	25.21	
Nov–Dec 96	**System Activation**					
1997	6	56.163	0.107	2	31.02	0.06
1998	7	55.872	0.125	1	31.02	0.03
1999	7	61.602	0.114	1	33.27	0.03
2000	9	69.018	0.13	3	35.29	0.09
2001	1	68.735	0.015	1	36.7	0.03
Jan–Mar 02	4	20.068	0.199	2	9.02	0.22
Ann. Avg.	7.67	65.28	0.21	2.67	33.90	0.19
% Increase	261.64%	39.88%	258.40%	344.44%	34.47%	

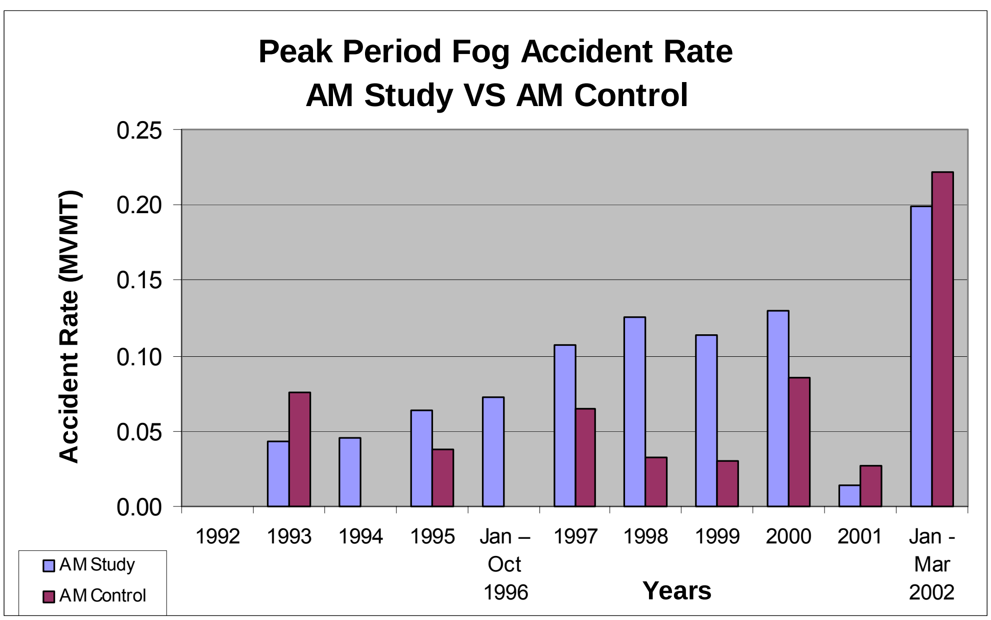

Figure 4.9.3.1 Fog Peak Period Collision Rate AM Study Vs AM Control.

4.10 Secondary Collisions

The ‘after’ period for this analysis extends only through March 2002, and the ‘before’ period is terminated at the end of October 1996, just before the CAWS system activation. This avoids the shift of accidents occurring during the first two months after system activation into the ‘before’ period. The control section is exclusively the control directions of I-5 and SR-120. The supplemental control sections of SR-99 and I-205 are not included.

4.10.1 Identification of Primary and Secondary Collisions

One goal of CAWS is to help prevent chain reaction collisions, referred to here as “related collisions” to distinguish this broader definition from multi-car “pile-ups”. Note that "primary" collisions are those collisions found to be a causal factor in at least one secondary collision, and do not include those collisions for which no secondary collisions were reported. For a collision to be classified as a primary, it must have at least one secondary associated with it.

In order to determine if a given collision was related to a previous collision, it was necessary to examine both TASAS records and the individual collision reports for every accident. Since reports usually do not explicitly indicate secondary status, we considered as key factors the temporal proximity, evidenced by the relative date and time for collision pairings, and geographic proximity in view of the traffic flow direction. Discrimination rules for this report generally followed those applied by Richard Raub (18). An interview conducted with Officer Montez of the Stockton CHP office helped determine average response times for local emergency personnel to collision sites as well as incident management methods. But a deeper examination was often needed: For example, in some cases a collision on I-5 was found to have been a related to a collision occurring on SR-120. Collisions causing congestion in the opposite flow direction were also included (looky loo effect) if a clearly causal relationship was indicated in the accident reports.

While some primary and secondary collision occur in opposite directions, all comparisons are separated according to direction because only the study direction is affected by the CAWS that might alert drivers of an accident obstruction ahead.

4.10.2 Primary Collisions

It is worthwhile to examine primary collisions, especially in proportion to all accidents, since a primary accident, as defined herein, is a key to one or more other accidents. A smaller proportion would indicate that a lower percentage of overall accidents were related.

During both the before and after periods, in both the study and control directions, we found a total of 235 secondary collisions that were deemed to be related to 164 primary collisions. Restricted to just fog-related collisions, these numbers reduced to a total of 12 secondary collisions related to 9 primary

collisions. However, we found only two related collisions that occurred on fog days in the control direction during both the before and after periods, so while fog data are normalized to the control direction, they are not effective for analysis.

Table 4.10.2.1 shows raw, yearly, directional numbers of primary and secondary collisions and the proportion of all collisions that are primaries. Related collisions are represented in several different ways. Primary collisions were isolated, and the ratio of these to the total of all collisions except secondary collisions is shown as a percentage. Secondary collisions are excluded from the normalization basis to assure that a reduction in this percentage, which normally would be a positive safety indicator, would not be incorrectly enhanced by an increase in secondary collisions (which would increase the denominator of the ratio). Collision totals were normalized to MVM and, when fog-day collisions are isolated, they are normalized to fog-day MVM. All are compared to the control direction using the same normalizations.

Figure 4.10.2.1 shows all-weather primary collisions normalized to total VMT for both the study and control directions. Figure 4.10.2.2 is a graphical representation of the proportion of primary collisions to the total of all collisions except secondary collisions.

A decrease in primary collision rates would indicate that the occurrence of secondary collisions is also decreasing, since they are related. And referring to the last column of Table 4.10.2.1, an increase in the ratio of primary collisions to secondary collisions is an indication that when reaction collisions occur, they involve fewer secondary vehicles. Both these metrics are indicators of the possible differential effectiveness of the CAWS for drivers in the study direction.

Table 4.10.2.1. Primary and secondary collisions, by year.

	Year	Direction	Primary	Secondary	Total collisions that are not secondaries	% of all collisions that are primaries	Ratio of primaries to secondaries
BEFORE	1992	Control	3	7	96	3%	1:2.33
		Study	3	3	77	4%	1:1.00
	1993	Control	8	9	83	10%	1:1.13
		Study	4	6	80	5%	1:1.50
	1994	Control	3	3	95	3%	1:1.00
		Study	4	6	80	5%	1:1.50
	1995	Control	4	6	135	3%	1:1.50
		Study	4	6	93	4%	1:1.50
	1996	Control	7	9	76	9%	1:1.29
		Study	7	11	85	9%	1:1.57
AFTER	1997	Control	7	9	118	6%	1:1.29
		Study	10	14	113	9%	1:1.40
	1998	Control	8	14	117	7%	1:1.75
		Study	10	16	126	8%	1:1.60
	1999	Control	4	11	123	3%	1:2.75
		Study	14	14	131	11%	1:1.00
	2000	Control	13	18	158	8%	1:1.38
		Study	27	41	213	14%	1:1.52
	2001	Control	7	11	148	5%	1:1.57
		Study	15	18	181	8%	1:1.20
	Jan – Mar 2002	Control	1	2	20	5%	1:2.00
		Study	1	1	30	3%	1:1:00

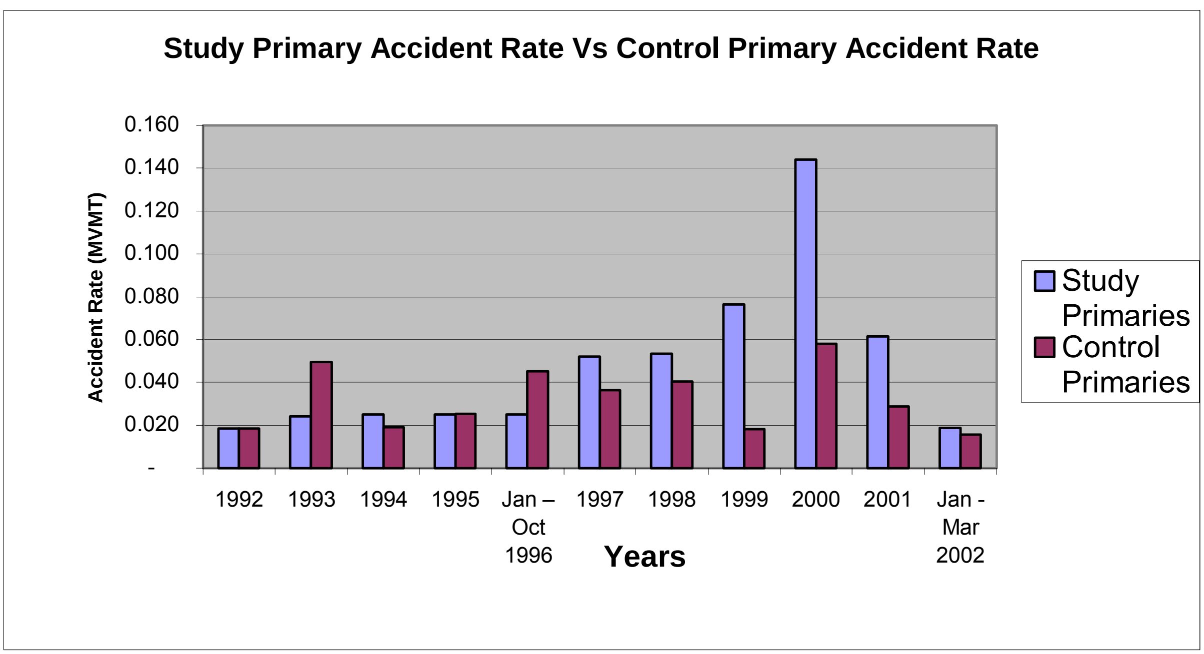

Figure 4.10.2.1. Primary Collision Rates, Study and Control Areas.

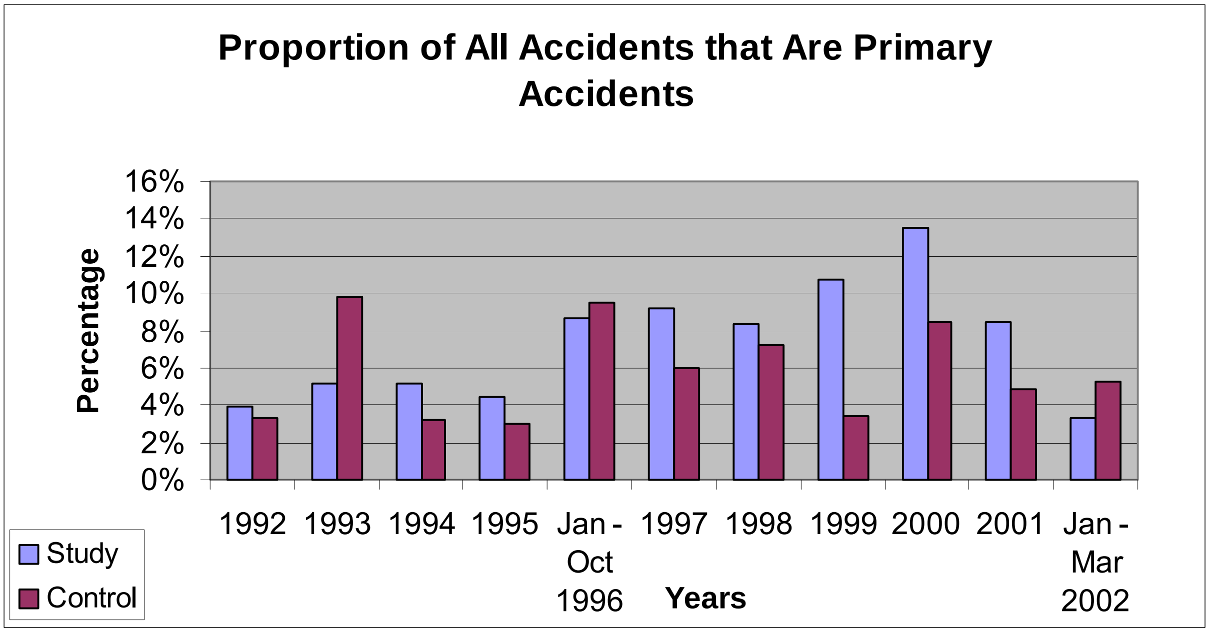

Figure 4.10.2.2. Proportion of Primary Collisions to All Collisions.

Figure 4.10.2.1 shows a substantial increase in primary collision rates in the CAWS study direction compared with the control direction, after activation of the CAWS. This indicates an increase in the number of related collisions, counting each related group just once (indexed by the primary collision). This rate reaches a peak in 2000, and the ratio between the study and control directions peaks in 1999. Rates in both directions decline abruptly after 2000. The study-to-control ratio decreases dramatically also in the last two years of observation. Since volume in both directions increased progressively during these years, as indicated previously by Table 4.3.1.2, this suggested an area-wide improvement decoupled from traffic volume, which was most pronounced in the study direction. Figure 4.10.2.2 shows a similar pattern, with primary collisions (therefore related collisions) accounting for a larger percentage of all collisions compared with the control direction 1997-2001, followed by a reduction in early 2002. These are negative indications of the effect of the CAWS system on related collisions for the first five years after activation, followed by the start of positive indications in 2002.

4.10.3 Secondary Collisions

While primary collisions are important because there would be no secondary collisions without them, the CAWS system is particularly empowered to prevent secondary collisions by its ability to warn drivers of slowed or stopped traffic ahead. Therefore a reduction in secondary collisions, or the ratio of secondary collisions to primary collisions in the study direction would serve as possible confirmation of this intended function of the CAWS.

Secondary collisions were normalized to vehicle miles traveled (MVM), and for secondary collisions in fog, to fog-day MVM. Figure 4.10.3.1 shows secondary collision rates in the CAWS study and control directions. The figure makes clear that secondary collision rates have always been greater in the study area compared with the control area, before and after the CAWS, although the ratio generally increases after the CAWS, and reaches significant levels of imbalance in 1998 and 1999. While the study direction peaked numerically in 2000, a similar but lesser peak occurred in the control direction also, conceivably related to the intermittent construction activities 1999-2002 which affecting both directions. A consistent reduction in secondary collisions occurred in both directions between 2000 and 2002, despite the progressive increase in volume in both directions, reported previously in Table 4.3.1.2. The trend is consistent with that observed for primary collisions, reported in Figure 4.10.2.1.

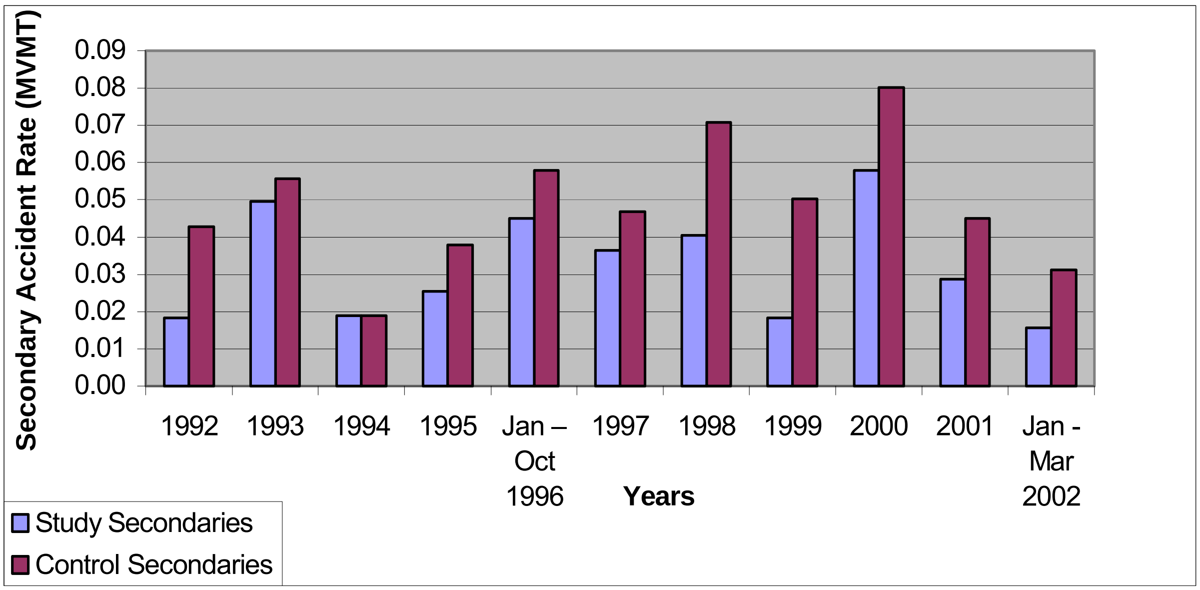

Figure 4.10.3.1. Secondary Collision Rates, by year.

4.10.4 Related Collisions in Fog

The two primary capabilities of the CAWS are the ability to alert drivers about hazards ahead, and to moderate the flow of traffic in the fog. Therefore, probably the best single indication of the effectiveness of the CAWS would be its ability to prevent secondary collisions under foggy conditions.

Table 4.10.4.1 is similar to Table 4.10.2.1 except that it considers only collisions for which fog was coded as a contributing factor in the CHP accident report. The first two columns contain raw data for primary and secondary fog collisions, followed by the three previously discussed relationships between primary, secondary and total collisions, in this case restricted on to collisions in fog. In all cases, a fog secondary collision must be associated with a fog primary collision.

Table 4.10.4.1. Primary and secondary collisions in fog, by year.

Year	Direction	Primary	Secondary	Total fog collisions that are not secondaries	% of all fog collisions that are primaries	Ratio of primaries to secondaries
1992	**Control**	0	0	0	0%	N/A
	Study	1	1	3	33%	1:1.00
1993	**Control**	0	0	2	0%	N/A
	Study	0	0	3	0%	N/A
1994	**Control**	0	0	0	0%	N/A
	Study	1	1	3	33%	1:1.00
1995	**Control**	0	0	1	0%	N/A
	Study	0	0	2	0%	N/A
1996	**Control**	0	0	1	0%	N/A
	Study	1	1	2	50%	1:1.00
1997	**Control**	0	0	2	0%	N/A
	Study	3	6	7	43%	1:2.00
1998	**Control**	0	0	1	0.5%	N/A
	Study	1	1	7	0%	1:1.00
1999	**Control**	0	0	1	0%	N/A
	Study	1	1	18	6%	1:1.00
2000	**Control**	1	1	3	33%	1:1.00
	Study	0	0	2	0%	N/A
2001	**Control**	0	0	1	0%	N/A
	Study	0	0	3	0%	N/A
Jan – Mar 2002	**Control**	0	0	3	0%	N/A
	Study	0	0	4	0%	N/A

Figure 4.10.4.1 is a graphical representation of the second column from the right in Table 4.10.4.1, showing the percentage of all fog collisions that are primary collisions in the study and control directions. The very small numbers must be kept in mind when viewing this graphic. The distilled observation is that in the five years before the CAWS, there were a total of six related collisions in fog in the study area, while there was zero in the control area. In the five years after the CAWS, there were thirteen related collisions in the study direction, while there were two in the control area. Clearly, the study area was prone to related collisions in fog both before and after the CAWS, and areas encountered an increase in related fog collisions, but the study direction fared worse in the after period. This is a negative finding for the effect of the CAWS on related collisions, although it is questionable if the numbers are large enough to show a true trend beyond random events. The finding is consistent with the all-weather findings of § 4.10.2 and 4.10.3.

