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Evaluation of Wet Weather Accident Causation Criteria

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ABSTRACT

Title: Evaluation of Wet Weather Accident Causation Criteria

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This report documents findings from analysis of traffic collision data from sites that display high collision rates only under wet pavement conditions. These sites were selected using Caltrans safety engineers' field reports, Wet Table C "investigation required" locations, and a new approach called Continuous Risk Profile (CRP).

The geometric features at the sites were studied via field visits and review of as-built plans. Rapid spatial changes (i.e., vertical and horizontal curve in short distance), narrower lane width, lack of median, and wider total freeway width were some of the notable geometric features observed at these sites. There were also other features found to be responsible for diminishing drivers' visibility. These features are explained in detail with the aid of photographs taken during the field visits.

Findings showed significant differences in wet and dry collision distribution across traveling lanes at some locations. Speeding remained the primary collision causative factor regardless of pavement condition, but was more dominant under wet than dry pavement conditions at all observed locations.

Keywords: Freeways, Wet Weather Accident, Continuous Risk Profile, Partners for Advanced Transit and Highways California, Safety, Traffic Accidents

GLOSSARY OF ACRONYMS AND TERMS

AADT: Annual Average Daily Traffic

AC: Asphalt Concrete

CRP: Continuous Risk Profile

HCCL: High Collision Concentration Location

Minor-A: Any Caltrans highway facility maintenance project ranging from $120,000 to $750,000

Minor-B: Any Caltrans highway facility maintenance project under $120,000

PCC: Portland Cement Concrete

SHOPP: State Highway Operation and Protection Program

Shoulder: The area between median and traveling lanes. There are two shoulder areas on both sides of freeway

SPF: Safety Performance Function

Table C: A list of HCCLs under dry pavement conditions, published by Caltrans

TASAS: Traffic Accident Surveillance and Analysis System

Wet Table C: A list of HCCLs under wet pavement conditions, published by Caltrans

EXECUTIVE SUMMARY

Caltrans publishes a list called Wet Table C, comprised of sites that display high collision rates under wet pavement conditions. Based on sites identified in Wet Table C, safety engineers from each of the districts conduct in-depth safety investigations to determine whether the identified sites indeed require safety improvement. Many freeway sites have been enhanced due to such efforts; however, Caltrans understands that the current system could benefit from further improvement.

In the first phase of study, 413 miles along six major freeways in Caltrans District 4 were selected as study routes. The six study routes were chosen because data was available for these particular routes. A continuous risk profile (CRP) approach was applied to screen for locations that uniquely exhibited high collision concentration location (HCCL) rates under wet pavement conditions along the study routes. CRP shows a much lower rate of false positives (55%) than Wet Table C (85%). This means fewer locations require detailed investigation, and resources can be used more efficiently.

Based on the HCCL along the California study routes, we conducted a geometry and accident data analysis to identify geometric factors which might be responsible for high collision rates on wet road surfaces. We determined the following:

- The study sites showing high wet weather collision rates have more frequent spatial changes in geometry along freeway segments than do adjacent sites with wet weather collision rates below the average.
- The study sites have narrower average lane width and are less likely to have medians than adjacent, lower HCCL sites.
- Changes in collision distribution were observed in comparisons of dry and wet pavement collisions.
- Speeding is more likely to be a dominant collision factor under wet pavement conditions.

Furthermore, in site investigations immediately following rainfall, we determined the following:

- We observed water accumulation (“wet-curb”) along the highway, especially at study sites.
- We determined that study sites are more likely to be located at vertical sags or curve sections.
- We observed heavy vegetation that might affect functioning of drainage systems at study sites.
- We also observed “water spray,” which reduces sight distance.

Further research is underway in a second phase of this study, aimed at developing more systematic ways of detecting high collision concentration locations (HCCLs) and identifying other causes of wet-related collisions.

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1 INTRODUCTION

To identify potential sites for safety improvement, Caltrans publishes a quarterly report, titled “Table C,” which identifies high concentration collision locations (HCCLs) within the California State highway system, utilizing information from the Traffic Accident Surveillance and Analysis System (TASAS) database. Caltrans also publishes an annual report called “Wet Table C,” comprised of sites displaying high collision rates under wet pavement conditions. The list is sent to safety engineers at each of the twelve Caltrans districts for in-depth safety investigation of the identified sites.

Many freeway sites have been improved due to such efforts; however, (1) the current Caltrans’ procedure for identifying HCCLs yields a high number of false positives, requiring safety investigation of sites where such investigations are not needed[1] (see Figure 1), resulting in suboptimal use of department resources; and (2) the number of collisions on California roadways related to wet pavement conditions and their associated costs remain excessive. In 2001 alone, 23,000[2] wet pavement-related collisions occurred within the California state highway system, costing the public hundreds of millions of dollars. The magnitude of the cost suggests that even a small reduction in the wet pavement collision rate could result in a substantial reduction in collision-related costs.

The objective of this research project is to identify geometric factors — whether they can be improved or not — that may contribute to a high concentration of wet weather related collisions, and to conduct a thorough investigation of site conditions, in addition to an analysis of traffic collision history.

A review of methods to detect HCCLs is presented in the next section. Following this review, we used a new method, Continuous Risk Profile (CRP), to identify HCCLs. The study routes and data are described in Section 3. We compared the results of the CRP method with those generated by Wet Table C, and identified potential geometric factors responsible for wet pavement collisions, as reported in Section 4. A brief discussion and implications follow in Section 5, with suggestions for future research described in Section 6.

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[1] Caltrans (2002). Table C Task Force Summary Report, pp. 21-31.

[2] Statewide Integrated Traffic Records System (SWITRS)

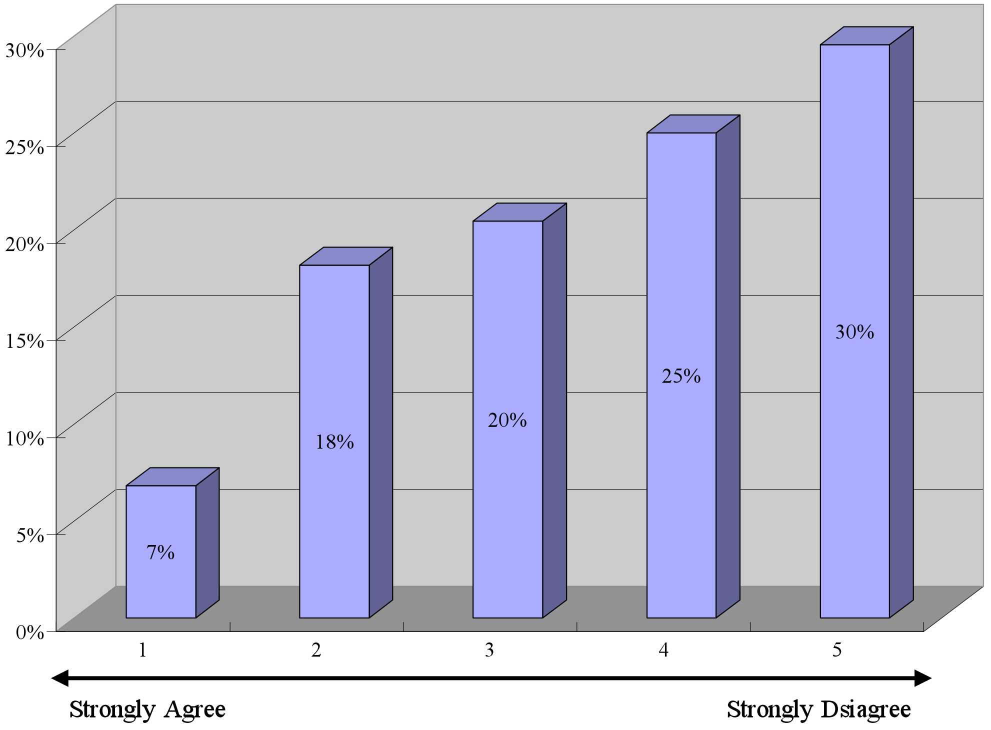

FIGURE 1
Survey Results of Table C Task Force Summary Report, Caltrans (2002)

2 QUALITATIVE DESCRIPTION OF EXISTING APPROACHES

Because falsely identified sites can hinder efforts to identify common geometric or other site conditions contributing to HCCLs, the first step towards identifying causative factors in accidents was to enhance the existing procedure for identifying HCCLs. We examined both the existing Caltrans sliding moving window approach and a new alternative approach called Continuous Risk Profile (CRP) for the purpose of identifying HCCLs along the 413 miles of freeways selected as study routes (see Table 3).

