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Understanding the Characteristics of Secondary Crashes on Freeways

by

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ABSTRACT

Research on secondary crashes has been limited, mainly due to the lack of incident data with sufficient details and related traffic data that are necessary for secondary crash analysis. In recent years, traffic management agencies have begun the implementation and maintenance of detailed databases that can be used for detailed analysis of incidents, including secondary crashes. In this paper, such a database is utilized in an effort to examine the relationships between primary incident characteristics and the likelihood and severity of secondary crashes. Summary statistics and logistic regression analyses were applied to understand these relationships. The derived regression model indicates that five factors have significant effects on the likelihood of incident occurrence. These factors are: the number of vehicles involved in the primary incident, the number of lanes at the primary incident site, the primary incident duration, time-of-day of incident occurrence, and whether or not vehicle rollover occurs during the primary incident. Secondary crash severity analysis confirms that secondary crashes are usually much less severe than other crashes, which could be an important factor when conducting benefit-cost analysis for incident management. The results show that incident visibility and the lane blockage durations of the primary incidents are significant contributing factors when determining the severity of secondary crashes.

Keywords: Safety Analysis, Secondary Crashes, Logistic Regression.
INTRODUCTION

Previous studies that evaluated the benefits of incident management programs have frequently assumed that these programs can reduce the likelihood of secondary crashes (1-3). Secondary crashes are those resulting from existing primary incidents, and they usually occur at the end of or within the queues that are formed due to primary incidents. A faster clearance of freeway incidents can reduce queue lengths and duration, thus reducing the potential for secondary crashes. This is considered one of the benefits of incident management strategies. To determine the extent of this benefit, however, it is important to determine the likelihood of secondary crash occurrence and the factors affecting this likelihood. In addition, understanding secondary crash causes and characteristics is useful in identifying potential improvements to incident management processes.

Research on secondary crashes has been limited. This is mainly due to the lack of incident data with sufficient details and related traffic data that are necessary for secondary crash analysis. In addition, there is no uniform definition of a secondary crash in terms of its spatial and temporal relationship to the primary incidents. Therefore, it has been difficult to associate an initial incident with secondary crashes and to confirm that the first incident was a contributor to these subsequent crashes (4).

Ideally, when identifying secondary crashes, it is desirable to have measurements of queue lengths during the primary incident conditions stored in the incident database and available for analysis. However, it is not possible to retrieve these measurements based on most existing traffic management center databases. For this reason, researchers generally link secondary crashes to primary incidents according to some pre-defined spatial and temporal criteria. The rationale is that a secondary crash should take place within a maximum distance upstream in the same direction of travel and within a certain time span of a primary incident. Raub (5) defined a secondary crash as any crash that occurs no more than one mile upstream of, and less than 15 minutes after, an initial incident. Moore et al. (4) defined these two spatial and temporal criteria as two hours and two miles upstream of the initial incident. Hirunyanitiwattana and Mattingly (6) suggested that the criteria be within 60 minutes and two miles upstream of the primary incident. Clearly, there is no agreement on a single definition of the spatial and temporal boundary criteria for secondary crash analyses among previous studies.

In recent years, traffic management agencies have begun implementing and maintaining detailed databases that include data collected from their intelligent transportation systems (ITS) such as incident management activities. As an example of such databases, the Florida Department of Transportation District 4 (FDOT D4) has implemented a comprehensive freeway incident database that allows detailed analysis of the incidents that occur on the three major corridors (I-95, I-75, and I-595) managed by the FDOT in Fort Lauderdale, Florida.

This paper presents an analysis of secondary crashes using the FDOT District 4 database mentioned above. A summary statistical analysis is conducted to study secondary crash characteristics. In addition, logistic regression models are applied for analyzing the effects of primary incident characteristics on the likelihood and severity of secondary crashes. Contributing factors for the likelihood and severity of secondary crashes are identified and discussed based on the results of the analysis. The developed model has shown that the number of lanes at the primary incident site, the number of lanes closed, the lasting time of the primary
incident, the time of day, and vehicle rollover occurrence are the significant contributing factors for secondary crash occurrence. Appropriate countermeasures can be taken to reduce the likelihood of secondary crash occurrence.

