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Analysis and comparison of safety models using average daily, average hourly, and microscopic traffic

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ABSTRACT

There have been plenty of traffic safety studies based on average daily traffic (ADT), average hourly traffic (AHT), or microscopic traffic at 5 min intervals. Nevertheless, not enough research has compared the performance of these three types of safety studies, and seldom of previous studies have intended to find whether the results of one type of study is transferable to the other two studies. First, this study built three models: a Bayesian Poisson-lognormal model to estimate the daily crash frequency using ADT, a Bayesian Poisson-lognormal model to estimate the hourly crash frequency using AHT, and a Bayesian logistic regression model for the real-time safety analysis using microscopic traffic. The model results showed that the crash contributing factors found by different models were comparable but not the same. Four variables, i.e., the logarithm of volume, the standard deviation of speed, the logarithm of segment length, and the existence of diverge segment, were positively significant in the three models. Additionally, weaving segments experienced higher daily and hourly crash frequencies than merge and basic segments. Then, each of the ADT-based, AHT-based, and real-time models was used to estimate safety conditions at different levels: daily and hourly, meanwhile, the real-time model was also used in 5 min intervals. The results uncovered that the ADT- and AHT-based safety models performed similar in predicting daily and hourly crash frequencies, and the real-time safety model was able to provide hourly crash frequency.

1. Introduction

Plenty of studies have linked crashes with traffic volume, geometric characteristics, etc. Among these research efforts, the majority are based on highly aggregated traffic data, for example, average daily traffic (ADT). However, if two roadways have the same ADT, one has high traffic volume during peak hours, but the other one's flow is evenly spread out throughout the day. These two roadways would likely have different crash profile. Since ADT does not give the traffic information at different time, some researchers used average hourly traffic (AHT) to represent traffic conditions for safety analyses (Martin, 2002). Some studies implied that the safety studies based on AHT the might perform better than ADT-based studies (Mensah and Hauer, 1998). Meanwhile, compared with ADT, microscopic traffic conditions prior to crashes are more related to the specific condition of crash occurrence. The impact of microscopic traffic on crashes can be captured by real-time safety analyses.

In an AHT-based safety study, one or several hours' worth of traffic data are averaged, and crash frequencies are aggregated in the corresponding hour(s); for example, the AHT in 8:00-9:00 A.M. in 2015 and the frequency of crashes that occurred during the same period. Then, models are applied to find the statistical relationships between hourly crash frequencies and AHT (Lord et al., 2005). If an expressway's AHT does not change in a day, an AHT-based study would be similar to an ADT-based crash study. Nevertheless, the subject of this study, expressway, generally has significant peak and off-peak traffic hours, so AHT-based crash studies for expressways might outperform ADT-based crash studies.

In a real-time safety analysis, each crash (and non-crash) is treated as an observation; however, in ADT- and AHT-based studies, segment is the study unit. The real-time safety study intends to find crash precursors using microscopic traffic data. The microscopic conditions that are just before crashes, for example, 5–10 min before crash occurrence, are considered as crash contributing factors and are defined as crash observations. On the other hand, if no crash happens, the conditions are defined as non-crash observations. By comparing crash observations with non-crash observations, crash precursors, which are relatively more "crash prone" than others, can be identified (Lee et al., 2002).

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The ADT-based, AHT-based, and real-time safety analyses have already been widely studied by previous researchers. However, almost all of the previous studies only focused on one or two of them. Since these three types of safety analyses all focus on safety, though based on different time intervals, the significant crash contributing factors in each type of safety analyses should be similar. Meanwhile, though lots of researchers used the AHT to estimate crash frequency (Martin 2002; Lord et al., 2005; Kononov et al., 2012), very few have compared the safety study based on ADT and AHT. Some researcher stated that AHT might provide better estimation of traffic safety than the ADT (Gwynn, 1967), but there is no enough quantitative analysis to test it. Thus, the study intends to find whether the sum of hourly crash frequency based on AHT-based study would outperform the ADT-based safety analysis in providing more accurate crash frequency estimation. In return, the study also intends to explore whether the ADT-based safety studies can be used in hourly crash frequency prediction if given the hourly traffic volume as weights. Furthermore, the cumulative of 5 min crash likelihood could theoretically provide crash frequency. However, whether the cumulative results would provide good estimation of crash frequency, it is still unknown.

The objectives of this study are as follows: (1) evaluate the performance of the three types of safety analyses in identifying important crash contributing factors; (2) compare their abilities of using the identified significant variables to predict traffic safety conditions at different time intervals. The following parts of the paper are organized into five sections. The second section reviews previous safety studies. The third section describes the data collected and presents preliminary analyses. The fourth section presents methodologies: statistical models used in crash estimations, the case-control design, and model comparison methods. The fifth section shows the model estimation and comparison results. Finally, the sixth section summarizes the finding and makes recommendations for future studies.