2.1 Sliding Moving Window Approach

A sliding moving window approach is currently employed by Caltrans to identify HCCLs. As the name implies, the approach compares the number of collisions observed within a fixed window of 0.2 mile with a predetermined number of collisions for significance. If the observed number of collisions exceeds the predetermined value, the 0.2 mile segment will be listed in Wet Table C for in-depth safety investigation. If the observed number of collisions is less than the predetermined value, the approach will slide the 0.2 mile window by 0.01 mile and repeat the analysis.

A predetermined number of collisions is estimated for significance using the following formula[3] :

$$N_E = \frac{R_E \times \text{Travel}}{10^6}$$

(1)

$$N_R = N_E + 2.576(N_E)^{1/2} + 1.329$$

(2)

Where

R_E = Average Accident Rate, in accident/million vehicle (ACCS/MV) or accident/million vehicle mile (ACCS/MVM)

= Base Rate + ADT factor

Base rate and ADT factor for different facilities can be obtained from Highway Safety Improvement Program Guidelines.[4]

N_E = Expected number of collisions for each highway group

N_R = Number of accidents required to be significant at the 99.5% confidence level

Travel = Average Daily Traffic (ADT) X Number of days X Length

For Wet Table C, R_E converts to $R_{E(Wet)}$ to include the wet factor.

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[3] Caltrans (2000). Table C Overview, pp. 5-6.

[4] Caltrans (2002). Highway Safety Improvement Program, pp. 5.34-5.40.

$$R_{E(wet)} = \frac{0.3(1 - wt\%) + 3.2(R_E)}{1 + 2.2(wt\%)}$$

(3)

Where

$R_{E(wet)}$ = Average Wet Accident Rate, in wet accident/million vehicle (ACCS/MV) or wet accident/million vehicle mile (ACCS/MVM)

wt% = percentage of wet time, in decimal determined by % wet time of different county.

Then N_E and N_R for wet accident rate should be calculated by the $R_{E(Wet)}$.

When the observed rate exceeds the predetermined rate for a given facility type, the site is considered to be an HCCL. If the observed rate does *not* exceed the predetermined rate, the approach slides the window by 0.01 mile and repeats the same analysis.

The formula is function of traffic volume, type of facility, and the length of segment.

2.2 Continuous Risk Profile

Continuous Risk Profile (CRP) is a new method for assessing collision risk along a roadway, which addresses the limitations of the sliding moving window approach. Continuous risk refers to the concept that the road under examination is not analyzed in segments, but rather is considered as a whole. The profile produces a continuous linear output and shapes itself to the underlying true risk, producing an outcome measure of risk interpretable as a collision density per unit distance of roadway. The approach does not assume that factors causing collisions reside within a certain fixed segment length, but instead continuously monitors changes in collision rates.

The outcome of the CRP approach is highly reproducible and can be used to both proactively and reactively monitor the changes in risk over time, making it additionally suitable for quantifying the effectiveness of countermeasures.

Of the two methods described above used to identify HCCLs, the CRP approach is most suitable for screening continuous roadways such as freeways and highways and was therefore selected for use in this study. A detailed description of the CRP method is reported in Attachment A. In addition, Attachment B presents a discussion about the use of the CRP approach to identify sites with high collision rates, specifically under wet pavement conditions.

3 ROUTES STUDIED AND DATA SOURCES

Six main routes in District 4 offered the required data and were selected as study routes (see Figure 2 and Table 1). Table 2 presents the data sources used to analyze the collision data and geometric features of HCCLs along the study routes.

TABLE 1
Description of Six Study Routes in District 4

Freeway	Direction	Postmile		Length (miles)	Study Period
		Start PM	End PM		
SR-24	E and W	AL 1.8	CC 9.7	14	`94 – `03
I-80	E and W	SF 3.7	SOL 44.8	72.2	`94 – `03
I-280	N and S	SCL 0	SF 7.6	57.6	`94 – `03
I-580	E and W	AL 0	CC 7.8	56.5	`94 – `03
I-680	N and S	AL 0	CC 25.7	47.5	`94 – `03
I-880	N and S	SCL 0	AL 34.8	45	`94 – `03