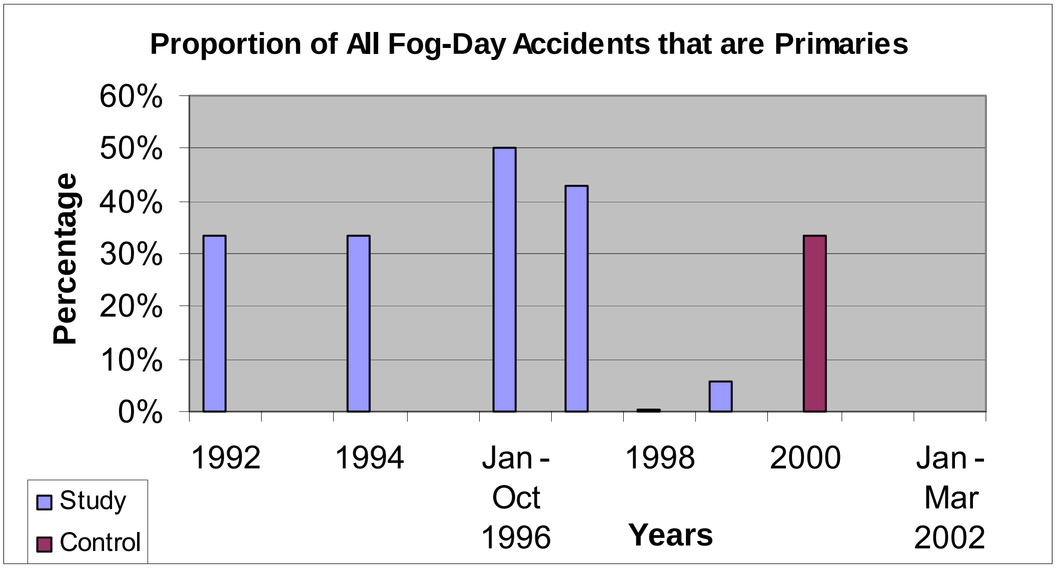

Figure 4.10.4.1. Proportion of Fog-Day Primary Collisions to All Fog-Day Collisions.

Figure 4.10.4.2 examines primary collisions in fog per hundred fog days in the study direction only, discriminated by major subsections in an effort to identify areas most prone to related fog collisions in fog. Calculation methods were the same as those used in § 4.9. During the before period there were no fog-primary collisions on I-5 North of SR-120.

Again, the small number of collisions diminishes the significance of these observations, but the location information is of some value: as in prior observations, the greatest problem occurred in the Mossdale Y merge area.

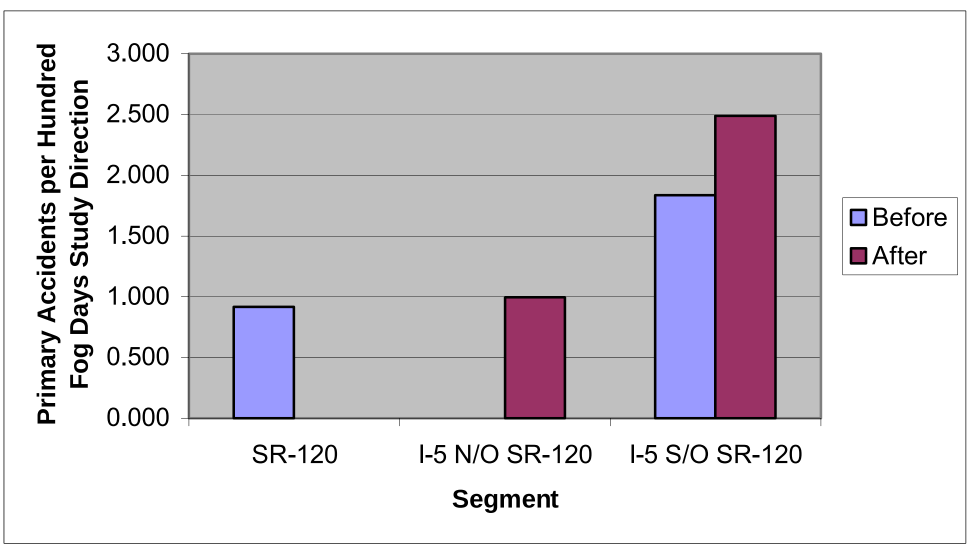

Figure 4.10.4.2. Primary Fog Collisions Per Hundred Fog Days.

Turning back to collision rates normalized to Fog-Day MVM, a comparison between the control and study directions is shown in Figure 4.10.4.3. Again, the plot is sparse due to the small number of collisions that me this stringent criteria. For the years 1993, 1995, 2001 and 2002, there were no related collisions in fog in either the study or control directions. (Please note this is also the case for all subsequent plots of primary collision in fog.) There was only one year (2000) in which fog-primary collisions occurred in the control direction. Unfortunately, in that year there was no data for the study direction, so no direct comparison of control direction to the study direction is possible.

Figure 4.10.4.3 and the similar plots that follow it, are included only because of the particularly high value of these types of collisions as an indicator of the effectiveness of the CAWS. The graph shows a concentration just before and just after the activation of the CAWS, but no clear indications that might bear on the effectiveness of the CAWS.

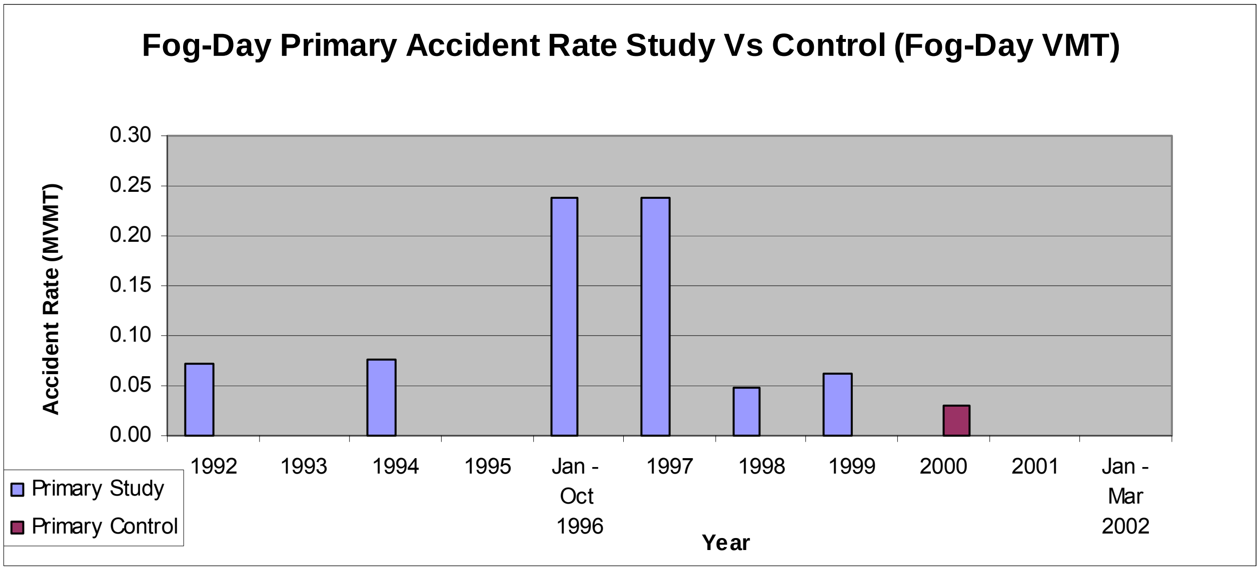

Figure 4.10.4.3. Fog-Day Collision Rates for Primaries (Normalized to Fog-Day VMT).

Since the number of days designated as fog days varied quite a bit year to year, it is useful to examine the same data normalized to the more even exposure basis of total annual travel volume (MVM). This is shown in Figure 4.10.4.4. Again, primary collisions are used as an indicator of groups of related collisions. This figure shows that the nearly equal value for 1996 and 1997 shown in Figure 4.10.4.3 were actually due to nearly twice the collision rate in 1997 compared with 1996, but the number of fog days increased in 1997 by the same ratio. Otherwise, within the quantization noise, the yearly rates in the study area were relatively constant both before and after the CAWS, and this type of collision was completely absent in 2001 and 2002.

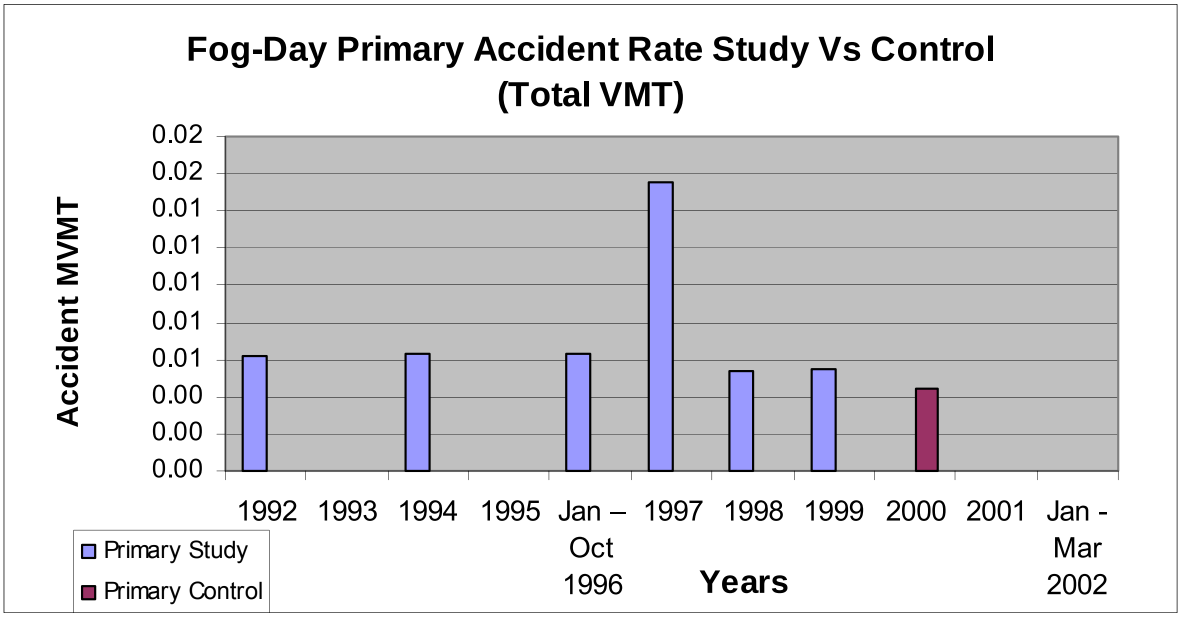

Figure 4.10.4.4. Fog-Day Collision Rates for Primaries (Normalized to Total MVM).

Figure 4.10.4.5 and Figure 4.10.4.6 duplicate the presentations of Figure 4.10.4.3 and Figure 4.10.4.4 but compare secondary collisions normalized to fog-day MVM in the study and control directions. Because there are often more secondary collisions than fog collisions, magnitudes and relations between rates are different from those of the primary collisions. These graphs reveal a significant increase in secondary collisions in fog, normalized to either overall travel volume, or fog-day travel volume, during the year immediately after the activation of the CAWS, followed by almost none in later years.

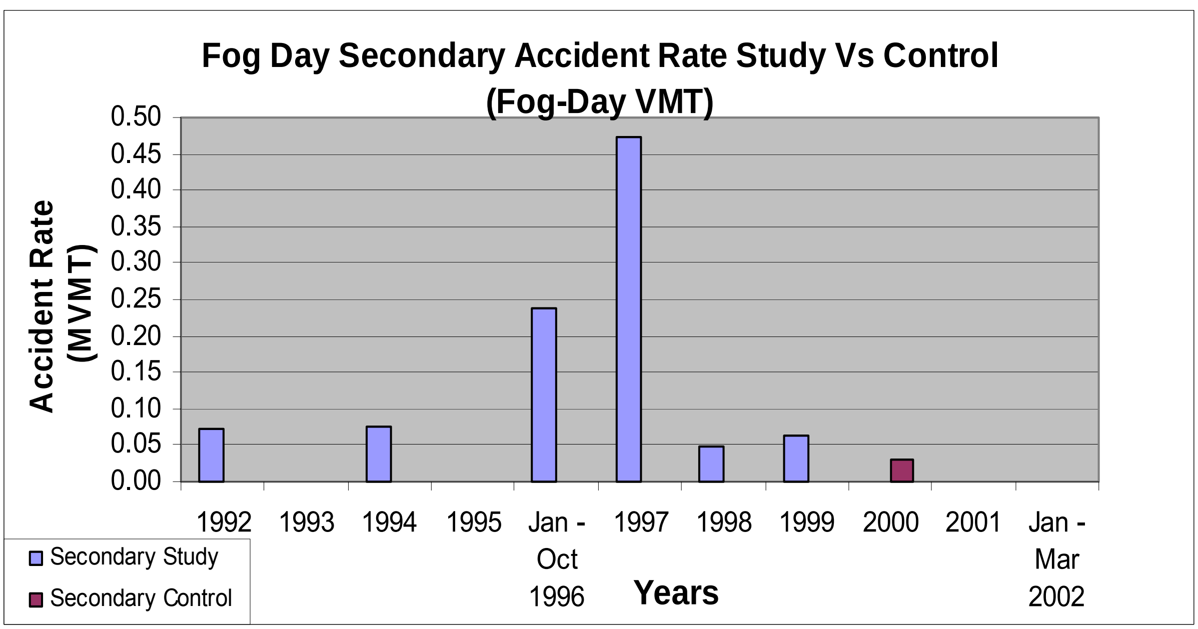

Figure 4.10.4.5. Fog-Day Collision Rate for Secondary Collisions, Normalized to Fog-Day MVM.

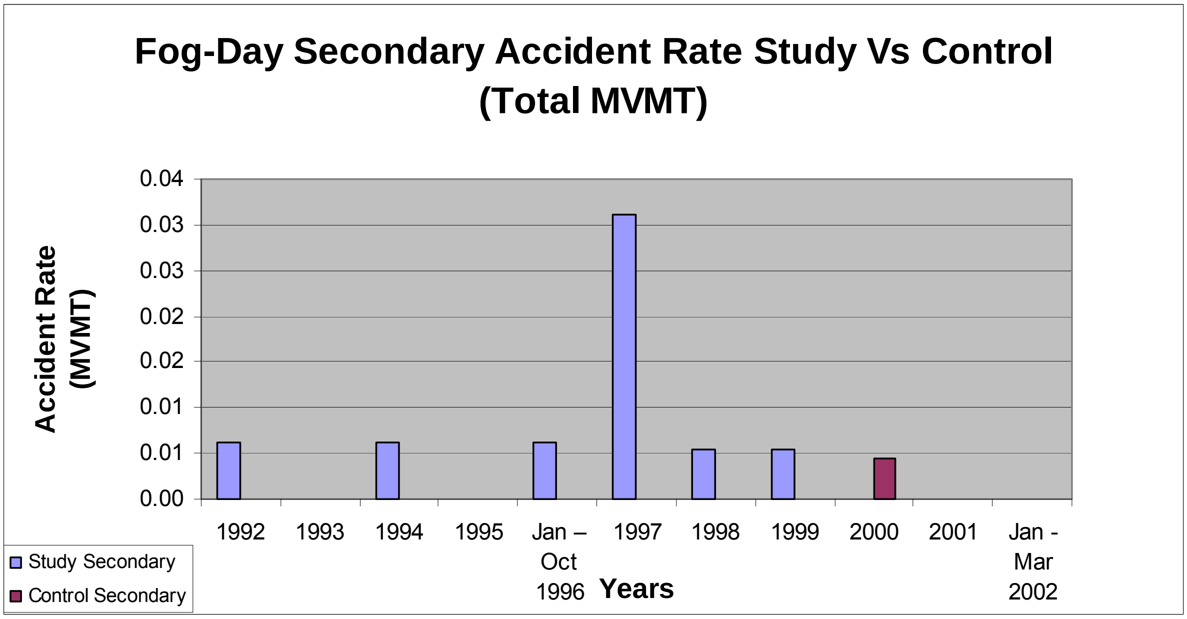

Figure 4.10.4.6. Fog-Day Collision Rates for Secondary Collisions, Normalized to Total MVM.

As illustrated by the last four graphs, there was an unusual spike in related collisions in fog in the year immediately after the activation of the CAWS, followed by a drop to almost none. While speculative, it is worth pointing out one of the findings from Section 3 of this report: during the first nine months of operation, the CAWS system used an incorrect mapping between the traffic sensors and the associated CMSs. This was corrected in late 1997. This software configuration error resulted in activation of the wrong CMS and inappropriate patterns of activation of traffic warning messages in some situations. And since traffic messages override fog warnings, these would provide the dominant warning information viewed by drivers, even in fog. It is possible that this flawed control mapping during the first year of operation could have been a factor in the spike for this class of collisions in 1997.

Considered over the entire before and after periods, however, Figure 4.10.4.7 shows that when normalized simply to the number of foggy days (units of 100 fog-days), the CAWS study direction experienced a significant reduction in this class of collisions after the activation of the CAWS, especially in the critical Mossdale Y area. This is an overall positive finding for the CAWS. Interestingly, it is supported by the negative finding for 1997, since together they suggest that the CAWS does have the capability to positively influence this particular class of accidents when it is operating properly.

The missing bar for the before period on the segment of I-5 north of SR-120 is because there were no fog secondary collisions during this period.

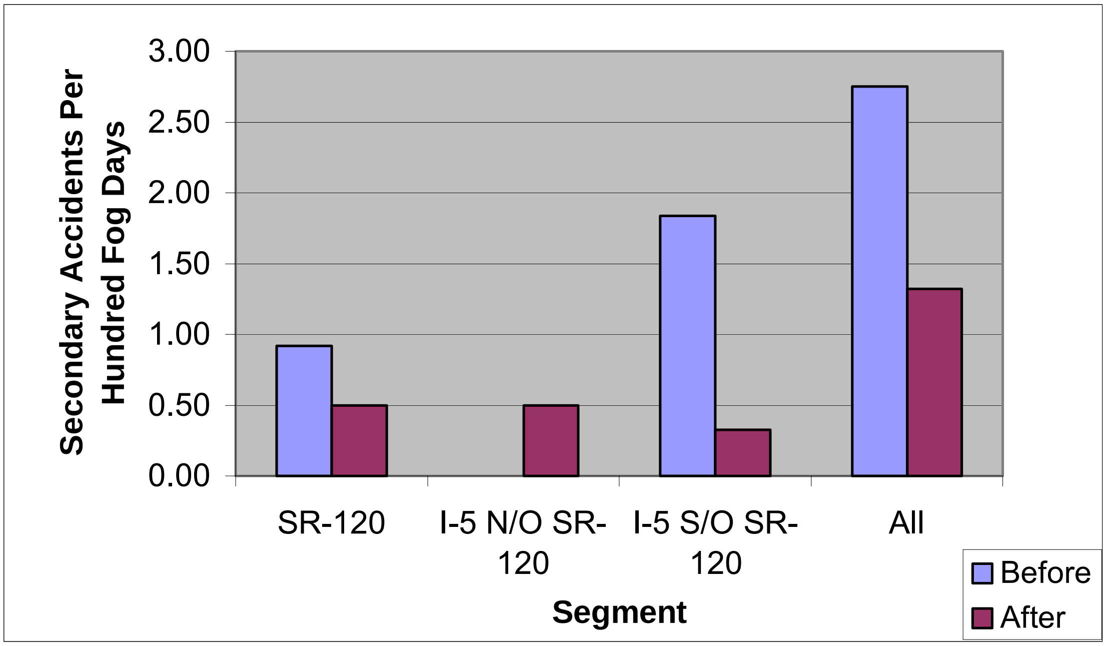

Figure 4.10.4.7. Secondary Collision Rates in Fog, Normalized to 100 fog days.

