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ABSTRACT
The objective of the study described in this paper is to identify common site features that may contribute to high collision rates under wet pavement conditions. To minimize falsely identified high collision concentration locations (HCCL) in evaluating factors contributing to high collision rate, this study accessed the magnitude of false positives (i.e., identifying sites for safety improvements that should not have been selected) by comparing HCCLs identified by the existing conventional sliding moving window approach with the ones identified by the Continuous Risk Profile (CRP) approach and the safety investigators field evaluation notes. The result shows that CRP approach can reduce the false positive rate by 30%.

Significant shifts in collision distribution across traveling lanes were observed at some of the HCCLs under wet and dry pavement conditions. Speeding was the primary collision factor regardless of pavement condition, but it became a more dominant factor under wet pavement conditions at all observed locations.

Rapid spatial changes (i.e., vertical and horizontal curve over a short distance), narrower lane width, lack of median, and wider total freeway width were some of the notable geometric features observed at these sites. Other features responsible for diminishing drivers’ visibility are also contributing factors.
1. INTRODUCTION

The California Department of Transportation (Caltrans) continuously monitors traffic collisions that occur on its roadways in an effort to identify sites that may require further safety improvements. Those identified sites are then reported in a list titled “Table-C” and “Wet Table-C” depending on whether the site displayed high collision rate under dry or wet pavement condition; Table-C is published quarterly while Wet Table-C is published annually.

The list is provided to safety engineers at each of the twelve Caltrans’ districts for in-depth safety investigation of the identified sites, and many freeway sites have been improved as a result of such efforts. However, the survey conducted in 2002 among safety engineers revealed that the current Caltrans’ procedure for identifying HCCLs yields a high number of false positives (i.e., identifying sites for safety improvements that should not have been selected) (1), resulting in non-ideal use of department resources. Despite ongoing efforts to deploy safety countermeasures, the number of collisions on California roadways related to wet pavement conditions and their associated costs remains excessive. According to the 2001 traffic collision data in Traffic Accident Surveillance and Analysis System (TASAS), about 160 fatal, 6,600 personal injury and 12,500 property damage only collision occurred California highway system, resulting in about one billion dollars based on the statewide collision costs (2). 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. Caltrans continues to pursue safety improvements, and this study was initiated as a part of the effort to address this problem.

Because falsely identified sites can hinder the efforts to identify common site conditions contributing to higher collision rate, the first step towards identifying collision factors was to enhance the existing procedure for identifying HCCLs. To this end, this study applied the Continuous Risk Profile (CRP) (3) approach over 400 miles of freeways in California. The performance of CRP and conventional sliding moving window approaches are discussed in Section 2 along with qualitative descriptions of the two approaches. Findings from analyzing the collision data from the sites identified in Section 2 and investigation of these sites are presented in Section 3. The paper ends with a brief summary and concluding remarks in Section 4.

2. METHODS FOR IDENTIFYING HCCL

Caltrans currently employees a sliding moving window approach to identify HCCLs along its roadways. 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 that window (i.e., the number of collisions required for significance at 99.5%). If the observed number of collisions exceeds the predetermined value, the 0.2 mile segment will be listed in Wet Table-C for further safety investigation. When the observed number of collisions is lower than the predetermined value, the approach will slide the 0.2 mile windows 0.01 mile increment and repeat the analysis (1). This predetermined value is a function of roadway classification, traffic volume and rainfall intensity of the region (2).

This approach implicitly assumes that (i) collision causative factors reside within the 0.2 mile segment and (ii) geometric factors affecting the collision rate remain constant within the segment under investigation (4). When these assumptions are violated – which is often the case on congested urban freeways – it can result in false positives.
When this approach was applied on six routes shown in Figure 1, indeed, a high false positive rate was found. The sliding moving window approach identified 62 sites over a one year period between July 2002 and June 2003, of which only nine sites were confirmed to be true positives by safety investigation engineers from the local district.

These falsely identified sites can hinder the efforts to identify common site conditions that can contribute to high collision rates. As a remedy, the Continuous Risk Profile (CRP), an approach that does not require assumptions (i) and (ii), was applied to the same six routes shown in Figure 1.