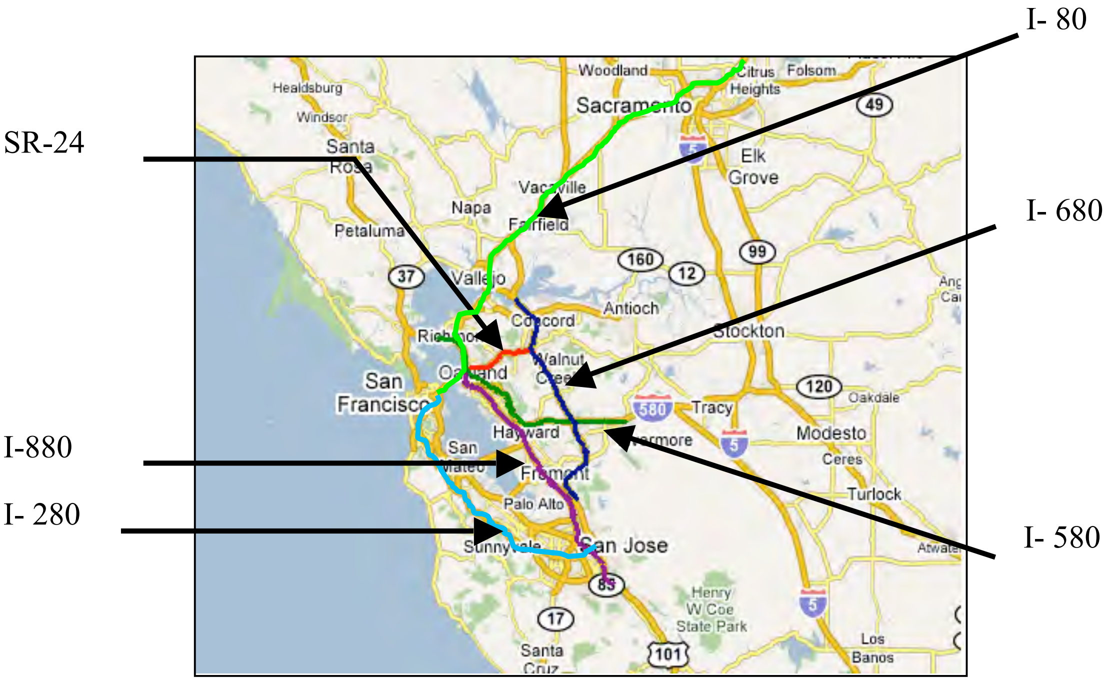

FIGURE 2
Map of Study Sites

TABLE 2
Data Sources

Data Type	Data Source	Period	Description
Collision	Traffic Accidents Surveillance and Analysis System (TASAS)	1999–2003	Collision database containing information associated with each collision occurring within the California state freeway system. Also includes highway infrastructure and traffic volume information. Used to detect HCCLs.
Geometry	Highway Performance Monitoring System (HPMS)	2003	A federally mandated inventory system and planning tool, designed to assess the nation's highway system. Used to identify geometric features responsible for wet pavement collisions.
	Aerial Photos: Google Earth (http://earth.google.com/)		A virtual globe program that maps the earth via superimposition of images obtained from satellite imagery, aerial photography, and GIS 3D globe. Used for site investigation.
	As-Built Plans	2003	Prepared by Caltrans, these plans detail existing as-built conditions. Used to identify true HCCLs.
Traffic Data	Freeway Performance Measurement System (PeMS, https://pems.eecs.berkeley.edu/)	2002	A tool for processing and analyzing traffic data collected by loop detectors and tags. Used for AADT and speed variation.
	Traffic Data Branch of Caltrans	2003	Average daily traffic information about the California state freeway system, provided annually by Caltrans. Used for AADT.
Weather	National Oceanic and Atmospheric Administration (NOAA)	1990–2005	Database containing precipitation information from the nation's whole weather station every 15 minutes. Used for preliminary analysis of precipitation and driver behavior.

4 FINDINGS

Wet Table C provides a list of sites requiring safety investigation. Caltrans safety engineers evaluate each of the sites to determine whether safety improvement is needed or not. If a particular site does indeed need to be improved (termed a "true positive"), the safety engineer recommends necessary countermeasures to improve the safety of the facility. If the investigation indicates that the site does not require any improvement (termed a "false positive"), the safety engineer will report it as a "no action required" site, indicating that the collision causation factor is not related to the geometric condition of the facility. In addition, the safety engineer will not recommend safety improvements at a true positive site if there is a corridor-wide safety improvement project scheduled to include the identified location.

To identify true positive sites (HCCLs), the research team based this study on 413 miles of California roadways selected as study sites from the following four sources; the true positives are the union of these four sets:

- Sites from Wet Table C recommended by Caltrans Engineers for improvement.
- Sites contained in SHOPP (State Highway Operation and Protection Program).
- Sites included in Minor A projects (Caltrans highway facility maintenance projects ranging from $120,000 to $750,000).
- Sites included in Minor B projects (Caltrans highway facility maintenance projects under $120,000).

The true positive locations were then compared with sites identified in existing Wet Table C and those selected by the CRP approach. The results are shown in Table 3, and Attachment C describes the detailed comparison method.

TABLE 3
Identification Performance of CRP versus Wet Table C

Route	Direction	Length	True Hotspots	Existing Method (Wet Table C)	CRP
SR-24	E	14.0	2	2	2
SR-24	W	14.0	3	3	3
I-580	E	76.2	1	2	2
I-580	W	76.3	0	11	4
I-680	N	70.5	0	11	5
I-680	S	70.6	2	4	2
I-880	N	46.0	0	20	1
I-880	S	45.7	1	9	1
Total		413.3	9	62	20
True positive rate				55%	85%
False positive rate				45%	15%

Neither approach produced *false negatives*, which lead to the exclusion of true hotspots. However, the *false positive* rate of the sliding moving window approach (used to produce Wet Table C) was three times greater than that of the CRP approach. False positives are not as serious a problem as false negatives; false positives result in safety engineers having to examine sites where investigations are not necessary, leading to non-ideal utilization of resources, while false negatives impose potential continued safety risks to the public. Nevertheless, it is of significant interest and considerable benefit to minimize the number of false positives.

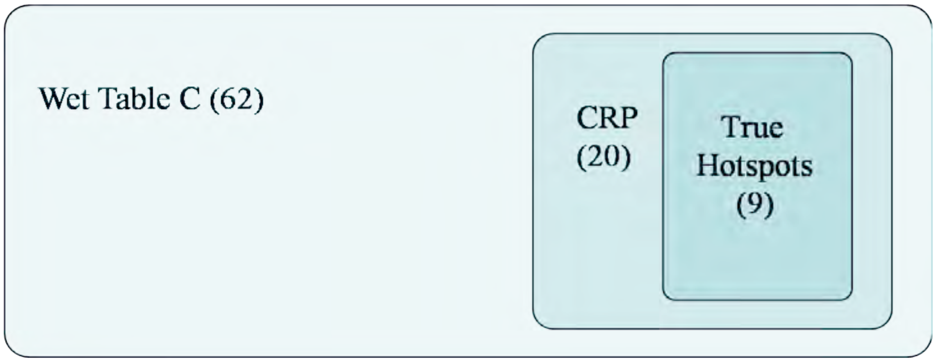

FIGURE 3
Identification Performance of CRP and Wet Table C

To identify wet collision causation factors, only the true hotspots need to be studied in detail. As the example in Figure 3 indicates, the hotspots are a small subset (9 total) of those selected by the sliding moving window approach (62 total). Findings from our study, including collision rate, collision distribution, primary collision factors, and geometric factors from these seven sites are described in the next three sections.

4.1 Changes in Collision Rate

Two of the true positive locations on westbound SR-24 were adjacent to each other; therefore, the collision data from the two sites were analyzed together. A safety improvement project had been completed at another site on westbound SR-24 earlier in the year subsequent to its identification in Wet Table C as a location requiring additional investigation. Since the site had been improved, the collision data from this site were not analyzed as part of our study. As a result, the nine true-positive locations were realigned into seven in Table 4.

Table 4 shows the collision rates at the true positive sites under both dry and wet pavement conditions. The site information is shown in the first five columns; the Annual Average Daily Traffic Volume (AADT) in the sixth column, followed by the highway classification.[5] The remaining four columns show the number of collisions observed during a one-year period under wet and dry pavement conditions, in addition to the minimum number of collisions required for the site to be reported as an HCCL.

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[5] Caltrans, Table B – Selective accident rate calculation.

None of the sites had collision numbers exceeding the 99.5 percentile for dry pavement conditions (see column 10-11 in Table 4), while collision frequencies at these sites under wet pavement conditions were either equal to or greater than the 99.5 percentile for wet pavement related collisions (see column 8-9 in Table 4). Sites 1, 3 and 5 far exceeded the criteria for initiating in-depth investigation, while the remainder of the sites marginally met the criteria.

The expected number of collisions requiring additional safety investigation is a function of AADT, as shown in equation (1) and (2). When AADT is overestimated, N_E will also be overestimated and may lead to false negatives. When AADT is underestimated, it may lead to false positives. To check the validity of the AADT reported in Wet Table C, AADT data from PeMS were used to compare the values (see column 6-7 in Table 5). The purpose of this exercise was to check the accuracy of the data itself, not to determine which data source was more reliable. There was no PeMS detector station in the vicinity of site 4; therefore, comparison was not made at the location. The comparison of the AADT from the two data sources is shown in Table 5. Except for sites 5 and 6, the AADT from the two data sources were comparable.

