13th COTA International Conference of Transportation Professionals (CICTP 2013)

Speed-accident relationship at urban signalized intersections

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Abstract

Speed is a key risk factor in road safety. The objective of this study is to investigate the relationship between speed characteristics and accident at urban signalized intersections. Accident prediction models are used for this purpose. Accident and speed data are collected at 65 urban signalized intersections. The speed-accident relationship is analyzed based on the developed models. It is found that both mean speed and speed standard deviation are positively correlated to accident frequency. Furthermore, the impact of mean speed and speed standard deviation on property damage only accidents is higher than on injury and fatal accidents.

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Selection and/or peer-review under responsibility of Chinese Overseas Transportation Association (COTA).

Keywords: Mean speed; Speed standard deviation; Accident frequency; Accident prediction model

1. Introduction

Among a range of contributory factors in road safety, the speed of motor vehicle is a well-documented risk factor which contributes to as much as one-third of fatal accidents (Bowie & Walz, 1994; Frith, Strachan & Patterson, 2006). For many years, researchers have conducted empirical studies to investigate the relationship between speed and accident occurrence. The results of these studies vary considerably. Some studies concluded that higher traffic mean speed or individual vehicle speed has adverse impact on accident occurrence, while some other studies stated that it is the speed variance not the mean speed that is related to accidents. In general, physical rules show that the higher speed leads to greater stopping sight distance and greater distance travelled during the driver’s reaction time. Furthermore, the likelihood of being seriously injured increases with higher speed since the kinetic energy released in the collision is correlated with the square of the speed. Therefore, investigating the relationship between accidents and various speed characteristics is extremely important to road safety improvement. It should be noted that most of the previous studies on speed-accident relationship mainly

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focused on rural areas rather than urban areas. This is surprising given the fact that the majority of road accidents occurred in urban area due to its complex road environment. This study attempts to investigate the relationship between speed and accident frequency at urban signalized intersections in one city in China. A number of accident prediction models will be developed which quantitatively relate the accident frequency to speed variables. Finally the models will be analyzed and the speed-accident relationship will be discussed based on the developed models.

2. Previous Research

Researches that examined the relationship between speed and accidents can be classified into two groups based on the speed measures being used. One group of studies looked at the absolute speed, i.e., individual vehicle speed or mean speed of road section. The other group of studies focused on speed dispersion, i.e., speed differences between individual vehicles or speed variance at road section level.

2.1. Absolute speed and accident

The earliest and best known study that attempted to examine the relationship between vehicle speed and the risk of accident involvement was conducted by Solomon (1964) in the United States. He found that the relationship between accident involvement rate and speed followed a U-shaped curve, i.e., speed values at around mean traffic speed having the lowest involvement rate while quite high rates associating with the travel speed that is much slower or faster than the mean speed. The findings of Solomon’s study is confirmed by Cirillo (1968) who examined daytime same direction accident involving two or more vehicles and concluded that the relationship between speed and the risk of accident involvement can be represented by a U-shaped curve. However, more recent studies by Fildes, Rumbold and Leening (1991) and Kloeden et al. (1997, 2001, 2002) obtained different results. Fildes et al. (1991) found that the relationship between accident involvement rate and vehicle speed is linear or slightly curvilinear: drivers travelling at excessive high speed are likely to have higher accident involvement rate than those travelling at mean speed, while drivers travelling slowly are likely to have lower accident involvement rate. Kloedent et al. (1997, 2001 and 2002) obtained exponential relationship between travel speed and the risk of accident involvement: the risk of accident involvement increases when the vehicle is travelling at increasing speed above the average speed.

Maycock, Brocklebank and Hall (1998) and Quimby et al. (1999) developed models representing the relationship between driving speed and driver’s accident liability. Both studies obtained power function which indicated that the increase in driving speed was associated with significant growth in accident liability. Maycock et al. (1998) found that every 1% increase in the driving speed was associated with 13.1% increase in accident liability while Quimby et al. (1999) found the increase in accident liability was 7.8%.