4.10.5 Related Collisions During Peak Periods

Table 4.10.5.1 lists all related collisions that occurred during the previously defined AM and PM peak traffic periods in both the study and control directions. The AM study period is compared with the PM control period, in an attempt to match the peak volumes and general traffic and driver characteristics. The values listed in the 'Primary' and 'Secondary' columns are raw data, whereas the '% of peak period collisions that are listed in the primaries' column, is the percentage of all peak period collisions that are primary collisions. Figure 4.10.5.1 represents this column graphically. The final column shows the ratio of primary collisions to secondary collisions.

Table 4.10.5.1. Peak Period Related Collisions AM Study Vs PM Control.

	Year	Direction	Primary	Secondary	Total number of peak period collisions not including secondaries	% of peak period collisions that are primaries	Ratio of primaries to secondaries
BEFORE	1992	PM Control	1	1	29	3%	1:1.00
		AM Study	1	1	19	5%	1:1.00
	1993	PM Control	3	2	22	14%	1:0.67
		AM Study	1	0	13	8%	1:0.00
	1994	PM Control	3	2	25	12%	1:0.67
		AM Study	2	3	21	10%	1:1.50
	1995	PM Control	0	0	12	0%	N/A
		AM Study	1	2	32	3%	1:2.00
	Jan – Oct 1996	PM Control	0	0	25	0%	N/A
		AM Study	4	6	40	10%	1:1.50
AFTER	1997	PM Control	2	2	47	4%	1:1.00
		AM Study	6	8	23	26%	1:1.33
	1998	PM Control	3	4	41	7%	1:1.33
		AM Study	3	5	46	7%	1:1.67
	1999	PM Control	0	1	65	0%	N/A
		AM Study	7	10	51	14%	1:1.43
	2000	PM Control	1	3	59	2%	1:3.00
		AM Study	14	22	83	17%	1:1.57
	2001	PM Control	3	5	49	6%	1:1.67
		AM Study	7	8	68	10%	1:1.14
	Jan – Mar 2002	PM Control	0	0	10	0%	N/A
		AM Study	0	0	10	0%	N/A

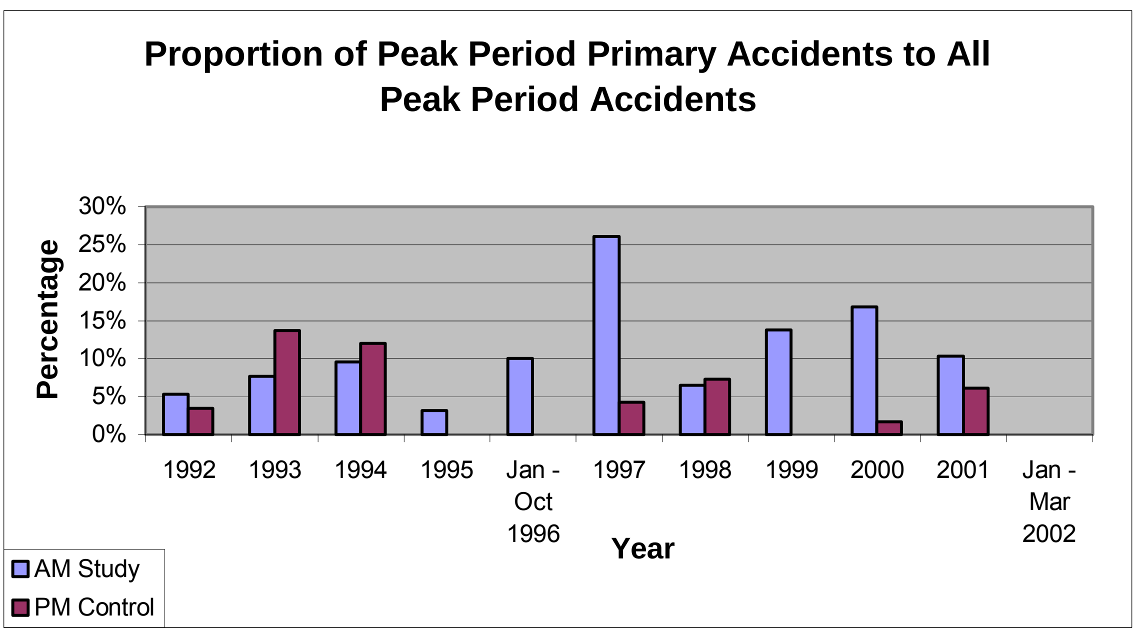

Figure 4.10.5.1. Proportion of Peak Period Primary Collisions to all Peak Period Collisions AM Study Vs PM Control.

This figure reports that in 1997, related collisions during the AM peak in the study direction made up an unusually large percentage of all peak period collisions. In the control direction during the PM peak period, related accidents were consistently a very small percentage of the overall collisions. High percentages and ratios of the study AM related accidents to the control PM related accidents also occurred in 1999 and 2000.

Table 4.10.5.2 duplicates the presentation of Table 4.10.5.1 but compares the AM peaks in both the study and control directions. As before, Figure 4.10.5.2 represents the data in the column '% of peak period collisions that are primaries'. Note that in when the AM control direction is now compared with the AM study direction, despite the slightly lower peak volume, related collisions make up a remarkably large percentage of collisions overall. And as will be seen in Figure 4.10.5.4, the overall actual collision rates in the control and study areas were nearly the same. The problem years for the AM peak in the control direction were 1996 and 1997. We have no information to explain this, but the trend for these years in the control direction may partially de-accentuate concerns about the 1997 peak in the study direction.

Table 4.10.5.2. Peak Period Related Collisions AM Study Vs AM Control.

	Year	Direction	Primary	Secondary	Total	% of Peak Period collisions that are Primaries	Ratio of Primaries to Secondaries
BEFORE	1992	AM Control	0	0	0	0%	N/A
		AM Study	1	1	2	5%	1:1.00
	1993	AM Control	1	1	2	8%	1:1.00
		AM Study	1	0	1	8%	1:0.00
	1994	AM Control	1	0	1	8%	1:0.00
		AM Study	2	3	5	10%	1:1.50
	1995	AM Control	1	2	3	8%	1:2.00
		AM Study	1	2	3	3%	1:2.00
	Jan – Oct 1996	AM Control	3	5	8	30%	1:1.67
		AM Study	4	6	10	10%	1:1.50
AFTER	1997	AM Control	3	5	8	30%	1:1.67
		AM Study	6	8	14	26%	1:1.33
	1998	AM Control	1	1	2	8%	1:1.00
		AM Study	3	5	8	7%	1:1.67
	1999	AM Control	0	1	1	0%	N/A
		AM Study	7	10	17	14%	1:1.43
	2000	AM Control	2	1	3	7%	1:0.50
		AM Study	14	22	36	17%	1:1.57
	2001	AM Control	3	2	5	13%	1.0.67
		AM Study	7	8	15	10%	1:1.14
	Jan – Mar 2002	AM Control	0	0	0	0%	N/A
		AM Study	0	0	0	0%	N/A

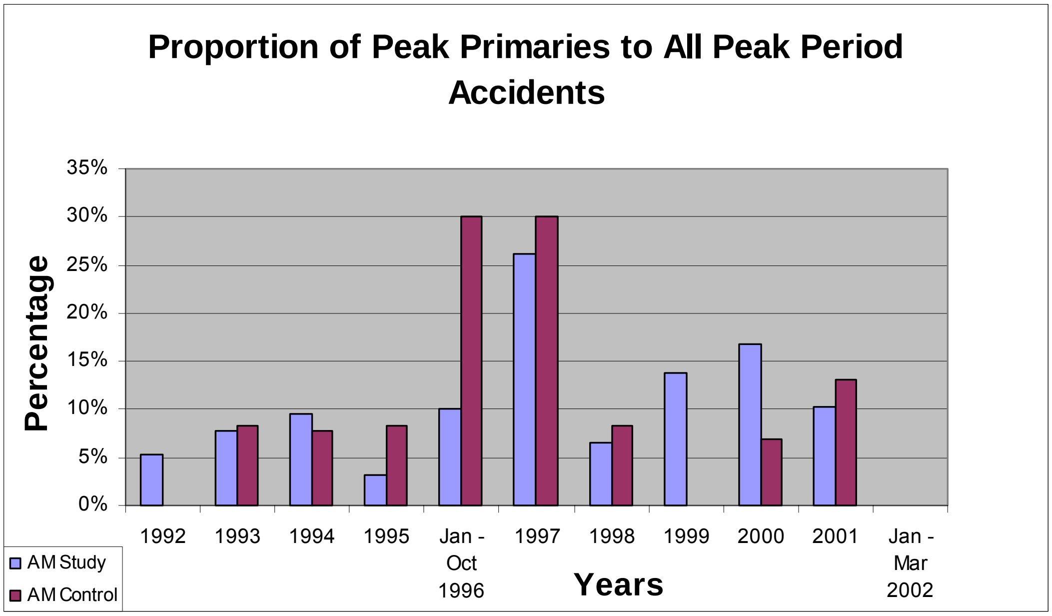

Figure 4.10.5.2. Proportion of Peak Period Primary Collisions to all Peak Period Collisions, AM Study Vs AM Control.

Whereas Figure 4.10.5.1 and Figure 4.10.5.2 examined proportions of related collisions to overall collisions during peaks, Figure 4.10.5.3 shows peak period primary collisions normalized to travel volume in MVM, comparing the study and control directions. During 1995, 1996, and 1999, there were no primary collisions in the control direction. There were no related collisions the first three months of 2002.

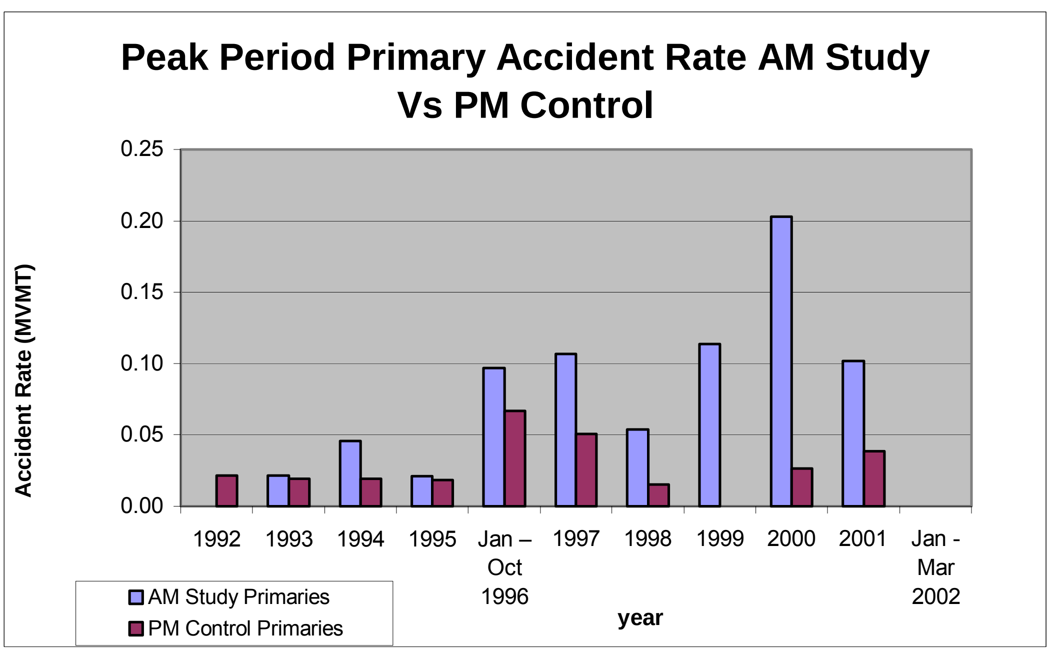

Figure 4.10.5.3. Peak Period Primary Collision Rate, AM Study Vs PM Control.

Figure 4.10.5.3 indicates that both in an absolute sense and in comparison with the PM control direction, the study area experienced a large increase in the rate of related collisions during the AM traffic peak in the years after the activation of the CAWS, peaking in 2002, and then declining in 2001. The three-month period of observation for 2002 was too short to draw valid conclusions about the trend from 2001.

When the two AM peak traffic periods are compared in Figure 4.10.5.4, the trend is nearly identical.

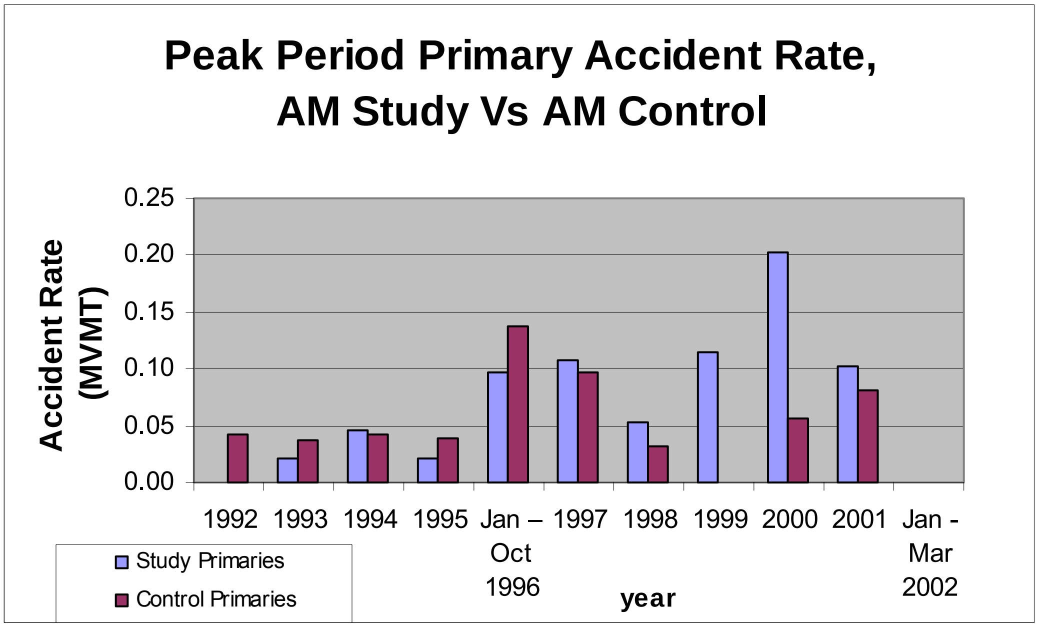

Figure 4.10.5.4. Peak Period Primary Collision Rate AM Study Vs AM Control.

Since the number of secondary collisions per primary can vary, Figure 4.10.5.5 shows all peak period secondary collisions normalized to peak period MVM for both directions. During 1992 there were no study direction peak period primary collisions, and no related collisions at all during the first three months of 2002. For years after 1996, there are consistently higher secondary accident rates during the AM peak, especially when compared with the control PM peak. Again, a peak is reached in 2000 followed by a decline to below the 1999 level. However, rates in the control direction during the opposite peak remained very small. These generally negative (but hopeful after 2001) findings are consistent with and amplify somewhat the findings for primary accidents.

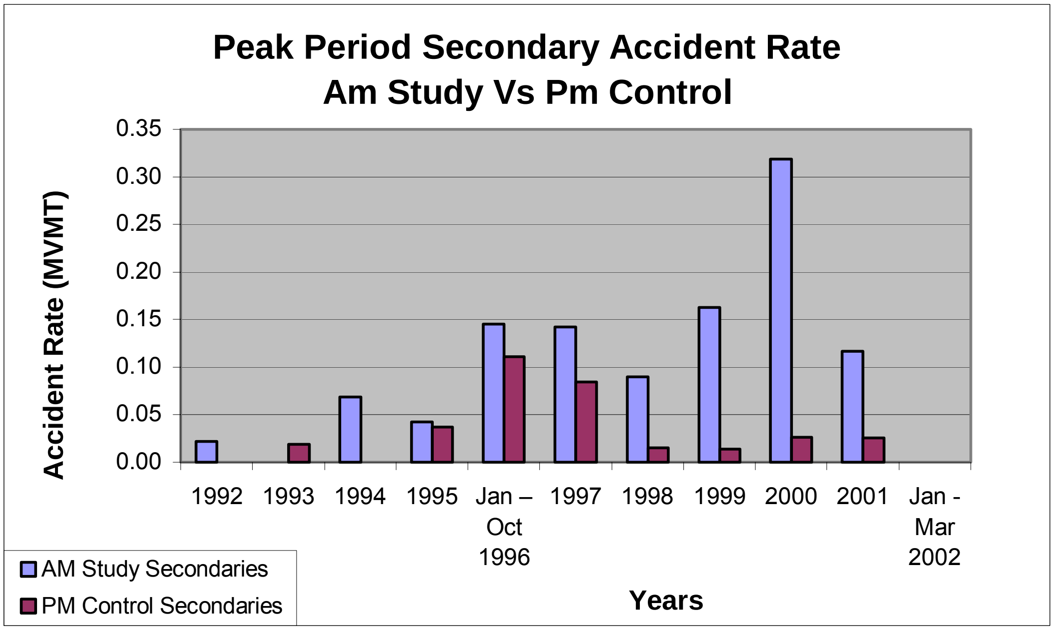

Figure 4.10.5.5. Peak Period Secondary Collision Rate, AM Study Vs PM Control.

Last, we examine repeat the presentation of Figure 4.10.5.5 except that we compare the AM peaks in both the study and control directions. Figure 4.10.5.6 shows the collision rate for secondary collisions occurring during peak period hours for both directions.

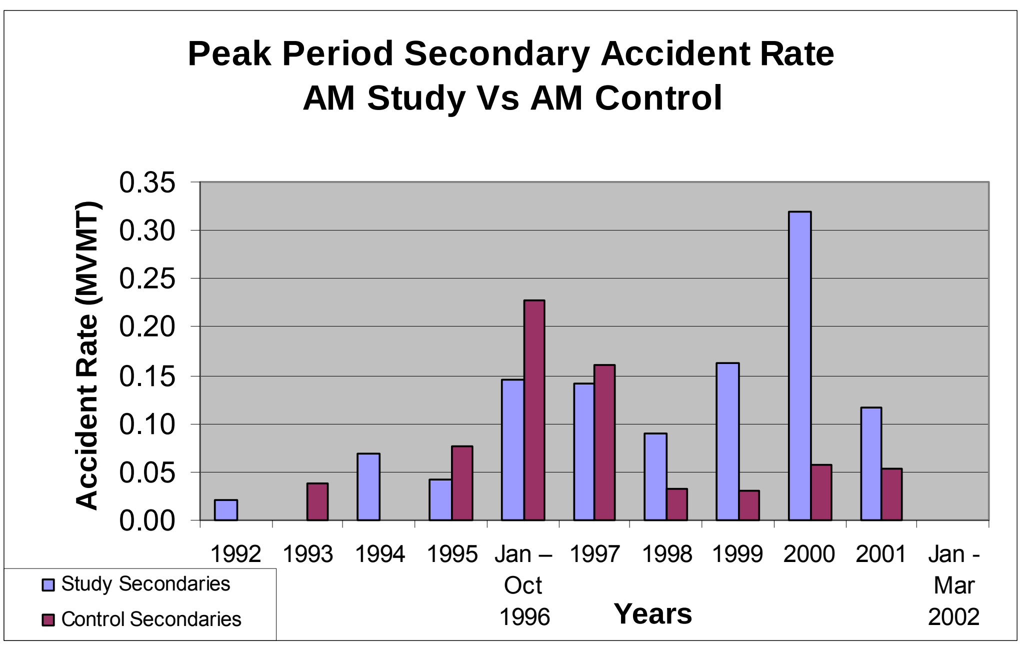

Figure 4.10.5.6. Peak Period Secondary Collision Rate, AM Study Vs AM Control.