DATA DESCRIPTION AND ANALYSIS

Starting on January 3, 2005, all information gathered from the freeway incident management program of FDOT District 4 in Fort Lauderdale, Florida has been stored in a comprehensive database called the Systems Management for Advanced Roadway Technologies (SMART) database. In addition to the incident start/closure time and geographic information, the SMART database also records environmental conditions, incident type and severity, lane and shoulder blockage information, number and type of vehicles involved, incident response status, and so on.

This study utilizes incident records stored in the abovementioned FDOT D4 database from January 2005 to January 2007. During the two-year period, FDOT D4 managed 95,844 road assists, which corresponds to 131 assists per day. Among these incidents, 7,903 were crashes. During the same time period, 4,435 incidents caused one or more lane blockages. In this study, lane blockage incidents serve as a base for identifying potential primary incidents.

Based on the literature, in this study, a secondary crash is defined as a crash that occurs at most two miles upstream of the primary incident location in the same direction of travel and within the period from the start of the primary incident to 15 minutes after the clearance of the primary incident. In addition, to be on the conservative side, this study assumes that only incidents with lane blockages can potentially cause secondary crashes. The reason is that it is assumed that incidents with only shoulder blockages usually have minor impacts on traffic and, therefore, are generally unlikely to cause secondary crashes.

To quickly identify secondary crashes, a program was written in this study in the DOT NET C# environment to link possible secondary crashes with primary incidents according to the spatial and temporal criteria listed above. The program identified 413 secondary crashes resulting from 352 primary incidents with lane blockages. Figure 1 graphically displays the three corridors managed by FDOT D4 and the spatial distribution of the identified primary incidents that have associated secondary crashes. As Figure 1 shows, the primary incidents with linked secondary crashes were concentrated on the I-95 and I-595 corridors.

SUMMARY STATISTICS

The summary statistics of secondary crashes for the three corridors are shown in Table 1. As Table 1 shows, the primary incident and secondary crash percentages for both directions of I-95 are significantly higher than those of I-595 and I-75. In Table 1 and the following tables, the primary incident percentage is calculated as the percentage of incidents with lane closures that were identified in this study as primary incidents. The secondary crash percentage is defined as the percentage of all crashes that were identified as secondary crashes. Table 1 shows that the primary and secondary crash percentages are the highest on I-95, followed by I-595, followed by I-75. Historical traffic volume data show that the AADT is about 265,000 for I-95, 168,500 for I-595, and 110,000 for I-75 segments in Fort Lauderdale, Florida. This indicates that there is a possible relationship between secondary crash percentage and traffic flow level.

TRB 2008 Annual Meeting CD-ROM  Paper revised from original submittal.
FIGURE 1 FDOT District 4 Managed Corridors and Distribution of Secondary Crashes.

TABLE 1 Secondary Crash Distribution by Freeway Corridors

<table>
<thead>
<tr>
<th>Freeway</th>
<th>Lane Blockage Incidents</th>
<th>Primary Incidents</th>
<th>Primary Incident Pct.</th>
<th>Crashes</th>
<th>Secondary Crashes</th>
<th>Secondary Crash Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-95 N</td>
<td>1,737</td>
<td>148</td>
<td>8.52%</td>
<td>2,857</td>
<td>174</td>
<td>6.09%</td>
</tr>
<tr>
<td>I-95 S</td>
<td>1,676</td>
<td>147</td>
<td>8.77%</td>
<td>2,787</td>
<td>176</td>
<td>6.32%</td>
</tr>
<tr>
<td>I-595 E</td>
<td>340</td>
<td>17</td>
<td>5.00%</td>
<td>650</td>
<td>19</td>
<td>2.92%</td>
</tr>
<tr>
<td>I-595 W</td>
<td>338</td>
<td>22</td>
<td>6.51%</td>
<td>640</td>
<td>23</td>
<td>3.59%</td>
</tr>
<tr>
<td>I-75 N</td>
<td>175</td>
<td>7</td>
<td>4.00%</td>
<td>500</td>
<td>7</td>
<td>1.40%</td>
</tr>
<tr>
<td>I-75 S</td>
<td>169</td>
<td>11</td>
<td>6.51%</td>
<td>469</td>
<td>14</td>
<td>2.98%</td>
</tr>
<tr>
<td>Overall</td>
<td>4,435</td>
<td>352</td>
<td>7.94%</td>
<td>7,903</td>
<td>413</td>
<td>5.22%</td>
</tr>
</tbody>
</table>
Table 2 presents the distributions of primary incidents and secondary crashes by month. Table 2 shows that the summer months (June, July, and August) have the highest percentages of lane blockage incidents, whereas December, June, July, August, and October are the five months with the highest percentages of secondary crashes. Because the summer months and December are vacation/holiday months, this may indicate that vacation and holiday traffic may have an impact on secondary crash percentages.