Difference (%) = (AADT in Table B - AADT in PeMS)/AADT in PeMS

TABLE 4
A List of True Hotspots (2002.7–2003.6, D4)

Site ID	Route	Direction	County	Cross Street	AADT	High-way Group	Observed Number of Wet Collisions	Expected Number of Wet Collisions (99.5%)	Observed Number of Dry Collisions	Expected Number of Dry Collisions (99.5%)
1	SR-24	E	Contra Costa	Camino Pablo	168100	H 65	17	11	2	42
2	SR-24	E	Contra Costa	Acalanes Rd.	168000	H 65	4	4	1	14
3	SR-24	W	Alameda	Fish Ranch Rd.	161000	H 64	42	18	20	68
4	I-580	E	Alameda	N. Flynn Rd.	117000	H 56	3	3	1	8
5	I-680	S	Contra Costa	Crow Canyon Rd.	162000	H 66	9	3	1	11
6	I-680	S	Contra Costa	Geary/Oak Pk.	274000	H 67	4	4	10	18
7	I-880	S	Alameda	Tennyson Rd.	215000	H 65	4	4	16	17

TABLE 5
Difference in AADT

Site ID	Route	Direction	County	Cross Street	AADT	AADT from PeMS	Difference
1	SR-24	E	Contra Costa	Camino Pablo	168,100	161,513	4%
2	SR-24	E	Contra Costa	Acalanes Rd.	168,000	159,209	6%
3	SR-24	W	Alameda	Fish ranch Rd.	161,000	166,944	-4%
4	I-580	E	Alameda	N. Flynn Rd.	117,000	N.A.	N.A.
5	I-680	S	Contra Costa	Crow Canyon Rd.	162,000	126,985	28%
6	I-680	S	Contra Costa	Geary/Oak Pk.	274,000	209,292	31%
7	I-880	S	Alameda	Tennyson Rd.	215,000	200,635	7%

4.2 Changes in Collision Distribution and Geometric Factors

One of the common factors responsible for wet weather related collisions is water accumulation at the shoulder area and water spilling over into the adjacent lane, causing uneven drag on only one side of the traveling vehicle. The collision data from each of the true hot spots collected over a 13-year period were analyzed to identify patterns in collision distribution. Some of the sites yielded insufficient data over a one-year period so that data from multiple years were combined. Figure 4 shows a simple schematic diagram of how the collision locations are coded in the TASAS database.

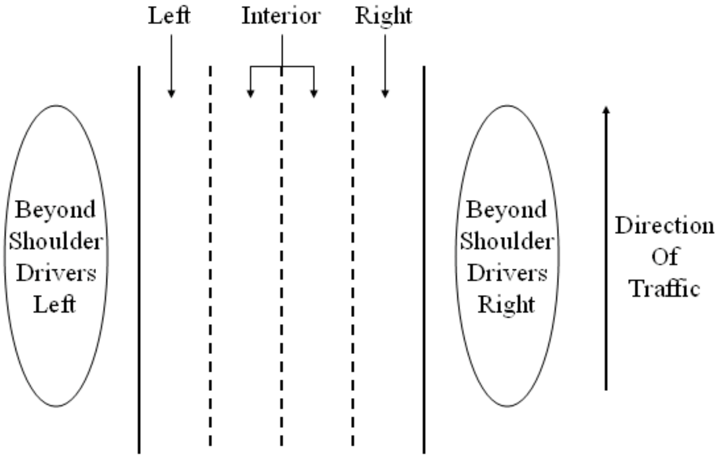
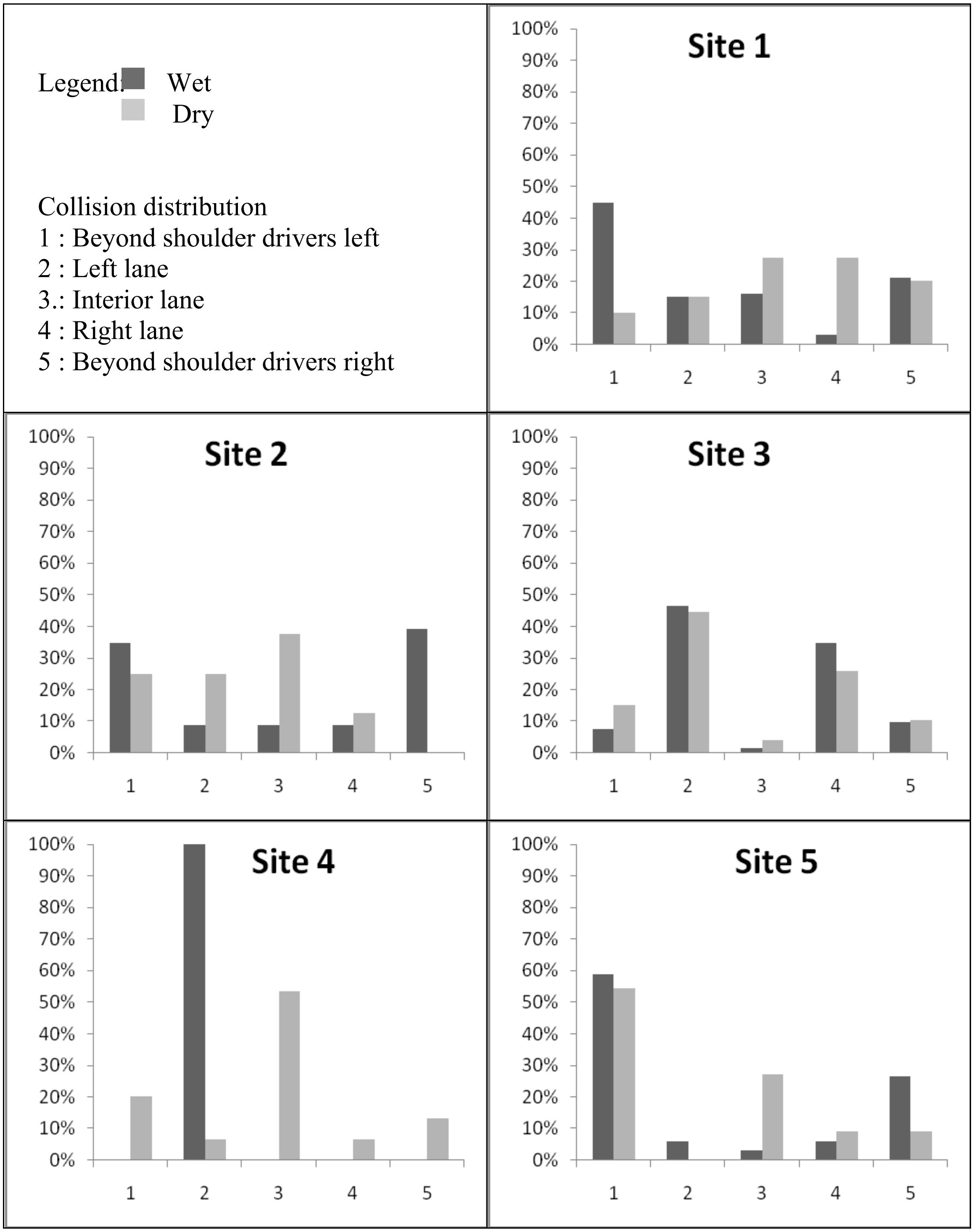


FIGURE 4
Sample Collision Location Coded in TASAS

Figure 5 shows the collision distribution between 1994 and 2006 at each of the true positive sites under dry and wet pavement conditions. Sites 1, 2, 4, 5 and 6 showed a noticeable shift in collision distribution, while no change in collision distribution was observed at other sites. To identify site conditions that might have contributed to the shift in collision distribution and high collision rates, the research team visited each of the sites. The findings from the site visits are presented in conjunction with further analysis in the following sections.