![Figure 1: A map of studied sites, Bay Area, California](image)

The CRP 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 the approach continuously monitors changes in collision rates. A detailed description of this approach as well as its other applications can be found in Chung et al. (3).

Rather than focusing on details of how the CRP can be constructed, a description of CRP plots is provided here with the aid of Figure 2. The x-axis in the figure is the postmile increasing in the direction of traffic and the y-axis shows the collision rate in number of collisions per unit distance. The dotted line is the predetermined collision rate used to generate the HCCL list in Wet Table-C and the description of highway group in the figure can be found in (2). The CRP plot displays wet weather related collision profile along the corridor. The sporadically appearing spikes in collision rate were prefiltered by using a moving average (5). The area under the CRP plot between two postmiles is the total number of collision between those locations. The area enclosed between the CRP plot and the dotted line is the excess number of collisions. The portion of CRP exceeding the dotted line is used to locate HCCL. The peaks marked by the dotted circles and denoted by P₁ pinpoints the HCCL along the corridor shown in the figure.
Wet Table-C provides a list of sites requiring safety investigation. Caltrans safety engineers evaluate each of the sites to determine whether improvement is needed or not. If the site is a true positive (i.e., identifying sites for safety improvements that should have been selected), the safety engineer recommends necessary countermeasures to improve the safety of the facility. If the site is a false positive, the safety engineer will report it as a “no action” required site, indicating that the collision causation factor is not found to be related to the geometric condition of the facility. In addition, the safety engineer will not recommend safety improvements at a true positive site if a corridor-wide safety improvement project covering the identified location has been scheduled.

Engineers also investigate sites that are not identified in Wet Table-C based on requests from the public or other agency. If these sites turn out to be a true HCCL, but not identified in Wet Table-C, these sites are considered as a false negative (i.e., not identifying sites for safety improvements that should have been selected).

Sites detected by the sliding moving window and CRP approach are together shown with the true HCCL in Figure 3 to explain the process of selecting sites that was used in subsequent analysis. Figure 3 shows the excess portion of CRP plot shown in Figure 2. The black solid lines shown at the top of the figure mark the location of sites identified by the sliding moving window approach, and the peak of CRP inscribed by dotted circle labeled P denotes to the HCCL site identified by CRP approach. The identified location (by both CRP and sliding moving window approach) marked by the solid rectangle is the true HCCL; the true HCCLs were always the subset of sites identified by the CRP approach and the sites identified by the CRP approach were a subset of HCCLs listed in Wet Table-C along the six routes. A summary of the comparison is shown in Table 1. Wet Table-C identified 62 sites of which only nine turned out to be true hotspots (false positive rate of 85%). On the other hand, CRP identified only 20 sites, of which none were true positive (false positive rate of 55%).
FIGURE 3 Comparison of True HCCL and Sites Detected by CRP and Sliding Moving Window Approach along I-880S

TABLE 1 COMPARISON OF THE CRP AND WET TABLE-C (source: Chung et al. (3))

<table>
<thead>
<tr>
<th>Route</th>
<th>Direction</th>
<th>Length</th>
<th>True Hotspots</th>
<th>Existing Method (Wet Table-C)</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-24</td>
<td>E</td>
<td>14</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>SR-24</td>
<td>W</td>
<td>14</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>I-580</td>
<td>E</td>
<td>76</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>I-580</td>
<td>W</td>
<td>76</td>
<td>0</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>I-680</td>
<td>N</td>
<td>71</td>
<td>0</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>I-680</td>
<td>S</td>
<td>71</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>I-880</td>
<td>N</td>
<td>46</td>
<td>0</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>I-880</td>
<td>S</td>
<td>46</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>413</td>
<td>9</td>
<td>62</td>
<td>20</td>
</tr>
<tr>
<td>True positive rate</td>
<td></td>
<td>15%</td>
<td>45%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False positive rate</td>
<td></td>
<td>85%</td>
<td>55%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the data available to us, neither approach identified false negatives. However, the false positive rate of the sliding moving window approach was three times greater than that of the CRP approach. False positives are not as a serious 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 strong interest and considerable benefits to minimize the number of false positives.