<table>
<thead>
<tr>
<th>Month</th>
<th>Lane Blockage Incidents</th>
<th>Primary Incidents</th>
<th>Primary Incident Pct.</th>
<th>Crashes</th>
<th>Secondary Crashes</th>
<th>Secondary Crash Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>256</td>
<td>22</td>
<td>8.59%</td>
<td>512</td>
<td>28</td>
<td>5.47%</td>
</tr>
<tr>
<td>February</td>
<td>252</td>
<td>18</td>
<td>7.14%</td>
<td>504</td>
<td>21</td>
<td>4.17%</td>
</tr>
<tr>
<td>March</td>
<td>328</td>
<td>22</td>
<td>6.71%</td>
<td>650</td>
<td>28</td>
<td>4.31%</td>
</tr>
<tr>
<td>April</td>
<td>304</td>
<td>25</td>
<td>8.22%</td>
<td>591</td>
<td>29</td>
<td>4.91%</td>
</tr>
<tr>
<td>May</td>
<td>357</td>
<td>24</td>
<td>6.72%</td>
<td>637</td>
<td>30</td>
<td>4.71%</td>
</tr>
<tr>
<td>June</td>
<td>345</td>
<td>33</td>
<td>9.56%</td>
<td>637</td>
<td>38</td>
<td>5.96%</td>
</tr>
<tr>
<td>July</td>
<td>394</td>
<td>35</td>
<td>8.88%</td>
<td>705</td>
<td>42</td>
<td>5.96%</td>
</tr>
<tr>
<td>August</td>
<td>401</td>
<td>37</td>
<td>9.23%</td>
<td>717</td>
<td>41</td>
<td>5.72%</td>
</tr>
<tr>
<td>September</td>
<td>414</td>
<td>26</td>
<td>6.28%</td>
<td>743</td>
<td>29</td>
<td>3.90%</td>
</tr>
<tr>
<td>October</td>
<td>551</td>
<td>43</td>
<td>7.80%</td>
<td>812</td>
<td>48</td>
<td>5.91%</td>
</tr>
<tr>
<td>November</td>
<td>386</td>
<td>32</td>
<td>8.29%</td>
<td>675</td>
<td>36</td>
<td>5.33%</td>
</tr>
<tr>
<td>December</td>
<td>447</td>
<td>35</td>
<td>7.83%</td>
<td>720</td>
<td>43</td>
<td>5.97%</td>
</tr>
</tbody>
</table>

Table 3 shows that Thursdays have the highest percentages of lane blockage incidents that act as primary incidents, as well as crashes that are secondary crashes. Thursdays are followed by Fridays in this regard. The weekends had the lowest secondary crash percentages. Table 3 also indicates that weekends generally have fewer lane blockage incidents and much lower secondary crash percentages.

<table>
<thead>
<tr>
<th>Day of Week</th>
<th>Lane Blockage Incidents</th>
<th>Primary Incidents</th>
<th>Primary Incident Pct.</th>
<th>Crashes</th>
<th>Secondary Crashes</th>
<th>Secondary Crash Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>677</td>
<td>53</td>
<td>7.83%</td>
<td>1,196</td>
<td>59</td>
<td>4.93%</td>
</tr>
<tr>
<td>Tuesday</td>
<td>736</td>
<td>58</td>
<td>7.88%</td>
<td>1,291</td>
<td>66</td>
<td>5.11%</td>
</tr>
<tr>
<td>Wednesday</td>
<td>620</td>
<td>45</td>
<td>7.26%</td>
<td>1,242</td>
<td>51</td>
<td>4.11%</td>
</tr>
<tr>
<td>Thursday</td>
<td>753</td>
<td>82</td>
<td>10.89%</td>
<td>1,391</td>
<td>99</td>
<td>7.12%</td>
</tr>
<tr>
<td>Friday</td>
<td>722</td>
<td>60</td>
<td>8.31%</td>
<td>1,362</td>
<td>76</td>
<td>5.58%</td>
</tr>
<tr>
<td>Saturday</td>
<td>512</td>
<td>29</td>
<td>5.66%</td>
<td>787</td>
<td>33</td>
<td>4.19%</td>
</tr>
<tr>
<td>Sunday</td>
<td>415</td>
<td>25</td>
<td>6.02%</td>
<td>634</td>
<td>29</td>
<td>4.57%</td>
</tr>
</tbody>
</table>