In the same-peak comparison, a substantially larger rate of secondary accidents occurred in 1996 and 1997 in the control direction, but otherwise the trends are the same as those in the PM control peak comparison. Again, a large imbalance between the study and control areas is seen peaking in 2002 and then declining to below the 1999 level.

Overall, the observations of this analysis of related accidents during peak periods do not support a finding of CAWS effectiveness in reducing related accidents during the AM traffic peak, although the beginnings of an improvement trend may be evident for 2002 and later years.

4.11 Construction and Other Unusual Surface Conditions

It was noted in previously that construction occurred on I-5 between 1999 and 2001 affecting both directions, in particular the section of I-5 south of SR-120. Indeed, construction and major maintenance activities are well known to create hazards and, despite the best efforts of road crews, have been shown to be associated with higher than normal collision rates.

Here we repeat some of the previous analyses using a revised data set in which collisions coded as occurring in the presence of unusual road surface conditions are removed. Otherwise the data set is unchanged. Note that collisions reported in the presence of unusual road surface conditions are just 6% of total collisions, of which 60% are coded as involving construction and 24% involve foreign materials in the roadway.

Table 4.10.5.1. Construction Projects Which Could Have Influenced Collision Rates in the Study and Control Directions of the CAWS.

Award Date	Acceptance Date	Rte	Location Desc	Desc Of Work	Size of Project	Est Impact CAWS Area	Directions Effected
03/24/94	01/02/96	120	FROM WEST YOSEMITE AVENUE UNDERCROSSING TO ROUTE 99/120 SEPARATION	WIDEN TO 4 LANE FREEWAY	Major	Major	Both
05/15/97	10/06/98	5	0.6 KM NORTH OF FRENCH CAMP ROAD AND AT THE CALAVERAS RIVER BRIDGE	CHANGEABLE MESSAGE SIGNS	Medium	Minor	Control
07/14/97	05/03/99	5	0.7 KM NORTH OF FRENCH CAMP ROAD TO HAMMER LANE	REPLACE PORTLAND CEMENT CONCRETE	Major	Minor	Both
04/02/98	08/03/98	120	IN SAN JOAQUIN AND STANISLAUS COUNTIES AT VARIOUS LOCATIONS	RESURFACE ASPHALT CONCRETE	Medium	Minor	Both
04/29/99	09/07/99	5	NEAR LATHROP AND MANTECA AT VARIOUS LOCATIONS	RETROFIT CHANGEABLE MESSAGE SIGN	Medium	Minor	Both
05/13/99	10/04/01	5	FROM 0.1 KM S. OF DEUEL OVERHEAD TO 0.6 KM N. OF FRENCH CAMP TURNPIKE UC	STRUCTURAL SECTION REPAIR	Major	Major	Both
06/15/99	08/02/00	5	AT VARIOUS LOCATIONS	CLOSED CIRCUIT TELEVISION SYSTEM	Medium	Minor	Unknown
01/21/00	02/13/01	5	AT VARIOUS LOCATIONS	REPLACE BRIDGE GUARD RAIL	Medium	Minor	Unknown
08/11/00	04/16/01	120	FROM 0.25 KM W. OF 99 AND 120 SEPARATION TO 0.6 KM W. OF JACK TONE ROAD	RESURFACE ASPHALT CONCRETE	Major	Minor	Both
01/04/02	07/10/03	5	NEAR LATHROP, FRENCH CAMP AND STOCKTON AT VARIOUS LOCATIONS	CONSTRUCT MEDIAN BARRIER	Major	Major	Both
02/20/02	02/03/03	5	NEAR LATHROP AT VARIOUS LOCATIONS	INSTALL CHANGEABLE MESSAGE SYSTEM	Medium	Major	Control
04/11/02	09/17/02	5	IN SAN JOAQUIN, STANISLAUS AND MERCED COUNTIES AT VARIOUS LOCATIONS	ASPHALT CONCRETE SURFACING	Medium	Minor	Both
05/17/02	11/04/02	5	NEAR LATHROP AT SAN JOAQUIN RIVER BRIDGE	RESURFACE BRIDGE DECK	Medium	Medium	Both
11/26/02	05/01/03	5	IN LATHROP AT ROUTE 5 AND 120 SEPARATION	INSTALL OVERHEAD SIGN	Minor	Minor	Unknown
05/27/03	09/25/03	5	IN SAN JOAQUIN AND MERCED COUNTIES AT VARIOUS LOCATIONS	TREAT BRIDGE DECKS	Minor	Minor	Both
06/07/04	06/21/05	120	IN MANTECA FROM AIRPORT WAY OC TO 0.1 KM WEST OF SPRECKLES ROAD UC	TRAFFIC MONITORING STATION	Medium	Minor	Unknown
11/09/04	05/06/05	5	IN SAN JOAQUIN AND CALAVERAS COUNTIES AT VARIOUS LOCATIONS	SEAL BRIDGE DECKS	Medium	Minor	Minor
03/15/05	07/28/05	5	IN SAN JOAQUIN COUNTY NEAR MOSSDALE AT SAN JOAQUIN RIVER BRIDGE	REHABILITATE BRIDGE DECK	Medium	Medium	Both
05/03/05	08/17/05	120	IN SAN JOAQUIN COUNTY AT VARIOUS LOCATIONS	ASPHALT CONCRETE SURFACING	Medium	Minor	Minor
03/24/94	01/02/96	120	FROM WEST YOSEMITE AVENUE UNDERCROSSING TO ROUTE 99/120 SEPARATION	WIDEN TO 4 LANE FREEWAY	Major	Major	Both
05/13/99	10/04/01	5	FROM 0.1 KM S. OF DEUEL OVERHEAD TO 0.6 KM N. OF FRENCH CAMP TURNPIKE UC	STRUCTURAL SECTION REPAIR	Major	Major	Both
05/17/02	11/04/02	5	NEAR LATHROP AT SAN JOAQUIN RIVER BRIDGE	RESURFACE BRIDGE DECK	Medium	Medium	Unknown
03/15/05	07/28/05	5	IN SAN JOAQUIN COUNTY NEAR MOSSDALE AT SAN JOAQUIN RIVER BRIDGE	REHABILITATE BRIDGE DECK	Medium	Medium	Unknown

Table 4.10.5.1 is based on data provided by Kevin Chan of Caltrans Construction Division in Sacramento. It shows all construction projects that took place either entirely or partially in the CAWS area, both the study and control directions, from 1994 through 2003 (limits of available records). These projects do not include unscheduled maintenance or emergency repair activities performed by Caltrans personnel, including accident-related roadway repairs. Four of these projects could have had a significant effect on collision rates in the CAWS area:

Table 4.10.5.2. Major Projects Affecting the CAWS Area.

03/24/94	01/02/96	120	FROM WEST YOSEMITE AVENUE UNDERCROSSING TO ROUTE 99/120 SEPARATION	WIDEN TO 4 LANE FREEWAY
05/13/99	10/04/01	5	FROM 0.1 KM S. OF DEUEL OVERHEAD TO 0.6 KM N. OF FRENCH CAMP TURNPIKE UC	STRUCTURAL SECTION REPAIR
05/17/02	11/04/02	5	NEAR LATHROP AT SAN JOAQUIN RIVER BRIDGE	RESURFACE BRIDGE DECK
03/15/05	07/28/05	5	IN SAN JOAQUIN COUNTY NEAR MOSSDALE AT SAN JOAQUIN RIVER BRIDGE	REHABILITATE BRIDGE DECK

The first involved the widening of much of the CAWS stretch of 120 from two to four lanes. The impact of this none-month project on this section of the CAWS area was probably substantial. The structural repair of I-5 included most of the segment of I-5 north of SR-120 in both directions. The last two smaller projects affected the segment of I-5 south of SR-120, both on the San Joaquin River Bridge. The directions affected aren't clear from available construction records, but it is assumed that both directions of the dual bridge were resurfaced at the same time. The latter project occurred in 2005, outside of our period of analysis.

In addition to the smaller (but significant) projects and unscheduled repair, it appears overall that most of the CAWS SR-120 segment was affected by construction during the control period, and that both directions of both segments of I-5 were affected by construction during the after period, and probably to nearly equal degrees. If construction were a potential causal factor in accidents, its deleterious effects after CAWS activation would probably show up more on the I-5 segments of the CAWS than the SR-120 segment.

4.11.1 All-Weather Collisions in the Absence of Construction

We consider here the control and study directions of the CAWS, as well as each direction of the supplemental control areas. Figure 4.11.1.1 shows the basic comparison for total accident rates analogous to that presented in Figure 4.4.1.2. On the whole, eliminating the collisions related to unusual surface conditions appears in this example to slightly reduce all the previous rates proportionally, with no change in the relative differences.

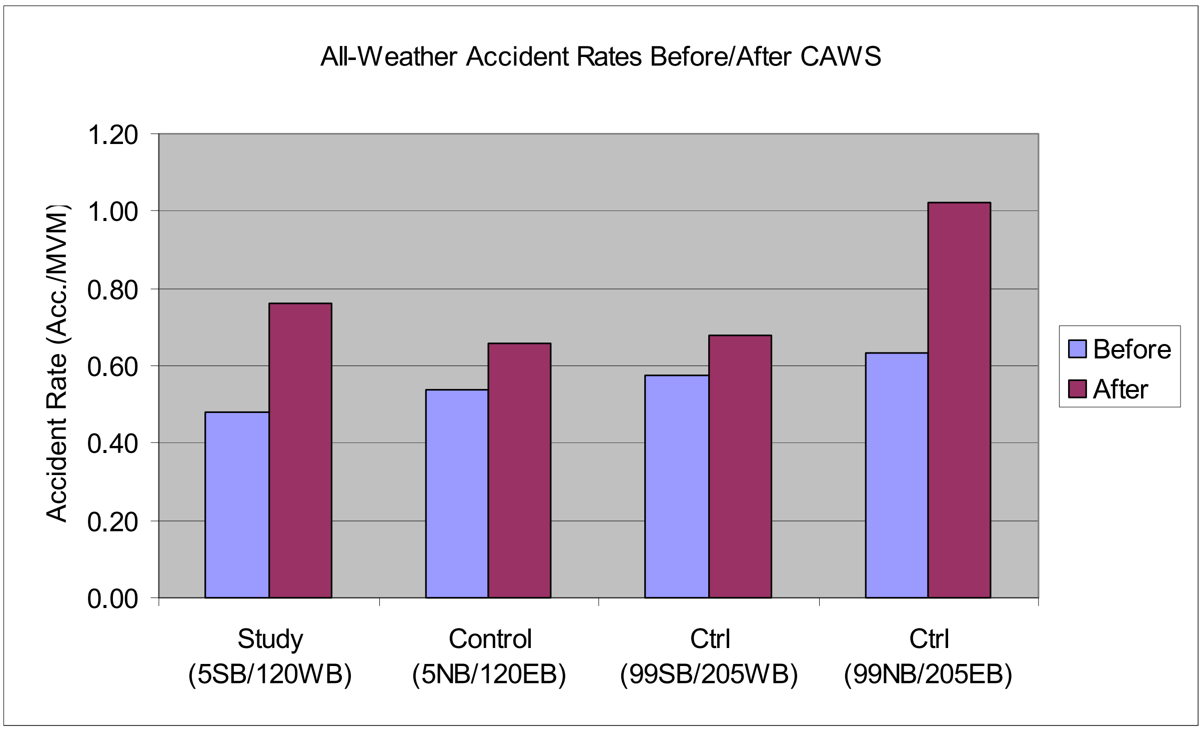

Figure 4.11.1.1. Before-After Comparisons for Total Accident Rates Without Unusual Surface Conditions.

4.11.2 Inclement Weather in the Absence of Construction

The same comparisons made using only collisions reported during inclement weather (rain and fog) appear in Figure 4.11.2.1. This graph is virtually identical to the corresponding graph shown in Figure 4.8.1.2. This is not really surprising, since construction would be expected to shut down if at all possible during periods of inclement weather.

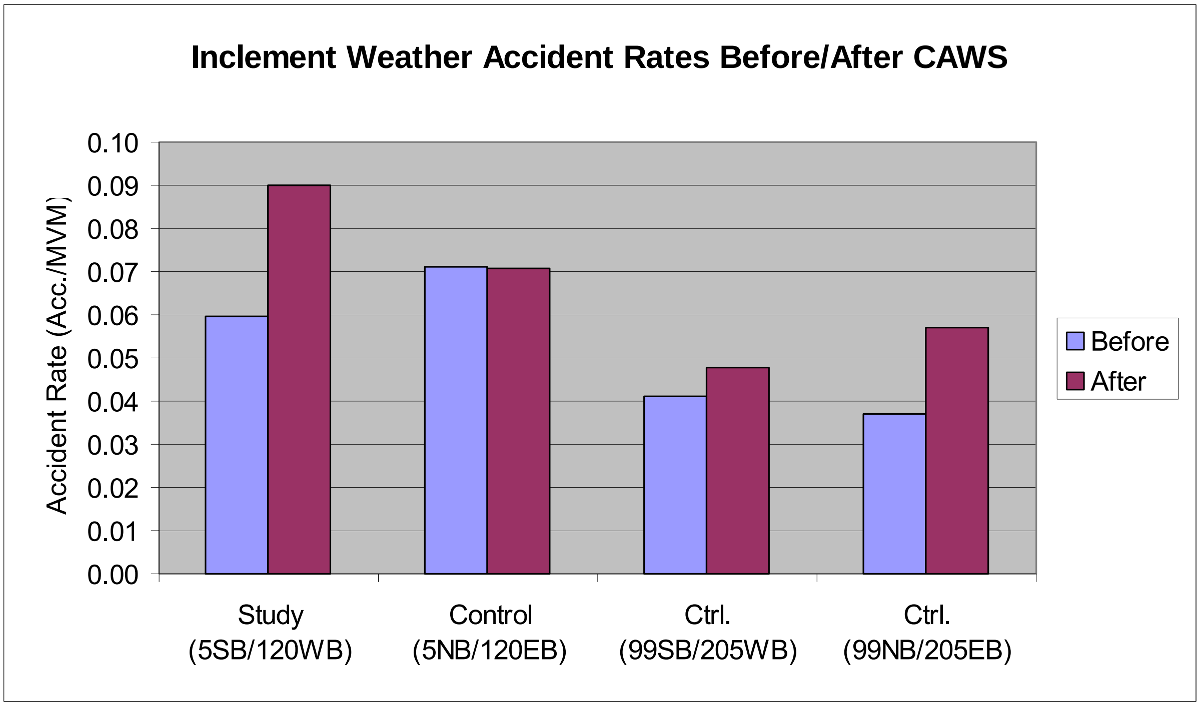

Figure 4.11.2.1. Inclement Weather Before-After Collision Rates for Study Direction and Controls Without Unusual Surface Conditions.

4.11.3 By Sub-section in the Absence of Construction

If we disaggregate the study section into its constituent sub-sections, the resulting collision rates shown in Figure 4.11.3.1 are almost identical to the comparisons shown in Figure 4.5.2.7 where collisions in the presence of unusual road surface conditions are included.

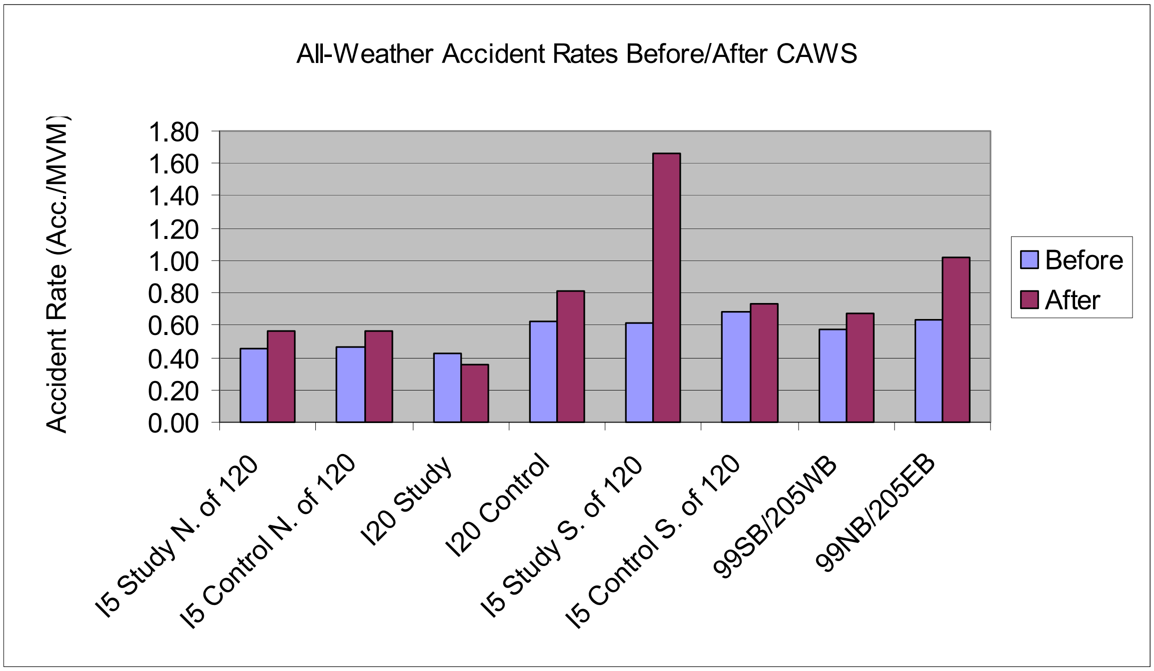

Figure 4.11.3.1. Before-After Collision Rates on Highway Segments and Control Without Unusual Surface Conditions.

4.11.4 Peak Traffic Periods in the Absence of Construction

As a final comparison, Figure 4.11.4.1 shows the all-weather AM peak period collision rates in the study direction compared to the control sections in the PM peak. Although there is a slight reduction in collision rates evident, especially in the after period, the comparisons are very similar to those shown in Figure 4.6.2.1, where collisions in the presence of unusual road surface conditions are included.

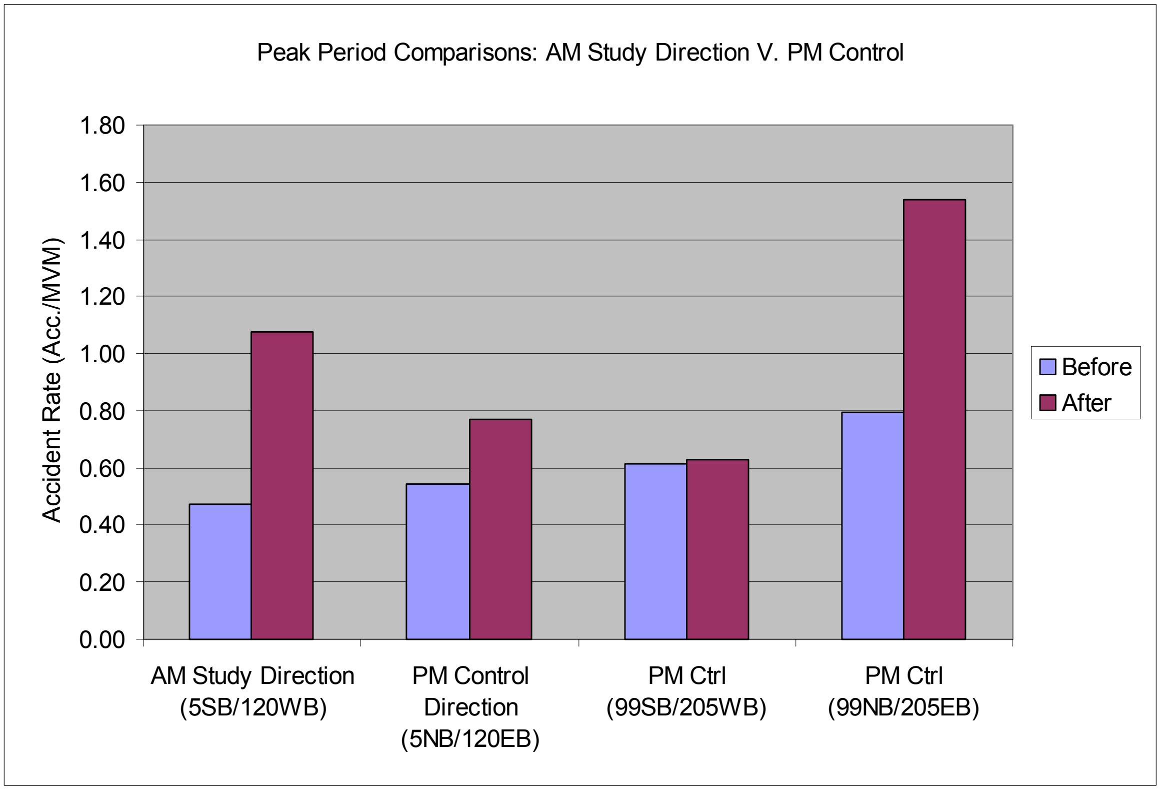

Figure 4.11.4.1. Peak Collision Rate Comparisons: AM Study Direction V. PM Control Without Unusual Surface Conditions

The conclusion from this investigation is that removing collisions occurring in the presence of unusual road surface conditions, which are mostly construction-related, reduces estimated collision rates slightly in all areas, but does not fundamentally change any of the previously reported findings.