Falsely identified sites can impede our effects in identifying geometric conditions that can contribute to high collision rate. The comparison shown in Table 1 presents the magnitude of false positive rate depending on the detection method, even when the same criteria and collision
data were used. Although CRP approach reduced the false positive rate by 30%, the CRP approach identified 11 sites in addition to the nine true HCCLs. All of these sites, indeed, displayed high collision rate. However, six of these locations were near major freeway interchanges and one near a bridge. Among the other four, two sites were located near mountainous areas characterized by strong wind—there is a wind farm in the vicinity. The collision rates at these locations were likely to have been influenced by their unique site conditions. The site conditions at the other two appeared to be similar to that of sites in the vicinity where collision rates were low. No apparent unique site condition was observed at those two locations. For the purpose of this study, only the true positive locations confirmed by the safety engineers were studied in detail, including collision rates, collision distribution, primary collision factors, and potential collision contributing geometric factors. These are discussed next.

3. FINDINGS

Changes in Collision Rate

Two of the true positive locations on SR-24W 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 SR-24W earlier in the year subsequent to its identification in Wet Table-C as an investigation required location. Since the site had been improved, the collision data from this site were not analyzed as a part of this study. As a result, the nine true-positive locations are realigned into seven in Table 2.

Table 2 shows the collision rates at the true positive sites under both dry and wet pavement conditions. The site identification number is in the first column and their location information is shown in columns 2-5. The highway group (2) is given in the sixth column followed by the number of collision observed during one year period and the number of collisions required for the site to be reported as HCCL under wet (columns 7-8) and dry (columns 9-10) pavement conditions. The last three columns show Annual Average Daily Traffic Volume (AADT) from two different data sources for the same location and the difference in the reported AADT.

Note that none of the sites had collision numbers exceeding the 99.5 percentile for dry pavement conditions (see columns 9-10 in Table 2), while collision frequencies at these sites under wet pavement conditions were either equal to or greater than the 99.5 percentile for the wet pavement related collisions (see columns 7-8 in Table 2). Sites 1, 3 and 5 far exceeded the criteria for initiating in-depth investigation, while the remainder of the sites just marginally met the criteria.

As it was stated earlier in this paper, the threshold collision rate of a given facility (beyond which the investigation is triggered) investigation is a function of AADT. When AADT is overestimated, the threshold 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 Freeway Performance Measurement System (PeMS) (6) were used to compare the values (see columns 11 and 12 in Table 2). The purpose of this comparison 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. Except for sites 5 and 6, the AADT from the two data sources were found to be mostly comparable.
\[ \text{Difference} \% = \frac{\text{AADT}_{\text{WetTable-C}} - \text{AADT}_{\text{PeMS}}}{\text{AADT}_{\text{PeMS}}} \]

### TABLE 2 A List of True Hotspots (July 2002–June 2003, D4)

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Route</th>
<th>Direction</th>
<th>County</th>
<th>Cross street</th>
<th>Highway group</th>
<th>Observed number of wet collisions</th>
<th>Number of collisions required for significance at 99.5%</th>
<th>Observed number of dry collisions</th>
<th>Number of collisions required for significance at 99.5%</th>
<th>AADT from Wet Table-C</th>
<th>AADT from PeMS</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SR-24</td>
<td>E</td>
<td>Contra Costa</td>
<td>Camino Pablo</td>
<td>H 65</td>
<td>17</td>
<td>11</td>
<td>2</td>
<td>42</td>
<td>168,100</td>
<td>161,513</td>
<td>4%</td>
</tr>
<tr>
<td>2</td>
<td>SR-24</td>
<td>E</td>
<td>Contra Costa</td>
<td>Acalanes Rd.</td>
<td>H 65</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>14</td>
<td>168,000</td>
<td>159,209</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>SR-24</td>
<td>W</td>
<td>Alameda</td>
<td>Fish ranch Rd.</td>
<td>H 64</td>
<td>42</td>
<td>18</td>
<td>20</td>
<td>68</td>
<td>161,000</td>
<td>166,944</td>
<td>-4%</td>
</tr>
<tr>
<td>4</td>
<td>I-580</td>
<td>E</td>
<td>Alameda</td>
<td>N Flynn Rd.</td>
<td>H 56</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>117,000</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>5</td>
<td>I-680</td>
<td>S</td>
<td>Contra Costa</td>
<td>Crow Canyon Rd.</td>
<td>H 66</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>11</td>
<td>162,000</td>
<td>126,985</td>
<td>28%</td>
</tr>
<tr>
<td>6</td>
<td>I-680</td>
<td>S</td>
<td>Contra Costa</td>
<td>Geary/Oak Pk.</td>
<td>H 67</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>18</td>
<td>274,000</td>
<td>209,292</td>
<td>31%</td>
</tr>
<tr>
<td>7</td>
<td>I-880</td>
<td>S</td>
<td>Alameda</td>
<td>Tennyson Rd.</td>
<td>H 65</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>17</td>
<td>215,000</td>
<td>200,635</td>
<td>7%</td>
</tr>
</tbody>
</table>