Table 4 shows the distributions of primary incidents and secondary crashes by six time periods: AM peak (6:00-9:00), midday (9:00-16:00), PM peak (16:00-19:00), and late night (19:00-6:00) periods for weekdays; and daytime (6:00-19:00) and nighttime (19:00-6:00) periods for weekends. Table 4 indicates that the AM peak period has the highest primary incident and
secondary crash percentages. On the other hand, the PM peak period has much lower primary incident and secondary crash percentages than the AM peak and Midday periods.

Table 4 shows primary incident distributions by number of lanes blocked and incident type. Table 5 suggests that incidents with two or more lanes blocked have a higher potential to cause secondary crashes than those with only one lane blocked. Table 5 also shows that about 95% of incidents with lane blockages are “Crash” or “Disabled Vehicle” incidents.

Table 5 shows primary incident distributions by number of lanes blocked and primary incident type. Table 5 suggests that incidents with two or more lanes blocked have a higher potential to cause secondary crashes than those with only one lane blocked. Table 5 also shows that about 95% of incidents with lane blockages are “Crash” or “Disabled Vehicle” incidents.
LOGISTIC REGRESSION MODEL FOR LIKELIHOOD OF SECONDARY CRASHES

Background

Regression analysis methods, especially linear regression models, are frequently used in transportation research for establishing relationships between a dependent variable and one or more independent variables. One objective of secondary crash model analyses is to estimate the likelihood of a secondary crash, given the characteristics of the potential primary incident. Because there are only two possibilities (0 or 1) for secondary crash occurrence, linear regression analysis (which assumes that the independent variable is distributed following a continuous normal distribution) is considered inappropriate. In this study, a logistic regression model is applied for analyzing the relationships between primary incident characteristics and the possibility of secondary crash occurrence. A similar approach was utilized in the study by Karlaftis et al. (7) for analyzing the likelihood of secondary crashes. The general form of incident occurrence probability in a logistic model is as follows:

\[ P(y_i = 1 \mid x_i) = p_i = \frac{e^{\alpha + \beta x_i}}{1 + e^{\alpha + \beta x_i}} \]

Respectively, the odds of an event occurring (odds ratio) is defined as follows (8):

\[ \frac{p_i}{1 - p_i} = e^{\alpha + \beta x_i} \]

where \( p_i \) is the probability that an instance \( i \) will occur, \( \alpha \) is the constant, \( \beta \) is the vector of coefficients for independent variables, and \( x_i \) is the vector of independent variables.

Potential Independent Variables

To predict the likelihood of secondary crashes, this study examined a set of primary incident and traffic characteristics that have the potential for possible inclusion in the developed logistic regression model. The following variables were considered for potential inclusion:

- Incident duration factors: It is logical to anticipate that the probability of secondary crash occurrence increases with an increase in primary incident durations. Two incident duration factors were extracted and considered in this study, namely, the total duration of a potential primary incident (detection plus response plus clearance durations) and the related lane blockage duration.

- Time factors: Time factors are good indicators of traffic conditions, driver alertness, and familiarity with the route. Three time factors were extracted, namely, the month of year, day of week, and time of day (AM, Midday, PM, Late Night, Weekend Day, and Weekend Night).

- Environmental condition factors: Environmental conditions at the incident site could have impacts on the likelihood of secondary crashes. For example, heavy rain may affect the freeway visibility conditions and, thus, may increase the possibility of secondary crash occurrences. Five condition factors were considered: “Pavement,” “Precipitation,” “Wind,”
"Visibility," and "Illumination." Collectively, the use of these factors reflects whether wet/dry pavement, rain, strong wind, poor visibility, and/or dark conditions are associated with secondary crashes.