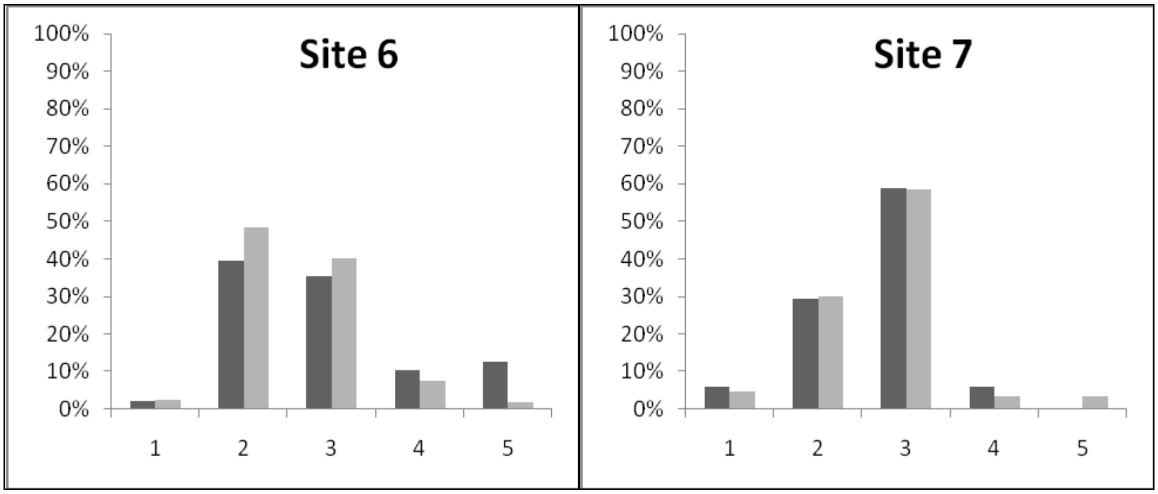


FIGURE 5
Collision Distributions With Respect to Pavement Type

4.3 Geometric Conditions and Primary Collision Factors

Figure 6 shows the CRP plots along 14 miles of eastbound SR-24 from data collected between 1994 and 2003. The plots illustrate how collision rates varied along the corridor over the decade. Sites 1 and 2, which experienced high collision rates under wet pavement conditions only, are indicated by dotted boxes. The annual CRP plots are shown together to demonstrate how the plots are reproducible over the years, and average collision count per unit distance over the ten years was used for the reference risk for each year.

During the site visits, a global positioning system (GPS) was used to record altitude data along the freeway. In Figure 5, the elevation profile of the corridor is demarcated by a solid grey line, with the altitude indicated by the right vertical axis. Locations of the two sites showing high collision rates (Sites 1 and 2) correspond to the locations of vertical sags on the highway.

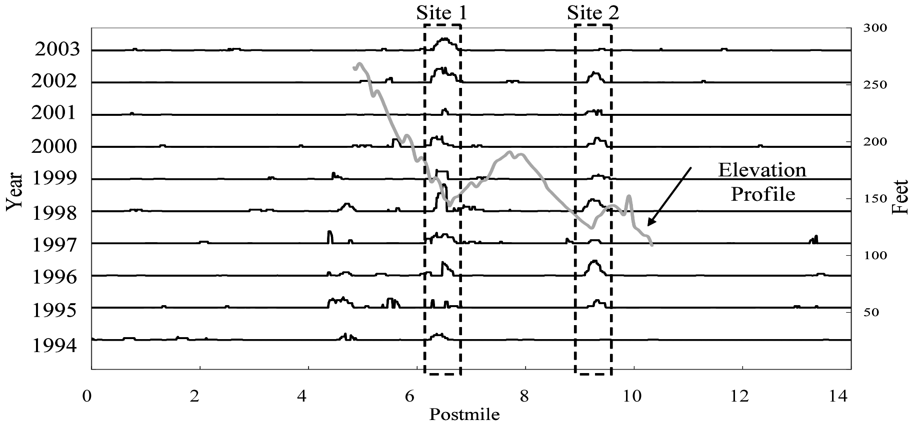
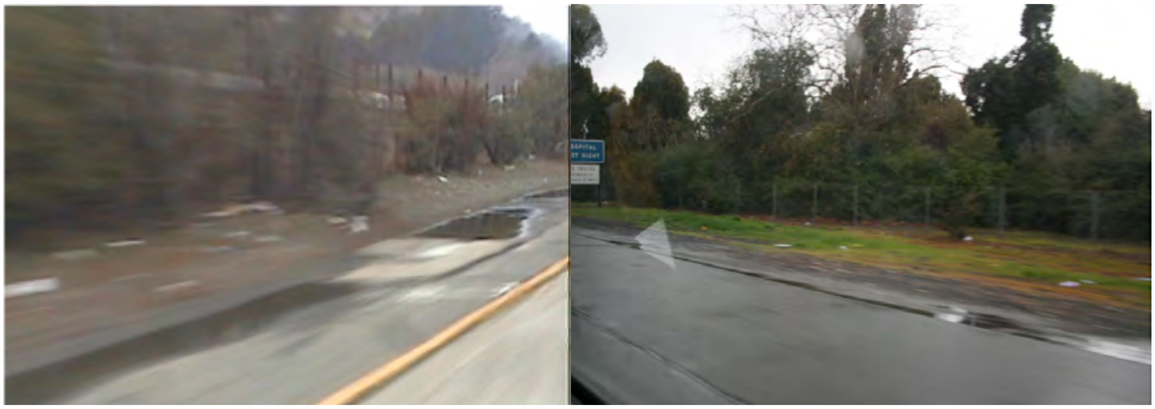


FIGURE 6
Wet Only CRP and Elevation Profile



PHOTOGRAPH 1
Water Accumulation on Drivers' Left Shoulder and Heavy Vegetation at Study Site 1

Photograph 1 was taken at Site 1 shortly after moderate rain, and as shown in the picture, accumulation of water beyond the shoulder on the drivers' left was observed. In addition, the presence of heavy vegetation along the road was also observed. This vegetation could potentially clog the drainage ditch during the rainy season and cause water to accumulate at the shoulder. We also observed "water spray," that can reduce sight distance at study sites (see Photograph 2).

PHOTOGRAPH 2
Water Spray at Study Site 19 and a Non-High Collision Concentration Location

Findings from a comparison of geometric features at HCCLs and their adjacent sites are summarized as follows:

- The proportion of Portland Cement Concrete (PCC) was higher in study sites, while asphalt concrete (AC) was more predominant in adjacent sites.
- The main and shoulder lanes were narrower in study sites than in adjacent sites.

- There was a higher ratio of freeway sections lacking medians in the study sites than in the adjacent sites.
- Changes in the number of lanes and total traveling width were observed in HCCLs.
- Vertical sag was often combined with an inadequate drainage system.
- On wide freeways (more than six lanes), water was more likely to stay on the road surface and to take longer to reach the drainage system at the shoulder.
- Poor pavement conditions resulted in water accumulation in the middle of the freeway.
- There was potentially clogging heavy vegetation in the vicinity of the drainage system.

Speeding remained the primary collision causative factor regardless of pavement conditions, but was an even more dominant factor under wet pavement conditions at all locations. The detailed breakdown of the changes in the distribution of primary collision causative factors is shown in Table 6.

TABLE 6
Primary Collision Factors at Study Sites

Primary Collision Factor	**Site 1**		**Site 2**		**Site 3**		**Site 4**		**Site 5**		**Site 6**		**Site 7**	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Influence of Alcohol	0.0	2.2	0.0	0.0	1.8	5.7	0.0	12.5	0.0	16.7	0.0	1.4	0.0	2.3
Following Too Closely	0.0	2.2	0.0	0.0	9.7	10.3	0.0	6.3	0.0	0.0	1.8	2.8	39.3	16.0
Failure to Yield	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Improper Turn	7.8	17.4	8.0	22.2	4.8	11.9	0.0	6.3	2.8	33.3	7.0	2.8	3.6	4.6
Speeding	87.4	34.8	88.0	55.6	77.1	49.0	100.0	56.3	97.2	16.7	75.4	71.7	48.2	54.9
Other Violations	1.9	19.6	0.0	22.2	4.8	16.5	0.0	18.8	0.0	25.0	12.3	17.9	5.4	18.9
Improper Driving	0.0	2.2	0.0	0.0	0.9	0.0	0.0	0.0	0.0	8.3	0.0	0.7	1.8	1.1
Caused by Other than Driver	0.0	15.2	4.0	0.0	0.4	5.2	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.1
Unknown	1.9	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.0	3.5	1.4	0.0	0.0
Fell Asleep	1.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Not Stated	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Other	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.1

5 DISCUSSION AND IMPLICATIONS

To identify geometric factors that may potentially contribute to high collision rates, we initially attempted to examine 62 sites designated in Wet Table C as “safety investigation required.” However, the research team determined from field visits, data analysis, and the survey report from 2002, that a substantial portion of the sites identified in Wet Table C could be false positives. We examined the current procedure for selecting the “investigation required” locations in addition to reviewing other methods of screening for high collision concentration locations (HCCLs) to identify true positives.