4.12 Collision Classification

4.12.1 Role as Indicators of CAWS Effectiveness

The CAWS has specific capabilities and objectives; it was designed to reduce collision rates and severity in fog, high winds, and in advance of prior traffic accident or congestion sites. It therefore would be expected to have a greater effect on some type of collisions than others. Therefore, aside from numeric totals and rates of collisions, there is some value in examining the relative mix of collision types. The CAWS is uniquely capable of providing advanced warning of slow or stopped traffic ahead, or other roadway obstructions, that may be beyond the sight distance of drivers. This is the basis for its traffic warning function, which overrides fog warning messages due to the relative urgency of this information.

This ability should be expected to especially affect a reduction in rear end collisions, and possibly collisions with objects in the roadway (including construction and traffic diversion barriers). Rear-end collisions in fog are the greatest concern in fog, since they can be directly attributed to driver visibility limitations. Conversely, head-on collisions would probably be minimally affected by the CAWS since they are not targeted by the repertoire of CMS messages (most of these accidents would be expected to occur due to wrong-way drivers on off-ramps).

It is expected that other factors could differentially affect the CAWS study area relative to the control area in each time period. In terms of relative exposure, traffic volumes increased significantly over these years, but approximately equally between the study and control directions.

4.12.2 All-Weather and Fog

We examine the breakdown of all collisions occurring in the study and control directions of the CAWS by classification assigned by the CHP officer filing the accident report, and by the coding of visibility as a causal factor. Unfortunately, the accident classification types used by the CHP do not conclusively identify the event that initiated the collision, but rather the outcome of the collision. Thus, an accident may be classified as an “Overturn” which was actually a rear-end collision resulting in an overturned vehicle. However, it is highly unlikely that an accident classified as a rear end collision was actually a head-on or sideswipe collision. Therefore, viewed conservatively, we may make reasonable inferences about the potential influence of the CAWS by examining the distribution of collision types in the study and control directions of the CAWS.

Table 4.3.1.1 shows these classification data for the CAWS study direction, for accidents in all weather conditions, followed by accidents occurring in fog. Table 4.12.2.2 shows equivalent data for the control direction. In these tables, the percentages are more important than the totals.

In these tables, we are focusing on the percentages rather than the accident totals.

Table 4.12.2.1 Collisions by type in the CAWS study directions in the years before and after the deployment of the CAWS, for all weather conditions and fog conditions.

	1993-1996				1997-2003			
Accidents	All-Weather		Fog		All-Weather		Fog	
Total	413	100.00%	15	100.00%	1150	100.00%	46	100.00%
Head On-A	2	0.48%	0	0.00%	9	0.78%	0	0.00%
Sideswipe-B	92	22.28%	3	20.00%	231	20.09%	10	21.74%
Rear End-C	82	19.85%	5	33.33%	409	35.57%	29	63.04%
Broadside-D	20	4.84%	2	13.33%	47	4.09%	0	0.00%
Hit Object-E	145	35.11%	2	13.33%	321	27.91%	6	13.04%
Overturn-F	37	8.96%	1	6.67%	65	5.65%	1	2.17%
Auto-Pedestrian-G	0	0.00%	0	0.00%	3	0.26%	0	0.00%
Other-H	35	8.47%	2	13.33%	63	5.48%	0	0.00%
Not Stated-<	0	0.00%	0	0.00%	2	0.17%	0	0.00%

Table 4.12.2.2. Collisions by type in the control directions of I-5 and SR-120 in the years before and after the deployment of the CAWS.

	1993-1996				1997-2003			
Accidents	All-Weather		Fog		All-Weather		Fog	
Total	456	100.00%	5	100.00%	1049	100.00%	13	100.00%
Head On-A	4	0.88%	0	0.00%	9	0.86%	0	0.00%
Sideswipe-B	90	19.74%	2	40.00%	183	17.45%	2	15.38%
Rear End-C	111	24.34%	0	0.00%	310	29.55%	6	46.15%
Broadside-D	18	3.95%	1	20.00%	55	5.24%	0	0.00%
Hit Object-E	169	37.06%	2	40.00%	342	32.60%	4	30.77%
Overturn-F	29	6.36%	0	0.00%	98	9.34%	1	7.69%
Auto-Pedestrian-G	2	0.44%	0	0.00%	3	0.29%	0	0.00%
Other-H	33	7.24%	0	0.00%	47	4.48%	0	0.00%
Not Stated-<	0	0.00%	0	0.00%	2	0.19%	0	0.00%

In the study direction prior to the CAWS, rear-end collisions accounted for 20% of all collisions, and 33% of the collisions in fog. After the CAWS, rear-end collisions accounted for 36% of all collisions, and 63% of the collisions in fog. Rear end collisions represented a significantly greater proportion of all accidents after the CAWS, especially in fog.

In the control direction prior to the CAWS, rear-end collisions accounted for 24% of all collisions, and 0% of the collisions in fog. After the CAWS, rear-end collisions accounted for 30% of all collisions, and 46% of the collisions in fog. Like the study area, the rear-end collisions were better represented after the CAWS, especially in fog. However, the increase was not as great.

4.12.3 Difference Trends

Figure 4.12.3.1 and Figure 4.12.3.2 compares the difference between the percentage of collisions of each type in the study area and the percentage of that type in the control area, with the blue (left) bar showing this difference in the years before the CAWS, and the red (right) bar showing this difference in the years after the CAWS. The difference in percentages had to be used rather than the ratio of the percentages since for some types of collisions there were zero occurrences in the control area for the given period.

$$\left.\frac{\text{Number of collisions of given type}}{\text{Total number of collisions}}\right|_{\text{Study Area}} - \left.\frac{\text{Number of collisions of given type}}{\text{Total number of collisions}}\right|_{\text{Control Area}}$$

Figure 4.12.3.1 shows the differences for all-weather accidents, and Figure 4.12.3.2 shows the difference for accidents occurring in fog. A positive (or negative) value means that this type of accident was relatively more (or less) prevalent in the CAWS study area compared with the control area during the given period.

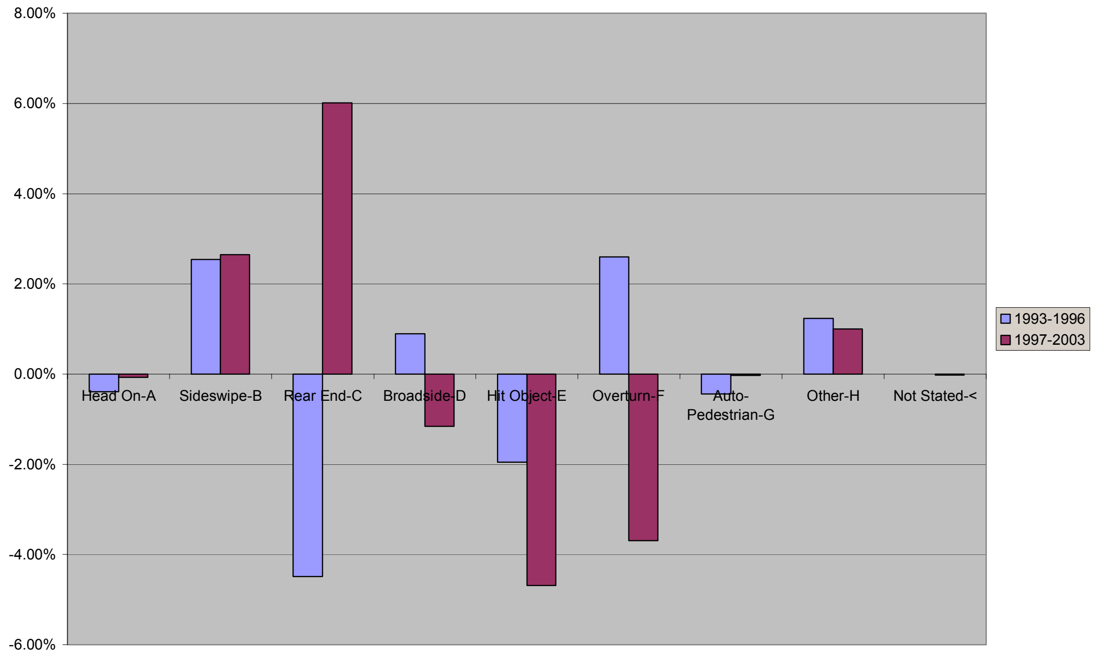

Figure 4.12.3.1. Difference in the percentages of rear-end collisions <u>in all weather</u> between the control and study areas in the years before and after the deployment of the CAWS.

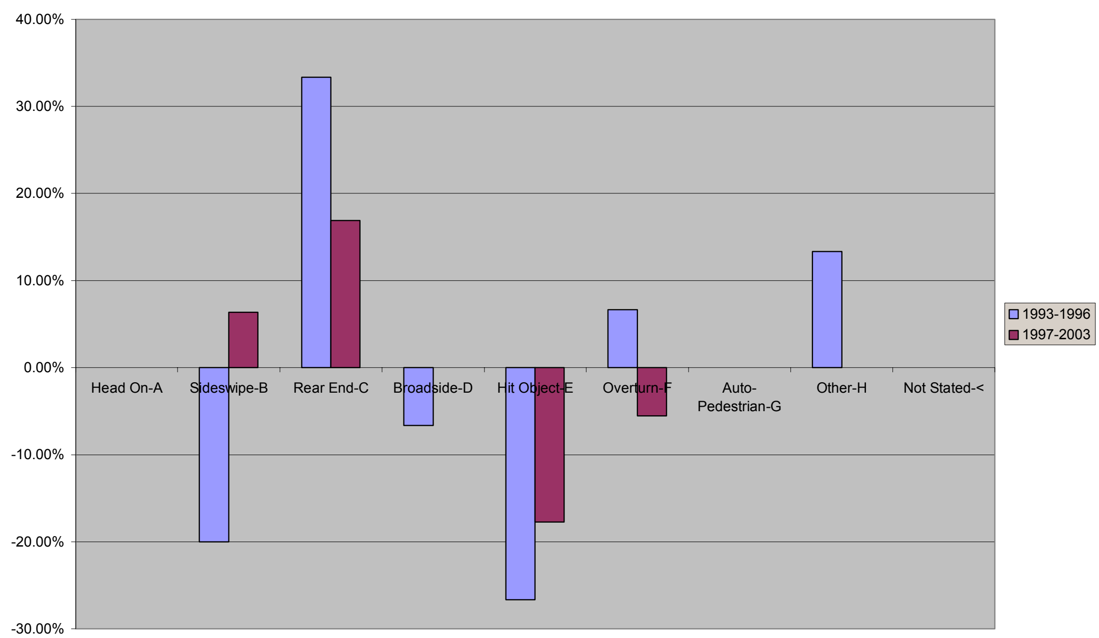

Figure 4.12.3.2. Difference in the percentages of rear-end collisions <u>in fog</u> between the control and study areas in the years before and after the deployment of the CAWS.

Focusing again on rear-end accidents, Figure 4.12.3.1 shows that in all weather conditions prior to the CAWS, rear-end collisions constituted 4.5% fewer of the collisions in the CAWS study direction relative to the control area, while after activation they constituted a 6% greater proportion of the overall accident mix, a net in crease of 10.5%. However, when rear-end collisions in fog were isolated, Figure 4.12.3.2 indicates that prior to the CAWS, rear-end collisions constituted 34% more of the collisions in the CAWS study direction relative to the control direction, while after activation they constituted only a 17% greater proportion of the overall accident mix, a net decrease of 17%.

Looking at the raw numbers for collisions in fog in the CAWS study direction, the rear-end collisions increased from 5 out of 15 total accidents before the CAWS to 29 out of 46 total accidents after the CAWS in the study area, but in the control direction they increased from 0 out of 5 in the before period to 6 out of 13 in the after period.

For comparison, for sideswipe accidents in fog in the study direction, 20% (3 out of 15) occurred before CAWS and 22% (10 out of 46) occurred after CAWS. While in the control area, 40% (2 out of 5) occurred before CAWS and 15% (2 out of 13) occurred after CAWS.

This portrayal of the data is subject to multiple interpretations. Rear-end collisions in fog were more prevalent in the study V the control directions of the CAWS area both before and after the CAWS, but the ratio was significantly less in the after period. This is a positive finding for the CAWS. This trend is not observed, however, for rear-end collisions overall. One could infer from these findings that if the lower increase in the study area after the CAWS for fog collisions could be attributed to the CAWS, the CAWS was more effective at reducing rear end collisions in fog than in weather conditions overall, a conclusion which is consistent with its design objectives. However, we caution that the small numbers for such a restricted class of collisions make the numeric trends subject to noise (natural random fluctuations) which dilute their significance.

4.13 Multivariate (Generalized Linear) Modeling Analysis

As previous noted, collision rates can provide misleading results since they are simple one or two-dimensional tabulations that ignore the possible complex interactions that may exist among the numerous traffic and environmental variables which apply to each highway segment and time period. Multivariate modeling provides an alternative approach to isolating the associations between collisions and related factors. For purposes of the present evaluation, it is useful due to the long period of observation and large number of intervening influences potentially affecting collision rates. A limitation of this approach is the large number of structural assumptions necessary, any of which can substantially affect the results. In particular, the selection of the form of the model(s), and the selection of appropriate comparison areas which, in this case, establish the non-CAWS baseline characteristics.

The following subsections describe the details of this modeling methodology and the principal results obtained.

4.13.1 Methodology and Data Sources

To support the multivariate modeling, a data set was developed with 3732 data records, each record corresponding to a one to two mile-long segment of directional highway, in a particular year and time period. Specifically, the data set was created by summarizing collisions and highway characteristics for:

- 27 contiguous highway segments on the study and control sections identified above (1.4 miles average length). Note that each segment generally runs from the midpoint of an interchange to the midpoint of the next interchange along the highway and includes one on-ramp and one off-ramp. Unless otherwise stated below, we include in the data set the entirety of the supplemental (SR-99 and I-205) comparison areas in both directions, and a 1.6 mile segment of southbound I-5 just prior to the CAWS study area. These additional highway segments greatly expand the external comparison areas, which serve as baseline non-CAWS areas.
- Exponential and modified exponential models assumed in all cases
- 2 directions of travel
- 12 calendar years (January 1992 through June 2003). The two-month period Nov and Dec 1996 immediately after the activation of the CAWS is absorbed into the non-CAWS year 1996 for numeric convenience. Jan-June results for 2003 are extrapolated to a full year.
- 6 time periods during the week, defined as follows:
    - Weekday 4 AM to 9 AM (weekday morning peak),
    - Weekday 9 AM to 2 PM (weekday midday),
    - Weekday 2 PM to 7 PM (weekday afternoon peak),
    - Weekday 7 PM to 4 AM (nighttime),

- Weekend 4 AM to 7 PM (weekend daytime),
- Weekend 7 PM to 4 AM (weekend nighttime).

The number of combinations 27x2x12x6=3888 exceeds the 3732 data records actually included. This is because collision data were not available for the thirteen segments of control sections SR-99 and I-205 in 1992, so the corresponding data records are not included.

The collision data were reduced and analyzed using SAS (Statistical Analysis System). The full data set contains 2321 "before" collisions, of which 930 involve fatalities and injuries (F&Is), and 6086 "after" collisions, of which 2204 are F&Is.

In addition to counts of annual total, injury, and fatal collisions within each highway segment during each time period, a variety of detailed collision characteristics were tabulated, including:

- Counts by type of collision
- Counts by type of object hit (for hit-object collisions)
- Counts by weather at the time of collision (clear, cloudy, rain, fog)
- Counts by weather-related surface condition (dry, wet, slippery)
- Counts by number of parties involved (one, two, three or more)
- Counts by violations involved
- Counts by unusual surface conditions (construction, reduced width, holes/ruts, loose material)
- Counts by lighting condition (day, dusk, dark).

Hourly data from three count stations on I-5, two stations on I-205, and one station each on SR 120 and SR 99 were used to calculate the directional mainline counts for the six time periods of the week and the maximum hourly one-hour counts by period, for each year.

In addition to the identifying the time frames of collisions and associated traffic counts, the data set includes a number of highway segment characteristics that in the analysis were related to the frequency and/or severity of collisions. These include:

- Section length (mi.),
- Number of directional lanes,
- Posted speed (in two categories: 55 or 65+),
- Proportion of trucks (downloaded from the Caltrans Traffic Data Systems site and assumed to be the same for all time periods),

- Number and proportion of days of major construction on the segment during the period, during the year (defined as one or more lanes closed),
- Number and proportion of days with heavy fog during the year,
- Number and proportion of days with rain during the year,
- Level of service during the peak hour of the period during the year (scale of A through F).

4.13.2 Analysis 1

For this analysis, the period mainline counts were interpolated and extrapolated for missing years, and factored for consistency with the AADT estimates for these highways reported in Table 4.3.1.1. The average daily on-ramp counts were similarly factored into time periods using the time-of-day distributions obtained from nearby directional mainline data. Although many assumptions were required to derive period and hourly counts in each year for the 54 directional highway segments and their included on-ramps, the quality and quantity of the available data and the numerous checks built into the factoring process give us confidence in using the resulting disaggregate traffic count data as the basis for statistical modeling.

Multivariate modeling utilized the complete disaggregate data set of 3732 actual and interpolated data records, each corresponding to a directional highway segment for a particular time period and year. The corresponding collision counts and related traffic and environmental characteristics for the segments are related to each other using what statistical analysts call a "generalized linear model," which is essentially a non-linear regression approach.

For many of the multivariate models, all 3732 observations were used. However, for some models that include the proportion of days with construction during the year, only 2916 data records were used, since the necessary construction data were unavailable for the years 1992 through 1994. In either case, the data set provides a generous number of data points with which to estimate the models.

Three slightly different generalized linear model specifications were tested with a large number of different candidate explanatory variables. They are:

- Model A: $$COLL_i = (\varepsilon^{\beta_0+\beta_1 L_i+\beta_2 ADT_i+\beta_3 CAWS_i+\beta_4 X_{i1}+\beta_5 X_{i2}+\ldots})ERR_i$$
- Model B: $$COLL_i = ADT_i(\varepsilon^{\beta_0+\beta_1 MVM_i+\beta_2+CAWS_i+\beta_3 X_{i1}+\beta_4 X_{i2}+\ldots})ERR_i$$
- Model C: $$COLL_i/L_i = ADT_i(\varepsilon^{\beta_0+\beta_1 ADT_i+\beta_2 CAWS_i+\beta_3 X_{i1}+\beta_4 X_{i2}+\ldots})ERR_i$$

Where: $COLL_i$ is the observed annual number of collisions observed in highway segment and time period i. In some models this is total collisions, in others it is F&I collisions.