- Incident type factors: Four factors were extracted for this category, as follows: "Incident Type" (Crash/Abandoned Vehicle/Disabled Vehicle/Debris, etc.), "Rollover," "Fire," and "Hazmat" (for hazard materials).

- Location and traffic condition factors: Two factors were considered in this category: "Corridor" (analyzed corridor per direction: I-95 N, I-95 S, I-595 E, I-595 W, I-75 N, and I-75 S) and the volume/capacity ratio (VC ratio) of the corridor segment on which the secondary crash occurs. To calculate the VC ratios, the 2005 hourly traffic volume data from the FDOT for the freeway corridor segments were matched to the specific time of day period at which a primary incident occurred. The freeway number of lanes information was extracted from the SMART database (9) and the freeway capacities were estimated based on the number of lanes by assuming a lane capacity of 2200 vehicles/hour/lane.

- Lane closure factor: As discussed above, incidents with two lane blockages are more likely to have associated secondary crashes. Therefore, the number of blocked lanes was included in the regression analysis.

- Injury condition factor: Injury and fatality conditions may have a significant impact on primary incident site conditions and time. Accordingly, an injury condition factor is investigated for inclusion in the model of this study.

- Vehicle type factors: Two factors were extracted for this category, "Commercial" (if a commercial vehicle is involved in the incident), and "Vehicle Type" (Car/Van, Tractor, Truck, Motorcycle, Emergency Vehicle, etc.).

It is worth mentioning that some of the above factors are correlated with each other. Thus, only some of the correlated factors are expected to be selected by the regression model. The significance of these factors was determined as part of the model development and testing process, as described below.

**Model for Secondary Crash Likelihood**

The binary logistic regression function of the Statistical Package for Social Science (SPSS) was used to develop the model. All of the factors listed in the previous section were included in the initial model, and the model was tested to determine the significant variables. A forward conditional criterion was used to add one best fit variable at a time during the regression process. All of the identified variables were significant at the 0.01 level. During the regression process, the log-transformation was applied to the incident duration factor for better model results. A correlation test showed that there was no strong relationship between the independent factors. The regression results are shown in Table 6, which indicates the following:

- The possibility of secondary crashes will increase when the number of vehicles involved in the primary incident increases.
• The total number of travel lanes at the primary incident site is also identified as an important factor for predicting secondary crash likelihood. When all other factors are fixed and the number of travel lanes at the incident site increases, the probability of secondary crashes increases. A possible explanation for this is that, when there are more travel lanes, the variations in travel speeds between the opened and closed lanes are higher. Hence, more travelers are likely to try to change lanes, causing more traffic turbulence and friction between travel lane traffic.

• Longer incident durations increase the likelihood of secondary crashes.

• When all other factors are fixed, the likelihood of secondary crashes is higher for the weekday morning peak (AM) and Midday periods compared to the other time periods. This result is consistent with the statistical results shown in Table 4. The coefficient of the AM factor is higher than that of the Midday factor, which suggests that the possibility of secondary crashes is the highest during the weekday morning peak periods.

• When all other factors are fixed, secondary crashes are more likely to occur when vehicle rollover occurs.

**TABLE 6 Logistic Regression Model Results for Secondary Crash Likelihood**

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-9.818</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Number of Vehicles Involved</td>
<td>0.115</td>
<td>0.015</td>
</tr>
<tr>
<td>Number of Lanes at the Incident Site</td>
<td>1.118</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Log(Primary Incident Duration)</td>
<td>0.526</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Midday (9:00-16:00)</td>
<td>0.397</td>
<td>0.007</td>
</tr>
<tr>
<td>AM (6:00-9:00)</td>
<td>0.847</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Rollover</td>
<td>0.565</td>
<td>0.003</td>
</tr>
</tbody>
</table>

**Model Statistical Results**

| Sample Size (N) | 4,435 | Model Chi-Square | 170.305 |
| Model -2Log-likelihood | 351.356 | Analogous $R^2$ | 0.326 |