The existing Caltrans method implicitly assumes that factors causing high collision rates reside within the window of 0.2 mile covered by the existing method. Additionally, some of the functional forms the method uses to estimate the expected number of collisions at the 99.5% level for a given facility were substantially different from those at other locations. There is a need to enhance the procedure to detect HCCLs and to update the functional form and its parameters in estimating the expected number of collisions at the 99.5% level.

The research team based its analysis not only on Wet Table C, but also on safety engineers’ field investigation reports and corridor-wide safety improvement project lists to identify true hot spots for inclusion in our study of wet weather related collision causative factors.

Collision rates at the selected study sites did not exceed the 99.5 percentile for dry pavement conditions, but all exceeded that measurement for wet pavement conditions. Notably, except for two sites along SR-24 and one site on I-680, the observed number of collisions was equal to the number of collisions required to initiate safety investigation. Since the number of collisions required for safety investigation is a function of traffic volume, an over- or under-estimated value of AADT could have caused the site to be either falsely identified or not identified. When the AADT from two different Caltrans data sources were compared, a difference of up to 31% was observed.

HCCLs are more likely to exist in areas of vertical sag and where water accumulation on the shoulder area occurs after rainfall. This problem can be exacerbated by the presence of heavy vegetation, which has the potential to clog the drainage system. Although changing the vertical alignment of freeways can be cost prohibitive, trimming foliage during the rainy season can mitigate water accumulation near the drainage area.

Further research is underway in a second phase of this study, with the goal of developing more systematic methods of detecting HCCLs and identifying other causes of wet-related collisions.

6 FUTURE RESEARCH

Since the roadway system in California was built to meet safety standards, roadway geometric conditions contributing to high collision rates were difficult to identify. To further ascertain these factors and negate their adverse effects, more true wet weather related hot spots need to be investigated. Improving methods for screening true HCCLs and monitoring the changes in wet weather related collision rates are potential subjects for future research. In addition, the Federal Highway Administration (FHWA) is currently evaluating the suitability of using the concept of Safety Performance Function (SPF) to identify HCCLs.[6] This method should be evaluated and compared with CRP.

In this study, we focused on the geometry factors that might cause wet pavement. However, there are other causation factors, including the level of precipitation as well as human behavior. These factors also need to be considered in order to reduce wet pavement collision rates. We conducted a preliminary study of these factors; findings are briefly reported in the following section.

6.1 Level of Precipitation

Numerous prior studies have found that precipitation raises the risk of traffic collisions significantly. If we determine the collision rate as a function of precipitation, we can help drivers more adequately prepare for the risks caused by precipitation. As a preliminary analysis, we studied daily precipitation rates and number of collisions on SR-24 from data collected between 1994 and 2003, employing a Poisson regression approach. A positive relationship between precipitation and collisions was found, confirming results from previous studies. However, to build a precise model for the risk associated with precipitation across California roadways, the sample size needs to be expanded to the statewide level.

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[6] Federal Highway Administration. (2002). Safety Analyst: Software Tools for Safety Management of Specific Highway Sites. White paper.

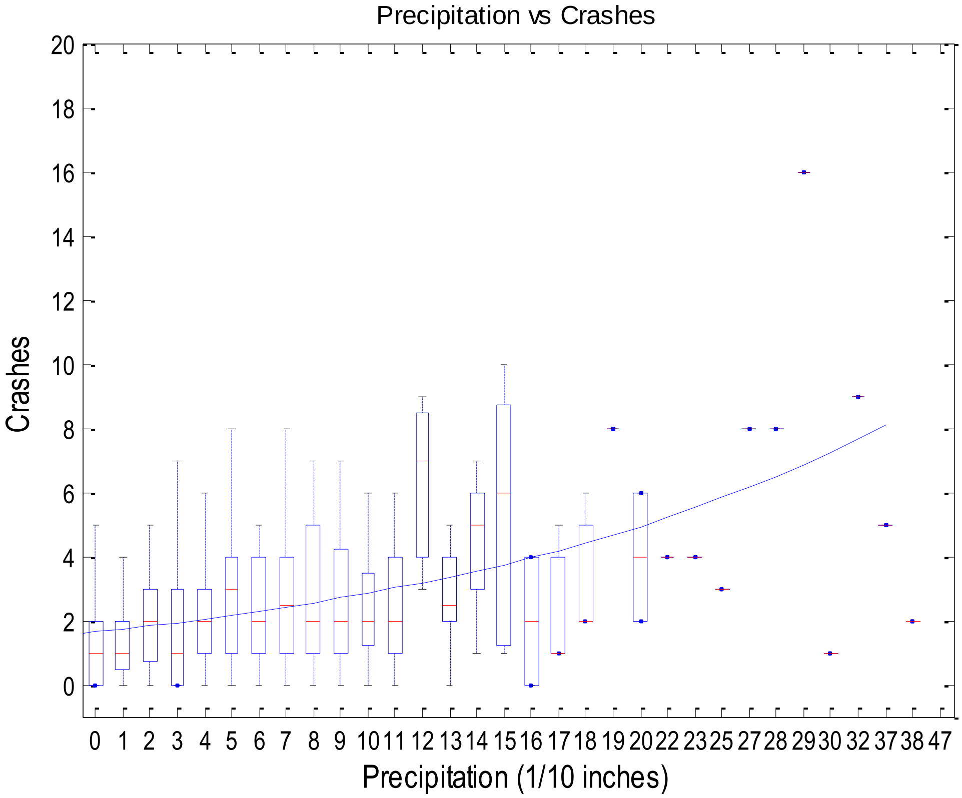

FIGURE 7
Relationship Between the Level of Daily Precipitation and the Number of Collisions (SR-24)

6.2 Drivers' Behavior

As described in Chapter 4, we determined that the primary collision causation factor is speeding, regardless of pavement condition. Undoubtedly, drivers' behavior, including speeding, is one of the most common causation factors in collisions.

Most studies report that precipitation reduces average driver speed by 2 to 10%. Despite this fact, speeding becomes a more dominant collision factor under wet pavement conditions. One possible explanation for this phenomenon is that while some drivers slow down during precipitation, others do not, leading to conflict. To determine whether this assumption is accurate, we need to study (1) the relationship between precipitation and variance of speed, and (2) the relationship between variance of speed and collision rates.

Our preliminary study was conducted using data from a 15-mile segment of I-680, comparing PeMS detector data under rainy and dry conditions. The average speed decreased slightly in free-flow conditions but increased under congested conditions. The variance of speed increased in both free-flow and congested traffic conditions, as shown in Table 8.