ε is the base of the natural logarithms (≈ 2.718).

L_i is the segment length (miles).

ADT_i is the average traffic in segment and time period i (divided by 1000).

$CAWS_i$ is either 0 or 1, indicating whether CAWS is present in segment and time period i.

MVM_i is the number of vehicle-miles divided by 1,000,000 (=L_iADT/1000).

X_{i1}, X_{i2}, etc. are other segment characteristics as identified in Section 4.13.1.

β_0, β_1, β_2, etc. are parameter values obtained from fitting the model to the data.

ERR_i is an error term accounting for random effects not explicitly considered in the model. ERR_i is assumed to follow the negative binomial probability distribution.

For each model tested, the sign and statistical significance of $CAWS_i$ was scrutinized to see if, when controlling for other included variables, collisions appear to be significantly affected by the presence or absence of the CAWS.

Well over 50 models with different specifications and combinations of variables were tested. Table 4.13.2.1 shows the results for twenty-five of these models for which all parameters, with the possible exception of CAWS, tested statistically significant and with logical algebraic signs. The twenty-five models are all of types B and C, mostly C, and are distinguished by the types of collisions considered. There are four collision types:

- Total collisions (F&I and property damage),
- F&I collisions,
- NoUnusual collisions, which means all collisions except those reported in the presence of unusual road surface conditions, which are primarily construction-related,
- NoUnF&I collisions, which means all F&I collisions except those reported in the presence of unusual road surface conditions, primarily construction-related.

Note that collisions reported in the presence of unusual road surface conditions are only 6% of total collisions, of which 60% involve construction and 24% involve materials in the roadway.

Table 4.13.2.1. Summary of Reasonable Multivariate Models

Seq.	Coll. Type	Type	CAWS	CAWS P	Time Period	ADT	MVM	Max HrFlo	% Trucks	# of Lanes	Post. Speed	LOS	Ramp ADT	%Days Rain	%Days Fog	% Days Const.
1	Total	B	Pos	0.28	OK		OK	OK		OK	OK					
2	Total	C	Pos	0.38	OK	OK		OK		OK	OK					
3	Total	C	Pos	0.05	OK	OK				OK	OK	OK	OK	OK		
4	Total	C	Pos	0.52	OK	OK				OK	OK	OK	OK	OK		
5	Total	C	Pos	0.02	OK	OK				OK	OK	OK	OK	OK		OK
6	Total	C	Pos	0.002	OK	OK				OK	Neg	OK	OK	OK	OK	OK
7	***Total***	***C***	***Pos***	***0.001***	***OK***	***OK***				***OK***		***OK***	***OK***	***OK***	***OK***	***OK***
8	Total	C	Pos	0.54	OK	OK		OK		OK	OK	OK	OK	OK		
9	F&I	B	Neg	0.97	OK		OK	OK	Neg	OK	OK					
10	F&I	C	Neg	0.57	OK	OK			Neg		OK	OK	OK	OK		
11	F&I	C	Neg	0.35	OK	OK			Neg			OK	OK	OK		OK-CL
12	***F&I***	***C***	***Pos***	***0.01***	***OK***	***OK***				***OK***	***OK-CL***	***OK***	***OK***	***OK***	***OK***	
13	F&I	C	Pos	0.34	OK	OK				OK		OK	OK	OK		OK-CL
14	F&I	C	Neg	0.56	OK	OK			Neg			OK	OK	OK		OK-CL
15	NoUnusual	B	Pos	0.8	OK		OK	OK	Neg-CL	OK	OK					
16	NoUnusual	B	Pos	0.58	OK		OK	OK		OK	OK					
17	NoUnusual	C	Neg	0.12	OK	OK				OK	OK	OK	OK	OK		
18	***NoUnusual***	***C***	***Pos***	***0.06***	***OK***	***OK***				***OK***		***OK***	***OK***	***OK***	***OK***	
19	NoUnusual	C	Pos	0.63	OK	OK		OK		OK	OK					
20	NoUnF&I	B	Neg	0.52	OK		OK	OK	Neg	OK	OK-CL					
21	NoUnF&I	B	Neg	0.22	OK		OK	OK	Neg	OK						
22	NoUnF&I	C	Pos	0.39	OK	OK				OK	OK	OK	OK	OK		
23	***NoUnF&I***	***C***	***Pos***	***0.38***	***OK***	***OK***				***OK***		***OK***	***OK***	***OK***	***OK***	
24	NoUnF&I	C	Neg	0.22	OK	OK-CL		OK	Neg	OK						
25	NoUnF&I	C	Neg	0.5	OK	OK		OK		OK						

In the case of CAWS, two columns of information are provided. The first (CAWS) indicates whether the sign of the CAWS variable in the model is positive (CAWS appears to reduce collisions) or negative (CAWS appears to increase collisions). The second (CAWS P) indicates the significance of the CAWS parameter. A P-value equal to 0.05 or less indicates significance at the 5% level, a threshold widely accepted as indicating statistical significance. A value in the 0.05-0.10 range is sometimes seen as noteworthy because it is close to being statistically significant.

The codes for the other variables in Table 4.13.2.1 are as follows:

- OK – the variable appears in the model with a reasonable magnitude and sign and with a parameter value significant at the 5% level,

- OK-CL the variable appears in the model with a reasonable magnitude and sign and with a parameter value close to being significant at the 5% level (between 5% and 10%),
- Neg – the variable appears in the model with the opposite algebraic sign from what is expected, and with a parameter value significant at the 5% level,
- Neg-CL the variable appears in the model with the opposite of the expected sign and with a parameter value significant at the 5-10% level.

In eight of the twenty-five models in Table 4.13.2.1, the CAWS parameter is statistically significant or close to significant. Of these, seven models indicate that CAWS is associated with reduced collisions. The one model that suggests a statistically significant negative effect of CAWS (#25) controls for the influence of so few other factors that it probably should not be regarded as meaningful. In the seventeen remaining models, the CAWS variable is usually not statistically significant, meaning that whether positive or negative, the variability of the effect is so large that we cannot say that the parameter value is other than zero. This can be interpreted to mean that the effect of the CAWS on collisions, while discernible in the data, is weak enough that it only appears in select models where the correct combination of other factors are properly controlled for.

- Of the remaining factors that appear in the models, the following are the expectations regarding magnitudes and signs:
- Time Period – Peak period collisions are generally higher than off-peak while nighttime collisions are generally higher than daytime, when other factors such as traffic counts are controlled for.
- ADT – The higher the amount of traffic in the segment and time period, the more collisions are expected.
- MVM – The higher the vehicle-miles traveled in the segment and time period, the more collisions are expected.
- Maximum Hourly Flow - The higher the peak hourly flow in the segment and time period, the more collisions are expected.
- % Trucks – The higher the proportion of trucks, the more collisions are expected. Note, however, that this variable enters a number of models with the opposite effect.
- # of Lanes – Wider freeways are expected to have fewer collisions than narrower freeways, when other factors like traffic volumes are controlled for.
- Posted Speed – Higher speeds are expected to be associated with more collisions, and more severity.
- Level of Service – Levels of service E and F are expected to have the most collisions and LOS A through C the least.
- Ramp ADT - The higher the traffic count using the on-ramp in the segment, the more collisions are expected.
- %Days Rain – The more rainy days in the year, the more collisions are expected.

- %Days Fog – The more heavy fog days in the year, the more collisions are expected.
- %Days Construction – The more days of construction in the year, the more collisions are expected. Note that this variable is never used with the NoUnusual and NoUnF&I collision types because the two are redundant.

Four of the models in Table 4.13.2.1 (#7, #12, #18, and #23), one for each collision type variable, are regarded as the strongest of the models found. All are type C models in which the response variable is the number of collisions of the type indicated per mile of segment length. These models are highlighted in the table and are documented in detail in the sections that follow.

4.13.2.1 Best Multivariate Model for Total Collisions

Model #7 is considered the best model relating total collisions per mile to various traffic and environmental factors. It incorporates a large and reasonable selection of explanatory factors, all of which enter the model in a logical and highly statistically significant manner. The details of the model calibration appear in Table 4.13.2.2.

Table 4.13.2.2. Best Multivariate Model for Total Collisions

Data Points (N): 2916		**Degrees of Freedom (DF):** 2899	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-0.3578	0.2128	--
CAWS = No	0.1661	0.0516	0.0012
CAWS = Yes	0	0	0.0012
ADT/1000	0.0733	0.0051	<0.0001
# Lanes = 1	-0.9997	0.2467	<0.0001
# Lanes = 2	-0.3801	0.0840	<0.0001
# Lanes = 3	-0.5492	0.0769	<0.0001
# Lanes = 5	0	0	<0.0001
LOS = A – C	-1.1640	0.1386	<0.0001
LOS = D	-0.4028	0.1401	<0.0001
LOS = E & F	0	0	<0.0001
Ramp ADT	0.6801	0.1410	<0.0001
% Days Rain	2.4521	0.4143	<0.0001
% Days Fog	4.4639	0.5573	<0.0001
% Days Construction	3.6097	1.0263	0.0004
Period = Wkdy 04-09	0.6130	0.0681	<0.0001
Period = Wkdy 09-14	0.5200	0.0684	<0.0001
Period = Wkdy 14-19	0.6071	0.0693	<0.0001
Period = Wkdy 19-04	0.5611	0.0693	<0.0001
Period = Wkend 04-19	-0.6609	0.1166	<0.0001
Period = Wkend 19-04	0	0	<0.0001

Note several general features of this model that also are found in many of the other models. Most notably, several factors (CAWS, #Lanes, LOS, and Time Period) enter the model as categorical variables, rather than as continuous variables. In these cases, one category is arbitrarily chosen as the base, and set to

zero. The parameters for the remaining categories estimate the effect on collisions per mile relative to the base. For example, the parameter value for CAWS=No estimates the effect on collisions per mile of not having CAWS in the highway segment, which in this case is positive. Thus, segments without CAWS (all highway sections before 1996 and control sections after 1996) are shown to have more collisions per mile than the segments served by CAWS.

A second general observation is the extremely high levels of statistical significance found for the majority of estimated parameter values, with P-values less than 0.0001 for all parameters except construction (.0004) and CAWS (0.0012). This can be attributed in part to the very large number of data points used in model estimation.

The parameter estimates can be used to provide a rough measure of the impact of CAWS (as well as other factors) on the response variable, collisions per mile. Because of the multiplicative, exponential structure of the models, we can say that when other factors are controlled for, segments without CAWS are expected to have on average $e^{0.1661} = 1.18$ times the number of collisions (18% more collisions) compared to segments served by the CAWS. Therefore, segments equipped with CAWS might be expected to have 1/1.18=1.15 or a 15% reduction in accidents. The standard error of the estimate (0.0516) provides a rough confidence interval around this average effect. That is, considering that we have about 95% confidence that the true parameter value is within plus or minus two standard errors of the estimate, we can say with 95% confidence that segments without CAWS are expected to have between $e^{0.1661-2x0.0516} = 1.065$ and $e^{0.1661+2x0.0516} = 1.309$ times the number of collisions (6.5% - 31% more collisions) as segments served by CAWS. The improvement is just as likely to be close to 6.5% as close to 31%, and it is most likely to be close to the middle value (18%). This would imply a 1- 1/1.18 = 0.15 or a 15% reduction in the number of accidents in sections with the CAWS.

The influence of other factors in the model also warrants attention. Among these, the #Lanes variable is noteworthy in the effect of the very wide section (#lanes = 5), which applies only to the two-mile long major weaving section on I-5 located between the junctions with SR-120 and I-205. As seen previously, collision rates are very high in this area. This is reflected in all the other width categories having negative contributions to collisions per mile compared to the base case (#lanes = 5). Of the remaining categories, the 1-lane directional segments along SR-120 that existed prior to 1996 have the lowest collisions per mile, although this is rather a special case. The 3-lane directional segments are next best, trailed by the 2-lane segments. This effect appears consistently in all of the models in which #Lanes appears as a variable.

Several other factors behave generally as expected. Relative to levels of service E and F, segments with less congestion have on average significantly fewer collisions. For example, segments with LOS A-C are expected to have $e^{-1.1640} = 0.31$ times the number of collisions (about 2/3 fewer collisions) as segments

operating at LOS E and F, when other factors are controlled for. The improvement in collisions for segments operating at LOS D is also significant relative to LOS E and F, but much less.

The effects of more days of rain, fog, and construction activities are positive as expected. This means that as these values for a highway segment and year increase, collisions increase. Having one more rainy day per year, about a 0.3% increase in rainy days per year, results in expected collisions per mile increasing by a factor of about $e^{2.4521*0.003} = 1.007$, roughly 0.7%. Similarly, the addition of one more fog day per year results in expected annual collisions per mile increasing by a factor of about $e^{4.4639*0.003} = 1.013$ or 1.3%.

Finally we consider the effect of time periods. In this case, the weekend nighttime period is taken as the base. It can be seen that the weekend daytime period is expected to have fewer collisions per mile than the corresponding nighttime, while all four of the weekday periods are expected to have more collisions per mile. The peak weekday periods (Wkdy 04-09 and Wkdy 12-19) are expected to have slightly more collisions than the weekday nighttime period, which in turn has more expected collisions than the weekday midday period. On the other hand, the weekday parameter estimates for all periods are similar, in light of the corresponding standard errors, so for this model those differences cannot be regarded as significant. However, the magnitudes of the expected weekday v. weekend period effects are quite large. For example, the weekday nighttime period is expected to have $e^{0.5611} = 1.752$ times the collisions per mile (75% more) compared to the weekend nighttime period. However, since there are 2/5 times as many weekend nighttime periods as weekday periods in each year, each weekday period is actually expected to have about 30% more collisions per mile (still a large difference).

4.13.2.2 Best Multivariate Model for Fatal and Injury Collisions

Model #12 is considered the best model relating fatal and injury collisions per mile to traffic and environmental factors. It has a structure similar to the total collision model described previously and, as before, all factors enter the model in a logical and statistically acceptable manner, although the levels of significance are not quite as strong as in the previous model. The only structural difference is that the categorical variable Posted Speed is in this model and %Days Construction is not. The details of the model calibration appear in Table 4.13.2.3.

Table 4.13.2.3. Best Multivariate Model for F&I Collisions

Data Points (N): 3732		**Degrees of Freedom (DF):** 3715	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-0.5763	0.1899	--
CAWS = No	0.1270	0.0507	0.0120
CAWS = Yes	0	0	0.0120
ADT/1000	0.0737	0.0047	<0.0001
# Lanes = 1	-0.6695	0.1401	<0.0001

# Lanes = 2	-0.3592	0.0719	<0.0001
# Lanes = 3	-0.5296	0.0673	<0.0001
# Lanes = 5	0	0	<0.0001
Posted Speed = 55	-0.0859	0.0441	0.0513
Posted Speed = 65+	0	0	0.0513
LOS = A – C	-0.9837	0.1138	<0.0001
LOS = D	-0.2956	0.1166	<0.0001
LOS = E & F	0	0	<0.0001
Ramp ADT	0.6430	0.1318	<0.0001
% Days Rain	2.6749	0.3928	<0.0001
% Days Fog	4.3938	0.5876	<0.0001
Period = Wkdy 04-09	0.6514	0.0622	<0.0001
Period = Wkdy 09-14	0.5656	0.0620	<0.0001
Period = Wkdy 14-19	0.6713	0.0631	<0.0001
Period = Wkdy 19-04	0.6615	0.0626	<0.0001
Period = Wkend 04-19	-0.6091	0.1056	<0.0001
Period = Wkend 19-04	0	0	<0.0001

Again one can note the extremely high levels of statistical significance that exists for the majority of estimated parameter values, with the exception of the speed limit. The CAWS variable is within significance limits, although less significant than before, and Posted Speed enters at a level of significance just slightly over the commonly accepted threshold of 0.05.

In this model, the effect of CAWS is a little less than for total collisions. When other factors are controlled for, segments without CAWS are expected to have on average $e^{0.1270} = 1.135$ times the number of collisions (13.5% more collisions) compared to segments served by the CAWS. This is equivalent to a 12% reduction in accidents predicted as a result of the CAWS. The standard error of the estimate (0.0507) indicates that we have about 95% confidence that segments without CAWS are expected to have between 2.5% and 26% more collisions than segments served by CAWS.

The effects of most other factors in the model are quite similar to the previous model for total collisions, although some magnitudes of effects, such as for congestion, are slightly less. The effect of Posted Speed indicates that, with other factors controlled for, when the 55 mph speed limit was in effect prior to late 1996, we would expect on average $e^{-0.0859} = 0.918$ times the collisions per mile (8% fewer collisions) compared to afterwards.

4.13.2.3 <u>Best Multivariate Model for Total Collisions Without Unusual Surface Conditions</u>

Model #18 is a variation on Model #7 in which the presence of highway construction and other unusual surface conditions is accounted for not by including the %Days Construction variable but rather by temporarily excluding from the data set all collisions coded as occurring in the presence of unusual road surface conditions. This reduces the total number of collisions from 8407 to 7878. Model #18 is considered the best model relating the adjusted total collisions per mile to traffic and environmental

factors. Its structure is the same as Model #7 except, of course, for the absence of the %Days Construction variable. As before, all factors enter the model in a logical and statistically acceptable manner, although the level of significance of the CAWS variable is not as strong as in the previous model. The details of the model calibration appear in Table 4.13.2.4.

Table 4.13.2.4. Best Multivariate Model for Total Collisions Without Unusual Surface Conditions

Data Points (N): 3732		**Degrees of Freedom (DF):** 3716	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-0.6019	0.1906	--
CAWS = No	0.0964	0.0513	0.0597
CAWS = Yes	0	0	0.0597
ADT/1000	0.0769	0.0047	<0.0001
# Lanes = 1	-0.6772	0.1444	<0.0001
# Lanes = 2	-0.3187	0.0734	<0.0001
# Lanes = 3	-0.5175	0.0690	<0.0001
# Lanes = 5	0	0	<0.0001
LOS = A – C	-0.9973	0.1163	<0.0001
LOS = D	-0.2945	0.1190	<0.0001
LOS = E & F	0	0	<0.0001
Ramp ADT	0.6689	0.1352	<0.0001
% Days Rain	2.2456	0.4064	<0.0001
% Days Fog	4.3707	0.5529	<0.0001
Period = Wkdy 04-09	0.6117	0.0641	<0.0001
Period = Wkdy 09-14	0.5275	0.0640	<0.0001
Period = Wkdy 14-19	0.6601	0.0647	<0.0001
Period = Wkdy 19-04	0.6197	0.0646	<0.0001
Period = Wkend 04-19	-0.6737	0.1073	<0.0001
Period = Wkend 19-04	0	0	<0.0001

The consistency between this model and Model #7 is noteworthy, not only because of the change made in the response variable but also because Model #18 uses data for two additional years (1992 and 1993) not used in developing Model #7. As before, most factors have very high levels of statistical significance. The CAWS variable, however, is not quite statistically significant, although it is so close to the threshold of 0.05 that the impact of CAWS can be considered meaningful.

In this model, the effect of the CAWS is less than in the previous models. When other factors are controlled for, segments without CAWS are expected to have on average $e^{0.0964} = 1.101$ times the number of collisions (10% more collisions) compared to segments served by the CAWS. The standard error of the estimate (0.0513) indicates that we have about 95% confidence that segments without CAWS would have between a 1% decrease and a 22% increase in collisions compared to segments served by CAWS. The fact that the 95% confidence interval includes the possibility that segments without CAWS have slightly fewer collisions is consistent with the CAWS parameter being not quite statistically

significant. To the extent that the difference between the two models is real, and not just random variation, the implication is that CAWS has a small incremental positive effect on collision reduction in the presence of unusual road surface conditions.