Nilsson (2004) presented “Power Model” to show the relationship between the average traffic speed and the number of injury accidents and fatal accidents. The model illustrated that the number of injury accidents, fatal & serious injury accidents, and fatal accidents was correlated with the second, third and fourth power of the average speed respectively. He finally concluded that when the average speed increased by 5%, the number of all injury accidents would increase about 10% and the number of fatal accidents would rise by approximately 20%.

It should be noted that all the aforementioned studies attempted to obtain one-to-one relationship between accident and speed. The one-to-one relationship ignores the impact of other factors influencing the speed-accident relationship, such as traffic volume and other road characteristics. Thus there is a concern that the true relationship would be masked due to these factors. One study by Baruya (1998) investigated how traffic speeds and accidents are influenced by traffic volume, road geometry and road environment. A model was developed which showed that the accident frequency was positively related to the volume, the road section length, the speed limit, the percent of speeding vehicles, and the number of intersections, while inversely correlated with the road
width. It should be noted that the accident frequency was inversely related to the mean speed according to the model. The author explained that this phenomenon is probably due to the effect of poor road design and geometry rather than the mean speed itself.

2.2. Speed dispersion and accident

The studies reviewed in the previous section generally examined the effect of absolute speed on accidents. This section summarizes the studies that focused on the relationship between speed dispersion and accidents.

Lave (1985) investigated the impact of average speed and speed variance on the fatality rate based on regression analyses of data from 48 states in United States. A total of 12 regression equations were developed and the results showed that most regression coefficients of average speed were negative while the coefficients of speed variance were mainly positive. The author concluded that reducing the speed variance, not the average speed, played the most important role in reducing fatalities.

Another study that investigated the relationship between speed variance and accident was conducted by Garber and Gadirau (1988). Several models were developed correlating the accident rate with various speed characteristics including average speed, speed variance, design and posted speed. It was found from the models that the correlation between average speed and accident rate was non-significant and thus the authors concluded that higher average speed was not necessarily correlated with higher accident rate. Another important finding of the study was that the accident rate was positively related to speed variance.

More recently, Taylor, Lynam and Baruya (2000) conducted a cross-sectional study in UK and found that the speed variance was an important factor influencing accident occurrence. In their study, a model was developed based on traffic flow, road geometry, vehicle speeds, and accidents data collected. It can be seen from the model that the accident frequency rose approximately with the second power of average traffic speed. It can also be seen from the model that the speed dispersion is positively related to the accident frequency and the relationship could be represented by exponential function. Consequently it was concluded that both the average traffic speed and speed variance could impact accident frequency and that they could not be substituted for each other.

As mentioned earlier, although the literature is extensive on the speed-accident relationship, the previous researches were mainly focused on rural areas rather than urban areas. Furthermore, the models in the previous studies were developed particularly for road sections but not for road intersections. This is surprising given the fact that the majority of road accidents occurred in urban area (especially at intersections) due to the complex road environment. It is accordingly necessary to conduct research on the effect of speed on accident at urban intersections. The following sections describe the methodology, data, results and conclusion of this study.

3. Methodology

The methodology used in this study is based on the development of Accident Prediction Models incorporating speed-related variables. The models form should satisfy certain conditions. Firstly, the accident frequency predicted by the model should not be a negative number. Secondly, the model should lead to zero predicted accident frequency when the values of exposure variables (such as traffic volume) are zero, while the predicted accident frequency is not expected to be zero if other explanatory variables have zero values. Thirdly, in order to use generalized linear regression modeling (GLM) approach to develop accident prediction model, a known link function must exist which can linearize the model form. The following model form which can satisfy the aforementioned conditions is adopted in this study:

\[ E(Y) = \alpha_0 V_1^{\alpha_1} V_2^{\alpha_2} \exp \sum_j \beta_j x_j \]  