TABLE 8
Average and Variance of Speed Under Rainy and Dry Weather Conditions

	Free-Flow Traffic Conditions			Traffic Congestion		
	Dry	Rainy	Significance at 95% Confidence Level	Dry	Rainy	Significance at 95% Confidence Level
Average speed	74.09	73.29	Different	4.51	5.22	Different
Variance of speed	67.53	70.61	Different	5.58	13.22	Different
The number of sample	2387	3968		165	997	

To analyze the relationship between speed variance and collision rate, four locations on I-680 were selected for study, as shown in Table 9. Case 1 was a “wet only” HCCL with higher wet collision rates than the statewide average, but lower than average dry condition collision rates. Case 2 was a “dry only” HCCL with higher dry collision rates than the statewide average, but lower than average wet condition collision rates. Case 3 was a “wet amplified” HCCL with both wet and dry collision rates higher than the statewide average, but where the number of wet collisions was much higher than the statewide average. Case 4 was a “dry amplified” HCCL with both dry and wet collision rates higher than the statewide average, but where the number of dry collisions was much higher than the statewide average.

We compared the average and variance of speed, and coefficient of variation under rainy and dry conditions as shown in Table 9. Coefficient of variation is the variance divided by the average and shows the relative variance with respect to the average. In all cases, the variance of speed under rainy weather conditions was higher than it was under dry conditions. However, the coefficient of variation is higher under conditions producing greater numbers of collisions.

To summarize, in the wet only and wet amplified cases, the coefficient of variation under rainy conditions is higher, while in the dry only and dry amplified cases, the coefficient of variation under dry conditions is higher. This means that the relative variance of speed is likely to be positively related to the number of collisions. For a conclusive determination, additional sites would need to be analyzed.

TABLE 9
Variance of Speed and the Number of Collisions

Case	Description	Average of Speed		Variance of Speed		Coefficient of Variation		
		Rainy	Dry	Rainy	Dry	Rainy	Dry	Difference
1	Wet only HCCL	68.55	76.93	41.59	44.04	0.61	0.57	0.03
2	Dry only HCCL	59.37	66.70	19.07	22.39	0.32	0.34	-0.01
3	Wet amplified HCCL	63.12	72.24	62.70	64.05	0.99	0.89	0.11
4	Dry amplified HCCL	89.69	99.85	56.50	71.89	0.63	0.72	-0.09
Average		70.18	78.93	44.97	50.59	0.64	0.63	0.01

7 ATTACHMENT A: CONSTRUCTING CRP

The CRP can be constructed by first cumulatively plotting collisions, *A(d)*, with respect to distance, *d*. Then, by rescaling using a reference risk, $B(d - d_0)$ determined by the user, one can visually identify extended segments of freeways with higher collision rates (see Figure 8). The rescaled cumulative collision count curve amplifies the changes in the slope of the curve, making it easier to observe how risk changes continuously with respect to distance.[7]

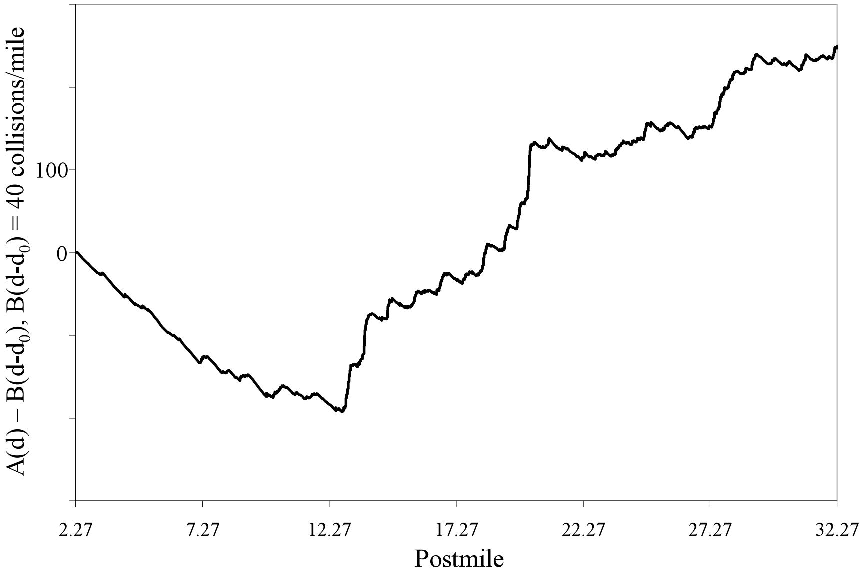

FIGURE 8
I-880 Northbound, Alameda County, California, 2003

Some of the fluctuations shown in the rescaled cumulative collision counts are due to statistical variations, and these variations can be pre-filtered[8] by using a moving average as shown in equation (4). This allows us to determine where the risk started to increase and decrease, and also to determine the locations of the localized peaks in risk.

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[7] Number of collisions observed at a given postmile.

[8] Ljung, L. System Identification - Theory for the User. Prentice-Hall, Upper Saddle River, New Jersey, 1999.

$$M(d) = \frac{\sum_{i=-\min(L/l,(d-d_0)/l)}^{\min(L/l,(d_{end}-d)/l)} A(d \; + i \times l)}{\min(L/l,(d_{end}-d)/l) + \min(L/l,(d-d_0)/l) + 1} \qquad (4)$$

For

$d = d_0 + k \times l$ and $k = 1,2,\ldots\frac{d_{end} - d_0}{l}$

Where

$A(d)$ = cumulative number of collisions
d_0 = beginning postmile
d_{end} = ending postmile
$D_{start} < D_{end}$
l = increment
$2L$ = size of the moving average
$k, \frac{L}{l}$ and $\frac{d_{end} - d_0}{l}$ are integers

Since we are only interested in HCCLs, we can then apply equation (5) to identify the positive portion of the rescaled smoothed cumulative curve:

$$K(d) = Max\left(M(d) - B(d), 0\right) \qquad (5)$$

Note that in equation (5), $K(d)$ will not only identify high risk locations, but also show the excess risk that the segment has compared to the reference risk, $B(d - d_0)$.

8 ATTACHMENT B: PROCEDURE FOR IDENTIFYING WET ONLY CONTINUOUS RISK PROFILE (CRP)

Figure 9 shows the CRP plotted using collisions occurring along a 45-mile segment of northbound I-880 in 2003 under dry pavement conditions. Figure 10 shows a similar plot for collisions occurring under wet pavement conditions. The *x*-axis shows the increase in postmile and the *y*-axis shows excess collision rates compared with $B(d - d_0)$, which represents the excess collision rate (number of collisions per mile) compared with the reference risk. The average dry and wet pavement collision rates in 2003 were used as the reference risk for Figures 9 and 10 respectively.

Many locations displaying high collision rates under dry conditions, marked by peaks in Figure 9, also displayed high collision rates under wet conditions, as marked by peaks in Figure 10. The reappearance of these peaks in both wet and dry weather is logical, since a site that displays high collision rates under dry pavement conditions will not become any safer under wet pavement conditions.

Figure 11 is the result of filtering out the redundant peaks in Figures 9 and 10. As a result, the peaks in Figure 11 identify the locations displaying high collision rates only under wet pavement conditions. As a result of this procedure, the unique HCCLs related to wet pavement conditions can be identified.