Data source: TASAS, Wet Table C, State Highway Operation and Protection Program (SHOPP) and PeMS from July 2002 to June 2003

### 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 spilling over into the adjacent lane, causing uneven drag on one side of the traveling vehicle. The collision data from each of the true HCCL 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 indicating how collision locations or travel lanes are coded in TASAS database. 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 routes. 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 4 Collision Locations Coded in TASAS

FIGURE 5 Collision Distribution

Legend: Wet ■ Dry □
Collision distribution
1: Beyond shoulder drivers left
2: Left lane
3: Interior lane
4: Right lane
5: Beyond shoulder drivers right
Geometric Conditions and Primary Collision Factor

Figure 6 shows the CRP plots along 14 miles of SR-24E between 1994 and 2003. The plot illustrates how the collision rate varied along the corridor over the decade. Sites 1 and 2, which displayed 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 in Figure 6.

During the site visit, a global positioning system (GPS) was used to record altitude data along the freeway. In Figure 6, 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 in Table 2) correspond to the locations of vertical sags on the highway.

![FIGURE 6 Wet Only CRP and Elevation Profile](image)

A photograph (see Figure 7) taken at Site 1 shortly after moderate rainfall shows the accumulation of water beyond the shoulder on the drivers’ left. The accumulation of water was observed only at the vertical sag and the pavement surface in the vicinity was fairly dry. In addition, heavy vegetation was present, which could potentially clog the drainage ditch during the rainy season and cause water to accumulate at the shoulder. No notable geometric features were observed at sites 4 and 6. At site 5, water spray, which impairs drivers’ visibility, was observed during the rainfall.

Speeding was recorded as the primary collision factor for 49% of all collisions under dry pavement conditions, and for 82% under wet pavement conditions. Even though speeding is the primary collision causative factor regardless of pavement conditions, it obviously became a more dominant factor under wet pavement conditions at all locations. This implies that a combination of speeding and wet pavement condition, as expected, is a significant contributor in wet collisions.
4. DISCUSSION AND FUTURE RESEARCH PLAN

To identify geometric conditions that can potentially contribute to high collision rates, this study was initiated to investigate the wet collision concentration locations designated in Wet Table-C, the method used by Caltrans to detect HCCLs. However, based on field visits, data analysis, and the survey report from 2002 (1), it was determined that a substantial portion of the sites identified in Wet Table C could be false positives, hindering efforts to analyze potential collision causative factors. To evaluate the magnitude of the false positive rate, HCCLs identified by existing sliding moving window approach were compared with the ones identified by CRP approach and safety engineers field report. Although CRP approach also produced false positives, it markedly reduced the false positive rate from 85% to 55%, a very substantial reduction.

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

High wet pavement collision rates were found to correspond to the locations of vertical sags on the highway with heavy vegetation. Vegetation could be a potential issue as it may clog drainage systems, causing standing water to remain on the road surface for a longer period of time. While changing the vertical alignment of freeways is cost prohibitive, trimming foliage during the rainy season could potentially mitigate water accumulation near the drainage area. High collision rates were also observed on wide freeways (more than 6 lanes), where water was more likely to stay on the road surface.

Most roadway systems were built to meet safety standard, roadway geometric conditions contributing to high collision rates were scarce. However, seeking further safety improvements is a continuing mission for highway operation and maintenance agencies, including Caltrans. To further understand the contributing factors and to negate their adverse effects, it will be worthy effort to investigate more wet weather related hotspots.
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