where,

\( E(Y) \) — predicted accident frequency during a specific time period,
The GLM approach of modeling traffic accident occurrence usually assumes an error structure that is Poisson or negative binomial. However, the assumption of negative binomial distribution for the error structure is more realistic than assumption of Poisson distribution since it has been shown (Kulmala, 1995) that most accident data is over-dispersed (i.e., their variance exceeds their mean). Thus the accident frequency at a certain road location is a random variable that obeys a negative binomial probability distribution with the following mathematical form:

\[
P(Y = y) = \frac{\Gamma(\kappa + y)}{\Gamma(\kappa) y!} \left( \frac{\kappa}{\kappa + \mu} \right)^\kappa \left( \frac{\mu}{\kappa + \mu} \right)^y
\]

(2)

The expected value and variance of \( Y \) is:

\[
E(Y) = \mu
\]

(3)

\[
Var(Y) = \mu + \mu^2 / \kappa
\]

(4)

where \( Y \) is the accident frequency at a location during a specific time period, \( \mu \) is the mean accident frequency at the location during the same time period, and \( \kappa \) is the negative binomial shape parameter.

Finally, there are two criteria to assess the goodness of fit of accident prediction model. The first criterion is to test whether the statistical measure—Pearson \( x^2 \) statistic is significant at a given confidence level. The second criterion is to test whether the scaled deviance (SD) is significant at a given confidence level. Both Pearson \( x^2 \) and scaled deviance are asymptotically \( x^2 \) distributed with n-p degrees of freedom.

4. Model Development

4.1. Data description

Speed, volume and accident data was collected for 65 signalized intersections located in one city in China. The data used for developing the accident prediction model included: the accident data in three years 2006~2008, average annual daily traffic of the major and minor approaches, the mean speed, and the speed standard deviation on the four approaches. The accident records can be classified according to their severity into two categories: injury and fatal accident, and property damage only (PDO) accident. Spot speeds were collected on weekdays for the four approaches of an intersection. The mean speed and speed standard deviation was estimated during the off-peak period.

4.2. Modeling results

A total of six accident prediction models incorporating speed-related variables are developed. The Pearson \( x^2 \) and scaled deviance of each model are significant at 95% confidence level. The t-ratios of the parameter estimates for the intercept, major traffic volume, and minor traffic volume are significant at 95% confidence level for all the six models. For four models correlating speed variables with PDO accident or total accident, the t-ratios of parameter estimates of mean speed and speed standard deviation are significant at 95% confidence level. However, for the two injury & fatal accident models, the coefficients of mean speed and speed standard deviation are insignificant at 95% confidence level but significant at 90% confidence level. The six models are listed below and their statistical test results are shown in Table 1.

\[
Model \#1: \quad E(Y) = 1.07 \times 10^{-4} V_1^{0.6102} V_2^{0.7024} e^{0.0103S}
\]

(5)
**Model #2:** \[ E(Y_1) = 6.74 \times 10^{-5} V_1^{0.6024} V_2^{0.653} e^{0.0025S} \]  
(6)

**Model #3:** \[ E(Y_2) = 5.04 \times 10^{-5} V_1^{0.6342} V_2^{0.7198} e^{0.119S} \]  
(7)

**Model #4:** \[ E(Y) = 8.94 \times 10^{-5} V_1^{0.7075} V_2^{0.6512} e^{0.0335SD} \]  
(8)

**Model #5:** \[ E(Y_1) = 6.21 \times 10^{-5} V_1^{0.6684} V_2^{0.5817} e^{0.0091SD} \]  
(9)

**Model #6:** \[ E(Y_2) = 3.24 \times 10^{-5} V_1^{0.7503} V_2^{0.6874} e^{0.0361SD} \]  
(10)

where,

- \( E(Y) \) — total number of accidents at intersection per 3 years,
- \( E(Y_1) \) — number of injury & fatal accidents at intersection per 3 years,
- \( E(Y_2) \) — number of PDO accidents at intersection per 3 years,
- \( V_1 \) — major road annual average daily traffic, veh/day,
- \( V_2 \) — minor road annual average daily traffic, veh/day,
- \( S \) — mean speed of the traffic approaching the intersection, km/h,
- \( SD \) — speed standard deviation of the traffic approaching the intersection.