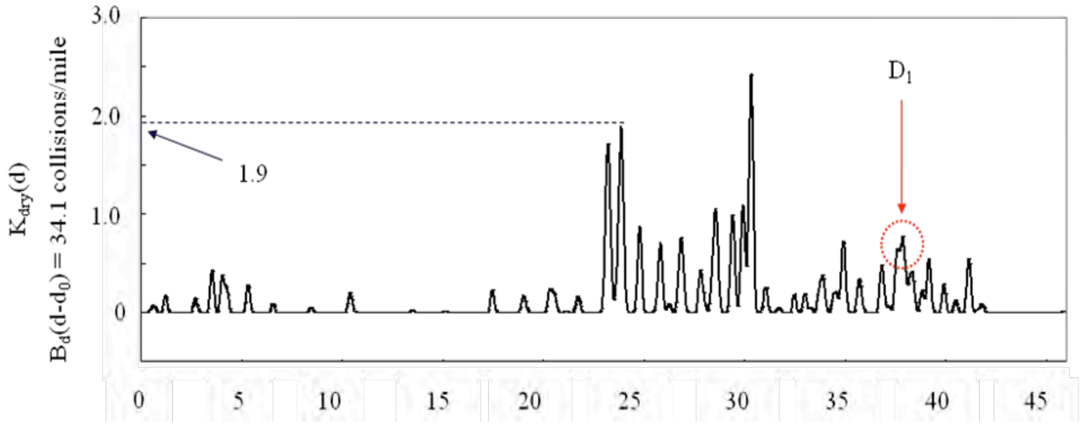

FIGURE 9
Dry Continuous Risk Profile

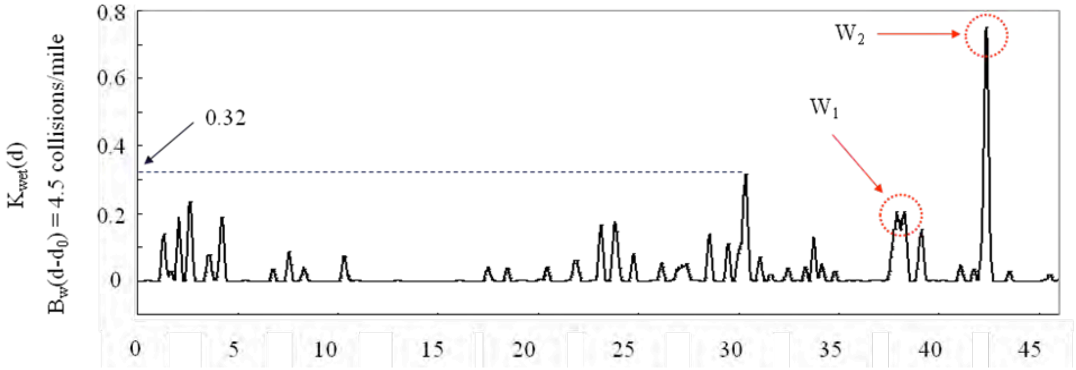

FIGURE 10
Wet Continuous Risk Profile

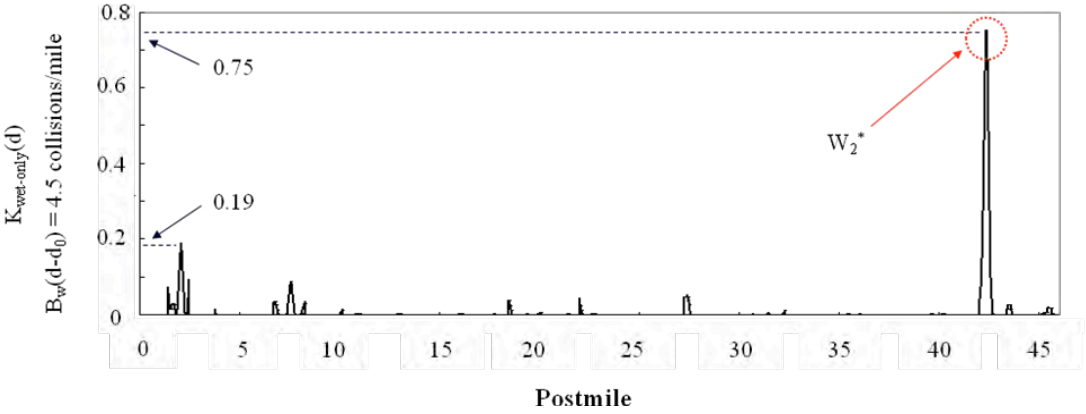

FIGURE 11
Wet-Only Continuous Risk Profile

9 ATTACHMENT C: THE CRP FOR THE COMPARISON WITH WET TABLE C

For reasonable comparison, the value of B(d) is set as the number of collisions required for significance at 99.5% using the Sliding Window Approach, converted to the number of collisions per unit distance. The value of B(d) is constant within the same type of facility, but changes discretely when the facility classification changes.

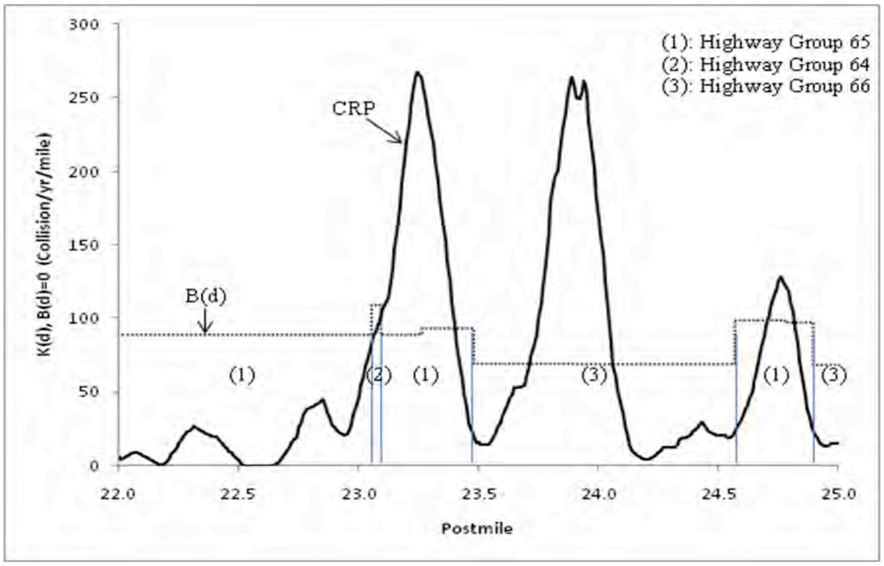

FIGURE 12
K(d) at B(d)=0 and B(d) at Significance at 99.5%, I 880 Northbound, 2005

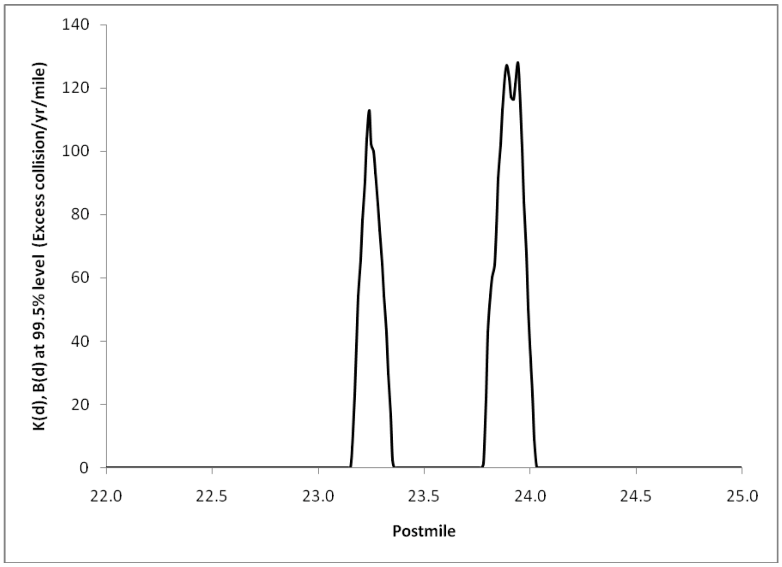

FIGURE 13
Excess Risk at a Significance of 99.5%, I 880 Northbound, 2005

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Statewide Integrated Traffic Records System (SWITRS) .