Table 6 also shows the overall statistical results for the developed logistic regression model. The analogous $R^2$ value, which is similar to the commonly used Coefficient of Determination $R^2$ in multiple linear regression analysis, is taken as a measure for goodness-of-fit. The analogous $R^2$ is defined as $1 - \frac{LL_M}{LL_0}$, where $LL_0$ is the log-likelihood of the initial model ($LL_0 = LL_M + Model$ Chi-Square) and where $LL_M$ is the log-likelihood of the final model. The analogous $R^2$ value is 0.326 for the model. The Chi-Square (Hosmer-Lemeshow) test of goodness of fit shows that the Chi-Square goodness of fit is not significant (0.409), which suggests that the model has an adequate fit.
SECONDARY CRASH SEVERITY ANALYSIS

To explore the relative severity of secondary crashes, a comparison was made between the primary crash severity rates used in the state of Florida based on statewide statistics and the secondary crash severity statistics obtained from this research. The "Florida’s crash severity table" includes the number of crashes with fatalities, injuries, and property damage only (PDO) per million-vehicle-mile traveled under different congestion situations. In this study, these numbers were converted to percentages of the total crashes for different congestion levels to allow easy comparison with those of secondary crashes. Four congestion levels were defined in the Florida crash severity table (Level 1: v/c ratio equal to 0-0.69; Level 2: v/c ratio equal to 0.69-0.89; Level 3: v/c ratio equal to 0.89-0.99; and Level 4: v/c ratio greater than 0.99). Figure 2 displays the comparison of percentages for crashes with fatalities, injuries, and PDO for different congestion levels and for the secondary crashes.

![Comparison of Crash Rates](image)

**FIGURE 2 Comparisons of Florida Crash Rates and Secondary Crash Rates.**

Figure 2 indicates that secondary crashes are generally much less severe than other crashes, with more than 90% of crashes being PDO crashes. Hence, the injury rates from secondary crashes are obviously much lower than those of other crashes, which should be noted when conducting benefit-cost analyses of incident management programs.

Logistic regression analysis was conducted to analyze the relationships between secondary crash severity and primary incident characteristics. The main goal of the logistic regression analysis for secondary crash severity is to identify major contributing factors and their effects. The same set of primary incident factors used in the secondary crash likelihood study was applied to the secondary crash severity regression analysis. All of the identified variables were significant at the 0.05 level. The log-transformation was applied to the lane blockage duration factor for better model results. The regression analysis results are shown in Table 7.
TABLE 7 Logistic Regression Results for Secondary Crash Severity

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-5.216</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Log(Lane Blockage Duration)</td>
<td>0.717</td>
<td>0.001</td>
</tr>
<tr>
<td>Visibility (0 for clear, 1 for foggy/heavy rain, etc.)</td>
<td>1.550</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Model Statistical Results

<table>
<thead>
<tr>
<th>Sample Size (N)</th>
<th>413</th>
<th>Model Chi-Square</th>
<th>16.691</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model -2Log-likelihood</td>
<td>57.579</td>
<td>Analogous $R^2$</td>
<td>0.225</td>
</tr>
</tbody>
</table>

Table 7 shows that two primary incident characteristics were identified by the logistic regression analysis process as affecting secondary crash severity, namely, the visibility conditions and the lane blockage duration of the primary incidents. When the visibility condition is clear (i.e., “Visibility” factor equals zero), secondary crashes are less likely to cause injuries or fatalities. This is understandable because travelers have longer times in which to react to queues in clear conditions. The model also shows that when the lane blockage duration of the primary incident increases, the possibility of severe secondary crashes increases. With longer lane blockage durations, traffic queues could be longer and more travelers may lose patience and try to change lanes, causing more severe incidents. Table 7 shows that this model can achieve an analogous $R^2$ of 0.225.

CONCLUSIONS

This research aims to study the relationships between primary incident characteristics and the possibility of secondary crashes. Summary statistics and logistic regression analyses were applied to understand these relationships. The derived regression model indicates that five factors have significant effects on the likelihood of incident occurrence. These factors are: the number of vehicles involved in the primary incident, the number of lanes at the primary incident site, the primary incident duration, the time of day, and if vehicle rollover occurred in the primary incident.

Secondary crash severity analysis confirms that secondary crashes are usually much less severe than other crashes, which could be an important factor when conducting benefit-cost analysis for incident management. The results show that traveler sight conditions (visibility) and the lane blockage durations of the primary incidents are significant contributing factors for determining the severity of secondary crashes.

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