Table 1. Statistical test results of developed models

<table>
<thead>
<tr>
<th>Model #</th>
<th>t-ratio</th>
<th>( V_1 )</th>
<th>( V_2 )</th>
<th>( S/SD )</th>
<th>Scaled deviance</th>
<th>( \chi )</th>
<th>Pearson ( \chi^2 ) (( \chi^2 ) table)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.87</td>
<td>4.31</td>
<td>6.48</td>
<td>2.02</td>
<td>70.57</td>
<td>5.83</td>
<td>64.37 (80.2)</td>
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<td>2</td>
<td>4.71</td>
<td>3.24</td>
<td>4.35</td>
<td>1.76*</td>
<td>65.36</td>
<td>5.46</td>
<td>58.27 (80.2)</td>
</tr>
<tr>
<td>3</td>
<td>6.34</td>
<td>4.43</td>
<td>6.22</td>
<td>2.18</td>
<td>73.64</td>
<td>4.79</td>
<td>62.86 (80.2)</td>
</tr>
<tr>
<td>4</td>
<td>5.99</td>
<td>4.36</td>
<td>6.72</td>
<td>3.25</td>
<td>71.34</td>
<td>6.21</td>
<td>59.67 (80.2)</td>
</tr>
<tr>
<td>5</td>
<td>4.79</td>
<td>3.87</td>
<td>4.61</td>
<td>1.85*</td>
<td>64.65</td>
<td>5.84</td>
<td>56.41 (80.2)</td>
</tr>
<tr>
<td>6</td>
<td>6.53</td>
<td>4.06</td>
<td>6.99</td>
<td>2.87</td>
<td>72.58</td>
<td>5.43</td>
<td>54.74 (80.2)</td>
</tr>
</tbody>
</table>

Note: * — insignificant at 95% confidence level

It can be seen from the developed models that the regression coefficients for speed-related variables are all positive, indicating that mean speed and speed standard deviation are positively associated with the number of injury accidents, PDO accidents, and total accidents occurred at urban signalized intersections. The higher mean speed, the higher the expected accident frequency. Similarly, the higher speed standard deviation, the higher the expected accident frequency.

It should be noted that the parameter of the mean speed in the PDO accident model (Model #3) has the highest value compared to injury & fatal accident model (Model #2) and total accident model (Model #1), indicating that the impact of mean speed on PDO accidents is stronger than on injury & fatal accidents. Also, the impact of speed standard deviation on PDO accidents is stronger than on injury & fatal accidents, since the parameter of the speed standard deviation in the PDO model (Model #6) has the highest value among Model #4~Model #6.
5. Conclusion

The objective of this study is to examine the relationship between speed characteristics and accident frequency at urban signalized intersections. To achieve this objective, speed and accident data are collected for 65 urban signalized intersections in one city in China for the development of accident prediction models that relate various speed characteristics to accident frequency. Mean speed and speed standard deviation are shown to be positively correlated to accident frequency. In addition, both mean speed and standard deviation have higher impact on property damage only (PDO) accidents than on injury & fatal accidents. The positive correlation between accident frequency and speed confirms what has been found in previously documented research which suggested that both the absolute speed and speed dispersion are important factors in road safety. It can also be drawn from this study that the speed-accident relationship holds true at urban signalized intersections.

Acknowledgements

Financial support of this study was provided by Xi’an University of Architecture and Technology Faculty Engineering Practice Program, Discipline Key Cultivation Plan Talent Cultivation Special Fund (Project No. XK201101), and Discipline Construction Key Cultivation Plan (Project No. XK201213) of Xi’an University of Architecture and Technology.

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