The effects of the other factors in the model are essentially the same as in the previous model for total collisions.

4.13.2.4 Best Multivariate Model for Fatal and Injury Collisions Without Unusual Surface Conditions

Model #23 is a variation on Model #12 for fatal and injury collisions. As before, the presence of highway construction and other unusual surface conditions is accounted for by temporarily excluding from the data set all collisions coded as occurring in the presence of unusual road surface conditions. This reduces the number of F&I collisions considered in the model from 3134 to 2978. Model #23 is considered the statistically best model relating the adjusted total collisions per mile to traffic and environmental factors. It is different from Model #12 in two important ways: it does not include Posted Speed, which appeared as not quite statistically significant in Model #12, and the CAWS variable turns out to be statistically quite insignificant. Model #23 also has the same structure as the previous Model #18. The details of the model calibration appear in Table 4.13.2.5.

Table 4.13.2.5. Best Multivariate Model for F&I Collisions Without Unusual Surface Conditions

Data Points (N): 3732		**Degrees of Freedom (DF):** 3716	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-1.0106	0.2568	--
CAWS = No	0.0627	0.0710	0.3751
CAWS = Yes	0	0	0.3751
ADT/1000	0.0599	0.0064	<0.0001
# Lanes = 1	-1.0368	0.2157	<0.0001
# Lanes = 2	-0.2857	0.1017	<0.0001
# Lanes = 3	-0.5611	0.0960	<0.0001
# Lanes = 5	0	0	<0.0001
LOS = A – C	-1.0423	0.1525	<0.0001
LOS = D	-0.3556	0.1535	<0.0001
LOS = E & F	0	0	<0.0001
Ramp ADT	0.8761	0.1812	<0.0001
% Days Rain	1.8206	0.5520	0.0010
% Days Fog	3.7408	0.7572	<0.0001
Period = Wkdy 04-09	0.3492	0.0884	<0.0001
Period = Wkdy 09-14	0.2844	0.0887	<0.0001
Period = Wkdy 14-19	0.4163	0.0884	<0.0001
Period = Wkdy 19-04	0.5199	0.0874	<0.0001
Period = Wkend 04-19	-0.5149	0.1462	<0.0001
Period = Wkend 19-04	0	0	<0.0001

There is considerable consistency in the parameter values between this model and previous ones. As before, this is noteworthy because of the changes in the underlying data. Except for the CAWS variable, all factors have high levels of statistical significance.

In light of the results obtained with the other data sets, it is surprising that the CAWS variable proved to have no significant association with the number of F&I collisions, when unusual surface conditions are excluded. That proved to be the case for this entire family of models, with the exception of Model #25 where the model specification omits several obviously important factors. In fact, in most of this model family, CAWS enters with a negative value, which if the effect were significant would indicate that there are more collisions in the presence of CAWS than otherwise.

To the extent that one can draw a conclusion from this particular model, it is that the impact of CAWS for this collision type is too weak to be detected through statistical analysis of the available data. This finding is consistent with the overall conclusion from examining the full group of models in Table 4.13.2.1, which is that while there is some evidence that CAWS is associated with collision reduction, the evidence is statistically weak.

4.13.3 Analysis 2

Following review by our external expert advisory panel, we repeated the prior analysis using a further-developed model and variations of the original wide-area dataset.

4.13.3.1 <u>Data</u>

In this analysis we considered first the same study and comparison areas used in Analysis 1, which includes not only the CAWS study and control directions on I-5 and SR-120, but also the relatively larger areas of SR-99 and I-205 characterized by somewhat higher traffic volumes. We then considered just the sections in this dataset located in the CAWS I-5/SR-120 study and control directions, since the geometric characteristics, fog and daily traffic volumes in these areas are much better matched. For both datasets, we removed sections for which we did not have actual collision data. This resulted in a somewhat smaller number of points in each dataset compared with Analysis 1. For the complete dataset, N=2674 for all areas, N=1158 for the study area only. All other structural aspects of the analysis remained unchanged, including the 1992-1996 pre-CAWS period (without CAWS in study direction), and the 1997-2003 post-CAWS period (with CAWS in study direction).

4.13.3.2 <u>Model</u>

Per the recommendation of the expert advisory panel, we utilized a model similar to Model C, which differs by (1) ADT (actually, ramp ADT) is not included as a covariate in the exponential part of the model, and (2) a seasonal parameter (Year Effect) is included:

$$Colli_i / L_i = \alpha ADT_i \exp(a + \sum_{j=1}^{n} b_j x_j)$$ [Collisions per mile per year]

As before, this is a generalized linear model, with the linearity revealed by taking the natural log of both sides of the model equation.

Model variables, same as prior model analysis:

- Criteria (dependent or predicted) Variable
  - Collision Rate (Colli/L) = The number of collisions divided by Length of Lane for each segment.

- Explanatory (Independent) Variables
  - ADT
  - P_Fog Proportion of the fog days in the year
  - CAWS_D CAWS binary variable. Reference (0) implies CAWS is present.
  - 6 time period variables. Reference is Weekend 7 PM to 4 AM.
  - The number of lanes variable. Reference is number of lane=5.
  - LOS variable. Reference is LOS= E & F.
  - Year binary variable, before/after CAWS. Reference (Year=0) for period before 1996 (pre-CAWS). This variable also served as a surrogate for the change in speed limits which occurred in 1996.

4.13.3.3 Method and Special Considerations

The methodology of the prior analysis was generally retained, with the following exceptions:

- Over 50 model configurations were tested in each of two groups: 1) with and 2) without the CAWS term. We conducted preliminary model development exercises without consideration of the CAWS to help develop and validate various model configurations, which accurately predicted influences that could be verified from actual data, such as the effects of ADT or the number of fog or rain days. Group (1) models provided this baseline, from which it was possible to compare for reasonableness the results of the Group (2) models which were specifically intended to reveal the effects of the CAWS system.
- Both the larger (I-5,SR-120,SR-99,I-205) data set and the smaller (I-5,SR-120) data set were evaluated.
- The model validation process included extensive testing of predictions against actual data when available, and a special emphasis on the reasonableness of the predictions generated by all model terms.

4.13.3.4 Results – All Collisions

For all model trials using the smaller dataset (CAWS study and control directions) the coefficients P_fog and CAWS_D are not significant. This means that the influence on total collisions of either the proportion of fog days or the presence of the CAWS was found to not be significant using any of these models. The results for the proportion of fog days are consistent with actual data both before and after the CAWS, lending credibility to the CAWS result.

For the extended area (larger dataset, same areas as Analysis 1), Table 4.13.3.1 shows the results of the best model excluding any accommodation for the CAWS, for the larger dataset. All terms in this baseline model were found to be reasonable both in sign and magnitude, and consistent with raw (non-modeled) results previously reported. All showed very strong statistical significance except the LOS_D binary variable, indicating an excessively random effect related to this level of service.

Table 4.13.3.2 shows the results of the best model including the binary CAWS variable, the coefficient of which estimates the relative influence of the presence or non-presence of the CAWS on the annual fog-collision count per mile. For all trial models the CAWS coefficient is not significant. The P-value (lower number indicates greater statistical significance) for the CAWS parameter was P=0.1636, well above the usual limit of 0.05. Results were approximately the same when the criteria variable was changed to collisions/(ADT*365) (volume-normalized collision rate) instead of collisions/mile/year. This means that it cannot be said that the presence of the CAWS can be associated with either a reduction or increase in collision rate or frequency.

The coefficients of the fog variables (P_Fog) are significant in both tables (excluding and including the CAWS term). The estimated coefficient values of 0.8578 and 0.9193 respectively are much less than those reported in Analysis 1, and more consistent with actual fog collision data.

The Year terms in both Tables (before and after CAWS implementation) have positive signs and the coefficients are statistically significant. That means that higher collision counts are estimated in the after-CAWS period (after 1996) than the before-CAWS period, which is confirmed by data reported in earlier sections of this report. The addition of a term for the effects of construction did not yield a significant p_construction influence on collisions in any model. This result is consistent with both the raw annual data and the results of Analysis 1.

The Ln_ADT coefficient for the influence of AADT (0.5 in the model with CAWS and 0.49 in the model without CAWS) is much larger than the value (0.07) predicted in Analysis 1, suggesting a much greater influence of traffic volume on fog collisions for all sections. This is at least subjectively consistent with the

general trend of increasing collisions with increasing traffic volume apparent in our presentations of raw collision data.

For other variables, the results are consistent in their signs and approximate magnitudes with those of Analysis 1.

Table 4.13.3.1. Results for Total Collisions, Best Model Excluding CAWS.

N=2674		**Adjusted R-Square:**	**0.2717**
	Estimate	**Standard Error**	**P-Value**
Intercept	-3.5118	0.4889	<.0001
LN_ADT	0.4876	0.0451	<.0001
P_FOG	0.8578	0.3896	0.0278
P_D_wd_04_09	0.3295	0.0477	<.0001
P_D_wd_09_14	0.2050	0.0467	<.0001
P_D_wd_14_19	0.3004	0.0483	<.0001
P_D_wd_19_04	0.3145	0.0473	<.0001
P_D_we_04_19	-0.1766	0.0682	0.0096
LANE_D_1	-0.5583	0.1041	<.0001
LANE_D_2	-0.3860	0.0523	<.0001
LANE_D_3	-0.4721	0.0483	<.0001
LOS_A_C	-0.7310	0.1038	<.0001
LOS_D	-0.1331	0.1077	0.2167
Year	0.2862	0.0771	0.0002

Table 4.13.3.2. Results for Total Collisions, Best Model Including CAWS.

N=2674		**Adjusted R-Square:**	**0.2720**
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-3.6314	0.4963	<.0001
LN_ADT	0.5026	0.0464	<.0001
P_FOG	0.9193	0.3920	0.0191
P_D_wd_04_09	0.3279	0.0477	<.0001
P_D_wd_09_14	0.2016	0.0468	<.0001
P_D_wd_14_19	0.2942	0.0485	<.0001
P_D_wd_19_04	0.3159	0.0473	<.0001
P_D_we_04_19	-0.1949	0.0694	0.0050
LANE_D_1	-0.5307	0.1060	<.0001
LANE_D_2	-0.3649	0.0545	<.0001
LANE_D_3	-0.4564	0.0496	<.0001
LOS_A_C	-0.7228	0.1040	<.0001
LOS_D	-0.1258	0.1079	0.2437
Year	0.2851	0.0771	0.0002
CAWS_D	**-0.0564**	**0.0405**	**0.1636**

4.13.3.5 Results – Fatal and Injury Collisions

We repeated the prior analysis for just fatal and injury collisions. The larger dataset (extended study area used in Analysis 1) was used for all trials.

Table 4.13.3.3 shows the baseline results of the best model excluding any accommodation for the CAWS. All terms in this model except the P_D_we_04_19 (Daytime, Weekend period) and the LOS_D (Level of Service D) binary variables were found to be significant and reasonable both in sign and magnitude, and consistent with raw (non-modeled) results previously reported. The weakness in these explanatory variables is apparently due to the relatively smaller number of F&I collisions.

Table 4.13.3.3. Results for F&I Collisions, Best Model Excluding CAWS.

Variable	Estimate	Standard Error	P-Value
Intercept	-0.92722	0.51202	0.0703
LN_ADT	0.14964	0.04774	0.0018
P_FOG	1.03693	0.40644	0.0108
P_D_wd_04_09	0.15175	0.05065	0.0028
P_D_wd_09_14	0.11741	0.04995	0.0188
P_D_wd_14_19	0.1689	0.05116	0.001
P_D_wd_19_04	0.17635	0.04995	0.0004
P_D_we_04_19	0.02967	0.07106	0.6763
LANE_D_1	-0.7036	0.11895	<.0001
LANE_D_2	-0.4053	0.05354	<.0001
LANE_D_3	-0.39533	0.04991	<.0001
LOS_A_C	-0.58685	0.09762	<.0001
LOS_D	-0.18243	0.09944	0.0668
Year	0.27363	0.08041	0.0007

Table 4.13.3.4. Results for F&I Collisions, Best Model Including CAWS.

N=2674	Adj R-Sq	0.1623	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-1.08596	0.51699	0.0358
LN_ADT	0.17074	0.04873	0.0005
P_FOG	1.12117	0.40798	0.0061
P_D_wd_04_09	0.14675	0.05065	0.0038
P_D_wd_09_14	0.11019	0.05001	0.0277
P_D_wd_14_19	0.1598	0.05129	0.0019
P_D_wd_19_04	0.17721	0.0499	0.0004
P_D_we_04_19	0.0025	0.07214	0.9724
LANE_D_1	-0.66313	0.12036	<.0001
LANE_D_2	-0.37292	0.05564	<.0001
LANE_D_3	-0.37074	0.0512	<.0001
LOS_A_C	-0.57531	0.09767	<.0001
LOS_D	-0.17008	0.09952	0.0876
Year	0.27034	0.08034	0.0008
CAWS_D	**-0.09044**	**0.04282**	**0.0348**

Table 4.13.3.4 shows the results of the best model including the binary CAWS variable CAWS_D. The estimated coefficient value of -0.09 predicts that F&I collisions decrease by 8.6% in sections in which the CAWS is not present (or equivalently, a 9.4% relative increase in collisions in sections served by the CAWS). Its P-value of 0.03 is within generally accepted limits for statistical significance, but indicates a somewhat lower significance than the equivalent Analysis 1 result (the reduced number of data points may contribute to this difference).

4.13.3.6 Results – Collisions in Fog

Since the primary purpose of the CAWS is to reduce collisions in fog, we attempted to examine the effect of the CAWS on just collisions coded as fog-related by the CHP. The larger dataset (extended study area used in Analysis 1) was used for all trials.

The number of observations for just collisions in fog is 131 for all areas, and 78 for the study area. With this small number of observations, a reasonable model fit is not expected. This is evident in the lack of statistical significance of many of the model variables, due to an inadequate number of data points. This is in stark contrast to Analysis 2 models for total and F&I collisions.

Table 4.13.3.5 shows the baseline results of the best model excluding any accommodation for the CAWS.

Table 4.13.3.6 shows the results of the best model which now includes the binary CAWS variable CAWS_D. The CAWS term is not within accepted significance range, but if it was, it would predict a 23% increase in collisions in sections in which the CAWS is not present.

Unfortunately, the weakness of these models for fog accidents due to data inadequacy prevents us from reporting results for the influence of the CAWS for this type of collision.

Table 4.13.3.5. Results for Collisions in Fog, Best Model Excluding CAWS.

Variable	Estimate	Standard Error	P-Value|
Intercept	-1.85541	2.41063	0.443
LN_ADT	0.37562	0.21979	0.0901
P_FOG	0.69853	1.92816	0.7178
P_D_wd_04_09	0.45742	0.40498	0.261
P_D_wd_09_14	0.18535	0.43134	0.6682
P_D_wd_14_19	0.40593	0.47763	0.3971
P_D_wd_19_04	0.35931	0.43574	0.4113
P_D_we_04_19	-0.2214	0.47602	0.6427
LANE_D_1	-1.25065	0.47955	0.0103
LANE_D_2	-0.63506	0.21668	0.0041
LANE_D_3	-0.55976	0.20598	0.0076
LOS_A_C	-1.18298	0.29224	<.0001
LOS_D	-0.71112	0.29053	0.0159
Year	0.73326	0.37662	0.0539

Table 4.13.3.6. Results for Collisions in Fog, Best Model Including CAWS.

N=2674	Adj R-Sq	0.1623	
Variable	**Estimate**	**Standard Error**	**P-Value**
Intercept	-1.71317	2.44599	0.4851
LN_ADT	0.36373	0.22263	0.105
P_FOG	0.52347	1.98519	0.7925
P_D_wd_04_09	0.46117	0.40656	0.259
P_D_wd_09_14	0.18892	0.433	0.6634
P_D_wd_14_19	0.398	0.47978	0.4085
P_D_wd_19_04	0.35711	0.43735	0.4159
P_D_we_04_19	-0.2127	0.47825	0.6573
LANE_D_1	-1.31344	0.50683	0.0108
LANE_D_2	-0.69387	0.26351	0.0096
LANE_D_3	-0.6088	0.24111	0.0129
LOS_A_C	-1.19639	0.29525	<.0001
LOS_D	-0.72265	0.29304	0.0151
Year	0.71724	0.38015	0.0617
CAWS_D	**0.08197**	**0.2074**	**0.6934**

4.14 Discussion and Conclusions

In our various analyses, we have examined historical accident data both overall and in a large number of subclasses, including accidents in fog, inclement weather, in the absence of construction, during peak and off-peak periods, cross-peak comparisons, primary and secondary accidents, and the proportions of accidents by CHP collision type classification such as rear-end, side-swipe, etc.

We have attempted to control for external effects in a large number of ways. These included normalization of accident frequencies to various metrics of exposure, including travel volume (MVM), annual number of fog or inclement weather days, and each type or class of collision relative to all collisions, or other types of classes of collisions.

We considered accident severity indicated by totals of fatal and injury accidents, property damage only accidents, and the number of vehicle involved in each reported accident.

We examined the locations of collisions, including the specific location of fatal accidents and accidents attributable to fog. Subsection sizes ranged from the three primary subsections of the CAWS (I-5 north of SR-120, I-5 south of SR-120, and SR-120 itself) to 0.25 mile segments intended to show in greater detail the locations of possible problem areas.

We especially considered the possible influence of roadway construction by repeating several prior analyses with these accidents removed from the data set.

In all analyses we compared the area influenced by the CAWS (the CAWS study direction) with a primary control area consisting of the opposite directions of the same highways, as well as two external highways used as supplemental control areas for some analyses. This helped to control for effect such as the change in the national speed limit or changes in driver attitudes that affected all areas at the same time.

We also fitted accident data acquired from both the CAWS and the supplemental control areas to various configurations of a multivariate model. By computer optimization of the model parameters for best fit, we inferred the possible influence of the CAWS on collision frequencies in segments of the CAWS study direction compared with segments of the comparison areas without the CAWS.

By this comprehensive process, we have attempted to not only infer the effectiveness of the CAWS in an overall sense, but to identify possible problem areas and corroborate the findings with driver behavior and operational assessment results from the other sections of this report, seeking to match statistical observations with possible causal chains.

This analysis was restricted to historic and recent numeric accident data obtained from TASAS and accident record reports maintained in the Caltrans District 10 office. We did not perform a detailed analysis of the text of accident reports, which might provide increased but more subjective insight into the role of CAWS in individual accidents. We did not conduct driver surveys that may have (with an expected high margin of error) revealed personal opinions or experiences of drivers about the effectiveness of the CAWS.

A conclusion for each type of analysis follows.

4.14.1 All-Weather Accidents

The results for the analysis of all-weather accidents at all times shows a slight increase in the control direction accident rates with a peak in the year 2000 for the after period. During the before period control direction accident rates were higher than study direction accident rates for four out of the five years of the before period. However, during the after period, study direction accident rates were higher than those of the control direction for the first five years after CAWS activation, but a relative improvement was observed in 2002 and the first six months of 2003 (please see Table 4.4.1.1 and Figure 4.4.1.1). In the year 2000, there was a significant peak in study direction accident rates—almost double the rates of the next highest study direction accident rate. By comparison with the external control area, both the study and control directions of the CAWS improved remarkably. Over the entire period 1997-2003 compared with the period 1992-1996, an average increase in travel-normalized collisions of 60% was observed in the study area, compared with 25%, 30% and 62% (average 39%) in the control and comparison areas.

To the extent that the CAWS may have been able to influence driver behavior, these results indicate that for all weather scenarios taken as a whole, the CAWS system did not positively affect collision rates for

the first five years, but may have been of benefit more recently. A possible reason for this trend may however, be found in the greater recent traffic volumes on these highways, evident in Table 4.3.1.1 for the year 2002.

It should be noted that when overall accidents are considered, they are dominated by collisions for which the CAWS system would have little or no influence, since they could not have been prevented by a fog-related warning message or advanced warning of slow or stopped traffic ahead. (These cases are better assessed by analysis of collisions in fog and/or secondary collisions.)

4.14.2 Accident Severity

Over the entire period 1997-2003 compared with the period 1992-1996, an average increase in travel-normalized fatal and injury collisions of 76.6% was observed in the study area, compared with 39.1%, 23.8%, and 55.3% (average 39.4%) in the control and comparison areas. In the critical study direction of I-5 south of SR-120, the proportion of all collisions that were property-damage-only increased, and the fatal and injury F&I proportion decreased. This was true for all collisions and for collisions in fog. Since the majority of the additional collisions were PDO rather than F&I, this reduction in the net severity of collisions represents a partially-redeeming improvement.

4.14.3 Results by Segments

A largely disaggregated view of collision totals per ¼-mile segment of the study and control directions in Figure 4.5.1.1 and Figure 4.5.1.2 made clear that the most severe concentration of accidents occurred in the merge section of I-5 and SR-120 at the junction of I-5 and SR-120. The density is elevated for both the study and control directions in this segment, but the density is much higher in the study direction in all years. The trend is clear for all accidents, accident in fog, and when counting the number of collision vehicles rather than accidents. Even as overall collision rates in the study area started to improve in 2002 and early 2003, rates in this area continued higher than all other areas as indicated by Figure 4.5.2.1 for all collisions and Figure 4.5.2.3 for fatal and injury collisions. While this area is expected by its geometry to be prone to higher collision rates, comparison before and after CAWS activation, and with all other control areas confirms that the increase in study direction in this area could not be attributed to the any of the factors that we attempted to control for.

Searching for explanations or contradictions in other findings, we note that a major structural repair project was underway during 1999-2001 affecting both the study and control directions. But according to TASAS records, the southbound direction of this segment of highway had the highest number of construction zone accidents in the year 2000 than any other year. While this could reflect the higher-than normal collision rate overall this year, it could also suggest that construction was causal factor. Also, from our analysis of Section 3 of this report we learned that the CAWS had operational issues related to its warning strategy that uniquely affected this area. In particular, drivers were sometimes not warned of stopped traffic ahead on the SR-120 approach when not all of the five lanes in this section were below 50

mph. The isolated local fog warning strategy implemented by the CAWS was found to sometimes lead to different fog warning levels for each of the approach directions to the Y during some fog events. And in 2002 and 2003, a non-operational relative humidity sensor at weather station 9 in the Mossdale Y inhibited the fog-warning capability of the CAWS in this area for an extended period of time.

Considered over the three main sub-sections of the CAWS area:

The study direction for SR-120 has a collision accident rate that is consistently better than that of the control direction for most years during both the before period and the after period. However, because the ratio of the rates in the study to the control directions did not increase when comparing the before period to the after period, it is difficult to determine whether these results are due to system implementation, or just characteristic of that segment of highway.

The results of the collision rate comparison for the segment of I-5 north of SR-120 closely resemble the results for the entire study area. This similarity reflects the fact that this segment of highway is the largest in the study area.

For the segment of I-5 south of SR-120 the study direction has a higher occurrence of inclement weather accidents than in the control direction, but the other two study direction segments show improvement from the before to after periods.

The proportion of fog-accidents to all accidents also suggests problem segments for fog accidents. Like the previous two segment analyses, I-5 South of 120 shows a significant increase in the occurrence of fog-related accidents during the after period. However, the study direction for SR-120 shows a definite improvement, and the segment of I-5 north of SR-120 in the study direction was the same in both the before and after periods.

In 2000, a peak in accident rates in the study direction South of SR-120 indicates that section is a problem area for that year. The last CMS is placed before this section, so southbound vehicles getting on the freeway after the last CMS may be more prone to accidents than those exposed to the warnings.

The proportion of fog-day accidents to all accidents shows some improvement in the study direction for SR-120, but the segment south of SR-120 is still a problem area.

Collectively considered, the SR-120 segment and I-5 north of SR-120 segment show a neutral to positive trend, with SR-120 showing a definite improvement for fog and inclement weather collisions in most of the after years. However, it is clear that the CAWS was not an effective safety enhancement in the I-5 segment of the CAWS study area south of SR-120. However, a negative effect cannot be inferred: considered in conjunction with the results of the driver behavior analysis of Section 4 of this report, it

would be highly unlikely that the CAWS could have had a sufficient influence to account for the unusually collision rates in this segment.

4.14.4 Peak and Cross-Peak Periods

Comparing the morning study direction peak with the evening control direction peak, we found that collision rates increased in the after years in the study direction, the control direction, and the both directions of the external control highways. However, the increase was greatest in the CAWS study direction, more than twice the pre-1996 level. The same trend was observed when only fatal and injury collisions were considered.

When midday weekday periods were compared, an increase in collision rates before-to-after occurred in all areas about equally. If the baseline is an expected increase, this is a comparably positive result.

While the weekday daytime pre-1996 and post-1996 comparisons seem similar across the board, the weekend and nighttime again shows an unusually large increase in the southbound study direction. These periods are usually characterized by a much greater percentage of drivers unfamiliar with the area. If, for example, daily commuters tended to disregard the CAWS warning messages, drivers during weekend evening periods might be more likely to comply with them.

Since the most concern regarding collisions in reduced visibility exists during the morning peak period, inclement weather collision rates were developed for collisions during that time period. During inclement weather, the collision rates increase nearly 2:1 in the CAWS study direction, while they decreased by almost the same ratio in control direction. For either direction of SR-99/I-205, the changes were much less pronounced. Collision rates decreased for fatal an injury collisions in both the CAWS directions, and one of the SR-99/I-205 directions. This indicates a substantial decrease in collision severity that effected both the study and control directions almost equally.

For the peak and cross-peak comparisons, on midday weekdays and weekend days, the results are neutral for the CAWS. The results are negative for the CAWS study direction during weekday commuting and weekend evenings. However, collision severity decreased in both the study and control directions, partially moderating the peak period increases.

4.14.5 Traffic Congestion

For the study direction of the CAWS and all control sections, collision rates for LOS D-F are generally higher than for LOS A-C, and they increase across the board in the post-1996 period. For LOS A-C conditions, there is not much difference in the increases among the study and control sections. For LOS D-F, some peculiarities are evident. A proportional collision rate increase of about 5:1 occurred for the CAWS study direction. At the same time, there is almost no before-after increase for one of the control section groups (SR 99 southbound and I-205 westbound). The seemingly huge jump in the collision rate

for the study direction under LOS D-E conditions may partly be discounted by the fact that these rates are based on an abnormally small level of exposure, especially in the before period.

The corresponding comparisons for fatal and injury collisions were also examined, and generally gave the same results seen in the analysis of total collisions.

4.14.6 Inclement Weather

When all inclement weather collision rates are considered over the entirety of the before and after periods, as in Figure 4.8.1.2, an overall increase in accident rates is observed in the study direction, while a slight decrease was observed in the control direction. A peak in 1998 is especially problematic. But the trend isn't consistent year-to-year, as shown in Figure 4.8.1.1. During the before period, one out of the five years had higher collision rates in the control direction, but in the after period, five out of the 6.5 years had higher collision rates in the study direction. Taken at face value, these results would show that the CAWS system does not positively influence inclement weather accident rates. However, the decline and improvement during 2002 and the fix six months of 2003 indicate a recent improvement trend, or that other factors may have been interfering for the previous years.

4.14.7 Collisions in Fog

The results for collisions of all classes in fog are mixed result. There appear to be desirable outcomes for the study directions on SR-120 and I-5 north of SR-120, compared to control sections, however the normalized number of collisions in fog increased substantially on southbound I-5 south of SR 120. The control highways vary, although most also show a decrease in the proportion of fog collisions after 1996. This occurred both for all fog collisions and the more serious F&I collisions, although since the numbers of F&I collisions in fog were small, the results for these are probably not significant. This is consistent with other patterns seen previously for that sub-section.

Fog collision rates during the AM peak traffic period were generally greater in the study than the control directions of the CAWS, but the numbers are too small to be considered significant.

4.14.8 Related and Secondary Collisions

There was a substantial increase in the rate of related collisions in the CAWS study direction compared with the control direction after activation of the CAWS. Rates in both directions decline abruptly after 2000. The study-to-control ratio decreases dramatically also in the last 1.5 years of observation. Since volume in both directions increased progressively during these years, this suggested an area-wide improvement decoupled from traffic volume, which was most pronounced in the study direction.

The ratio of secondary to primary collisions in the study direction generally increased after the CAWS, and reached a significant level of imbalance in 1998 and 1999. While the study direction peaked numerically in 2000, a similar but lesser peak occurred in the control direction also, conceivably related to

the intermittent construction activities 1999-2002 which affected both directions. A consistent reduction in the secondary collisions occurred in both directions between 2000 and 2002. The trend is consistent with that observed for primary collisions and collisions overall.

While the numbers are probably too small to be meaningful, related collisions in fog saw an unusual spike in related collisions in fog in 1997 immediately after the activation of the CAWS, followed by a drop to almost none. While speculative, this may be correlated with the incorrect mapping of the CAWS traffic warning function during the first nine months of operation discussed in Section 3 of this report. Considered over the entire before and after periods, and normalized simply to the number of foggy days (units of 100 fog-days), the CAWS study direction experienced a significant reduction in the count of this class of collisions after the activation of the CAWS, especially in the critical Mossdale Y area. This is an overall positive finding for the CAWS. Interestingly, it is supported by a strongly negative finding for 1997, since together they may suggest that the CAWS does have the capability to positively influence this particular class of accidents when it is operating properly. Overall, conclusions are generally neutral for the inferred influence of the CAWS on related accidents.

4.14.9 Construction

Construction activities affected both directions of the CAWS highways, especially SR-120 in 1994-96 and I-5 in 1999-2002. Trends during peak traffic period and in inclement weather differed little with the removal of construction-related collisions form the dataset. Overall it is concluded that removing collisions occurring in the presence of unusual road surface conditions, which are mostly construction-related, reduces estimated collision rates slightly in all areas, but does not fundamentally change any of the previously reported findings. The increased collision rate in the study section of I-5 south of SR-120 became greater in the absence of construction, which counter-indicates construction as a conceivable reason for the observed concentration of collisions in this area.

4.14.10 Collision Classification

Over all weather conditions, there was a substantial increase in the percentage of rear-end collision in the CAWS study direction after the CAWS compared with before the CAWS. When only rear-end collisions in fog are considered, the numbers also increased after the CAWS (from 5 out of 15 before to 29 out of 46 total accidents after), but the amount of the increase was substantially less than the corresponding increase that occurred in the control direction (from 0 out of 5 before to 6 out of 13 after). While the numbers may be too small for significance, this is a positive finding. Since rear-end collisions in fog represent one of the classes of accidents that would be expected to be most affected by the CAWS' warning capabilities, this is of particular interest in this evaluation.

4.14.11 Multivariate Modeling

The multivariate model analyses examined as many relevant geometric, traffic and environmental factors as possible in order to isolate the effect of CAWS while controlling for other factors in various

combinations. Two successive analysis efforts were conducted, using progressively more developed models. We considered the extended dataset including the SR-99 and I-205 comparison areas as well as the primary CAWS study and control directions on I-5 and SR-120.

It should be emphasized that the effect of CAWS is difficult to discern and it seems the impact of CAWS is weak enough that it only appears in a limited number of models where the correct combination of other factors are carefully and properly controlled for.

For the first analysis, covering the expanded data set, the majority of the multivariate models for total collisions and F&I collisions in which all parameters tested significant showed that the presence of CAWS has may be associated with a 15% reduction in total collisions, and 12% reduction in F&I collisions. When unusual surface conditions are excluded, the CAWS variable had a positive but not quite statistically significant effect on total collisions, and no significant association with the number of F&I collisions.

In the second analysis we incorporated the model recommendations of the expert advisory panel and considered both the expanded and the original datasets. None of the models for total collisions showed a significant influence of the CAWS on total collisions in either sense, positive or negative. This was true for the expanded data set including areas of SR-99 and I-205, as well as the primary CAWS study and control directions of I-5 and SR-120. For F&I collisions, the best model predicted a 9.4% increase in F&I collisions in sections served by CAWS, but at a level of statistical significance somewhat lower than that found in the first analysis effort. These models generated somewhat more reasonable predictions for other factors such as the influence of traffic volume, the annual proportion of fog days, and effects of the 1996 change in speed limits, which enhances our confidence in the results.

Using the latter class of models, we also attempted to examine the effect of the CAWS on just collisions coded as fog-related by the CHP. Unfortunately, the very small numbers of these collisions resulted in inadequate statistical significance for all trial models. We are therefore reluctant to report any results from a model-based analysis for the potential influence of the CAWS on just fog collisions.

4.14.12 Composite Conclusions, All Analyses

Overall conclusions are mixed and somewhat contradictory. Based on both raw and all normalizations of the data, encompassing all weather conditions, traffic levels, and collision classes, we found the CAWS associated with increased rates of collision during the first five years after its activation, but a consistent improvement trend after 2001. Over the entire period 1997-2003 compared with the period 1992-1996, an average increase in travel-normalized collisions of 60% was observed in the study area, compared with 30% in the CAWS control direction and 25% and 62% of on two directions of comparison highways

having somewhat higher daily traffic volumes (average 39%). For fatal and injury collisions an increase of 76.6% was observed in the study area, compared with 39.1%, 23.8%, and 55.3% (average 39.4%) on the control and comparison highways. Particularly problematic peaks were observed in 1997 and 2000. Results for targeted accidents such as collision in fog, rear-end collisions, or secondary collisions ran more generally negative. However, for a few targeted classes of collisions such as secondary collisions in fog, a positive effect may be evident. Controlling for the potential affects of construction, peak and cross-peak traffic, and changes in the driver population over time did not significantly alter these conclusions.

In an attempt to better correlate collision rate changes with individual influences, we fitted data in the CAWS and the three comparison areas to several generalized linear regression models. Results were mixed. Our initial analysis suggested that the presence of the CAWS may be associated with a modest overall safety improvement. Best model configurations in this effort resulted in predictions of a possible reduction of 15% in overall collisions, and 12% in fatal and injury collisions. However, a subsequent effort using modified models recommended by our expert advisory panel concluded that the CAWS could not be associated with a statistically significant influence on collisions in either a positive or negative sense, and that the CAWS may have a 9.4% negative influence on F&I collisions. It was not possible to reliably model collisions in fog due to the relatively low numbers of this type of collision in all areas.

The somewhat large variations in collision rates year-to-year that appear in most of the per-year data presentations are also cause for concern when we attempt to interpret these results. Travel volume appears to play a dominant and nonlinear role in these variations. For example, the peak in annual travel volume in the study direction in 2001 correlates well with the collision rate peak in 2000-01. But other factors are at work in this, and to greater extent in other annual variations, especially for specific collision types or classifications. Despite our best investigative efforts, we cannot fully identify or account for in our data presentations or models all the phenomena that may have influenced collision counts and rates in the CAWS or the comparison areas. This is usually the case in any study of this type, but it would be assuring if we could completely eliminate the need for conjecture in our attempts to explain the results.

Regarding the single question, “Based on collision data of all types, did the CAWS appear to be associated with an improvement in traffic safety?” we and our expert advisory panel feel that the overall results are inconclusive. It is clear to us that by qualified but arguable choices of emphasis and admission of results, an overall conclusion could be driven in either direction. It would not be unreasonable to infer a net positive overall benefit attributable to the CAWS, but of unknown magnitude.

We can with greater confidence present answers to a wide range of more restricted questions, dealing with collision rate trends, specific collision types, severity, weather conditions, highway segments, and the effects of a wide range of factors including traffic volume, congestion, roadway construction activities, speed, and more. These are presented below.

As mentioned above, collision rates in the CAWS study direction during the first five years increased more than the average for the control areas, but started to improve after 2001. One direction of the high-volume SR-99/I-205 external experienced almost the same trend as the CAWS study direction.

All analyses concur that after the activation of the CAWS, there was a disproportionate elevation in collision rates of all classes and under all conditions at the Mossdale Y junction of southbound I-5 and westbound SR-120. Results for SR-120 and I-5 north of SR-120 were considerably better, varying about a neutral-to-slightly-negative result in most analyses.

On midday weekdays and weekend days, the results are neutral for the CAWS overall. The results are negative for the CAWS during weekday commuting and weekend evenings. During inclement weather, the collision rates increased in the CAWS study direction compared with other areas.

During higher levels of service, collision rates in the study direction increased substantially compared with other areas. For lighter levels of service, results are close to neutral.

Of particular concern were collisions in fog, since the CAWS was specifically designed to reduce these. There appear to be desirable outcomes for the study directions on SR-120 and I-5 north of SR-120, however collisions in fog increased substantially on southbound I-5 south of SR-120. For secondary collisions in fog, a change in the collision type mix and lower increase than other areas suggest a positive effect for the CAWS, although the numbers are a bit small to be considered reliable.

For all weather conditions, there was a substantial increase in the rate of related (primary with one or more secondary) collisions in the CAWS study direction compared with the control direction after activation of the CAWS, although a decline is evident starting in 2001. The CAWS study direction experienced a significant reduction in the count of secondary collisions in fog, although the numbers are somewhat small to draw a clear inference.

Comparisons for fatal and injury collisions generally gave the same results seen in the analysis of total collisions. Despite the substantial increase in the Mossdale Y, the mix of collisions in this area shifted towards a higher percentage of property damage only and a lower percentage of fatal and injury, inferring a positive effect on collision severity.

Construction activities were found to be associated with a slight general increase in collisions in all areas, and had no significant effect on conclusions.

For all weather conditions, there was a substantial increase in the percentage of rear-end collision in the CAWS study direction after the CAWS compared with before the CAWS. When only rear-end collisions in fog are considered, the numbers also increased after the CAWS, but the amount of the increase was substantially less than the corresponding increase in the control areas. While the numbers may be too

small for significance, this is a positive finding, and rear-end collisions in fog represent one of the classes of accidents that would be expected to be most affected by the CAWS.

The results of the two generalized linear modeling efforts were somewhat contradictory. Best models generated in the first effort predicted a modest positive overall effect of the CAWS for all-weather collisions and fatal and injury collisions, a marginally significant positive result for collisions of all types in the absence of construction, and no significant indication for fatal and injury accidents in the absence of construction. No significant influence of the CAWS on collisions in fog was indicated by any of the models for this class of collisions.

The second model-based analysis was conducted using models recommended by our external panel of experts. None of the models showed a significant influence of the CAWS on total collisions in either a positive or negative sense. For F&I collisions, the best model predicted a modest increase in F&I collisions in sections served by the CAWS. We also attempted to examine the effect of the CAWS on just fog collisions, but the relatively small number of these collisions limited the statistical significance of the results for all trial models.

All results of our examination of collision data, both positive and negative, should be considered in view of the limited response of drivers to CAWS warning messages confirmed in the Driver Behavior Analysis. It is possible that drivers do not alter any aspect of their driving behavior, but do benefit from a heightened awareness of potential hazards beyond the information provided by their own perceptions. This effect would be expected even from static advisory signage. We cannot enter the minds of drivers. But their measurable actions lead us to limit the admissible range of influence that could possibly be attributed to the CAWS. It appears unlikely that drivers respond to dynamic messages to a sufficient degree to influence collision rates substantially in either a positive or negative sense. This is not attributable to the CAWS, but is a general characteristic of motorists confirmed by a number of other studies, and discussed in the Driver Response Analysis. We are therefore inclined to interpret the results of all analyses of historical collision data in an optimistic but limited sense.

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