2. Background

Based on ADT, the cause-effect relationship between crashes and traffic has been widely explored. The ADT-based safety study more focuses on the long-term safety of a roadway facility, and it also has been widely used in finding the potentials for safety improvements and in evaluating the effectiveness of countermeasures (Elyasi et al., 2016; Park and Abdel-Aty, 2015). However, some researchers stated that the relationship actually should be between crashes and the traffic conditions whose time is close to the time of crash occurrence, and the implantation of ADT in safety studies might produce biased results (Mensah and Hauer, 1998). It is recommended that traffic safety related studies should implement AHT or microscopic traffic other than ADT if they are available or it is encouraged that researchers would be better to collect AHT or microscopic traffic other than ADT in safety studies. Thus, AHT and microscopic traffic, which are closer to the time of crash occurrence than ADT, have been used.

AHT-based traffic safety studies were first conducted by Gwynn (1967). The author found a U-shape relationship between crash rates and hourly volume: high crash rates occurred in low and high hourly volume, and low crash rates were in median hourly volume. Later, Ceder, 1982used power functions to examine the relationship between AHT and hourly crash rates. In their study, different crash types (single- and multi-vehicle crashes) under different traffic conditions (free- and congested-flow conditions) were separately studied. Then, Persaud and Dzbik (1993) implemented generalized linear models to estimate crash frequencies based on AHT and ADT, individually. In their study, the AHT was estimated using the ADT. Martin (2002) investigated the impact of the AHT on crash severities.

In addition to AHT, other forms of hourly traffic parameters have been used to estimate hourly crash counts. Zhou and Sisiopiku (1997) used parabolic equations to explain the relationship between hourly volume over capacity (v/c) and crash rates for different crash types, for example, multi-vehicle crashes. Chang et al., 2000 also linked crash rates to hourly v/c. In their research, three types of freeway segments were studied: basic freeway sections, tunnel sections, and tollgate sections. Lord et al. (2005) applied hourly vehicle density and hourly v/c to the hourly crash frequency study for rural and urban freeways. Their results showed that vehicle density and v/c ratio were positively related to hourly crash frequencies.

Real-time safety studies intend to discover crash-contributing factors using microscopic traffic for freeways or expressways. In the majority of previous studies, microscopic traffic data were at 5 min intervals (Abdel-Aty and Pemmanaboina, 2006; Hossain and Muromachi, 2013a; Xu et al., 2013a), and the traffic 5–10 min before crashes were considered as crash contributing factors (Hossain and Muromachi, 2013a; Yu and Abdel-Aty, 2013). Different segment types have different crash mechanisms. Hence, researchers have conducted separate real-time safety studies for mainlines (Lee et al., 2002; Pande et al., 2005), ramp vicinities (Hossain and Muromachi, 2013a, 2013b), ramps (Lee and Abdel-Aty, 2006; Wang and Abdel-Aty, 2016), and weaving segments (Wang et al., 2015a). However, not enough real-time safety studies have compared crash potential for different types of expressway segments. Meanwhile, researchers studied different crash types in real time, such as single- and multi-vehicle crashes (Wang et al., 2015b; Yu and Abdel-Aty, 2013), rear-end and sideswipe crashes (Christoforou et al., 2011); and they studied different crash-contributing factors under different traffic conditions, for example, high- and low-speed conditions (Abdel-Aty et al., 2005). Furthermore, the relationships between crash severities and real-time traffic parameters have been explored (Xu et al., 2013a), for example, crashes were less severe under congested traffic conditions comparing with under un-congested traffic conditions.

The real-time safety analysis takes each crash and non-crash event as an observation, and the number of non-crash observations is always much greater than that of crash observations. Hence, almost all real-time safety analyses implemented the case-control design and selected some non-crash observations to represent the non-crash population. Moreover, several previous studies adopted the matched-case-control design to exclude the impacts of geometry and time of day on crash occurrence (Abdel-Aty and Pemmanaboina, 2006; Zheng et al., 2010). After the data collection based on the case-control design, models were mainly used to uncover crash contributing factors. The main statistical method of real-time crash estimations was the logistic regression model (Abdel-Aty and Pande, 2006; Hourdos et al., 2006). Additionally, several data mining methods have been used: Bayesian belief net (Hossain and Muromachi, 2013a, 2013b), support vector machine (Qu et al., 2012), and multilayer perceptron neural network (Pande et al., 2011). Data mining methods could possibly provide better model performance than logistic regression models. However, it might not be able to provide the quantitative impact of a parameter on crash occurrence.

To sum up, there have been plenty of AHT-based and real-time safety studies. The AHT-based safety studies might be able to find more accurate relationship between safety and traffic than the ADT-based studies. Previous researchers have conducted real-time safety analyses for different segment types and for different crash types. However, little to no research have compared the performance and usefulness of ADT-based, AHT-based, and real-time safety analyses. Meanwhile, the safety of different mainline segments types have not been compared.

3. Data preparation

The studied segments were from three expressways in Orlando, Florida: State Roads 408, 417, and 528. The study period was 884 days, which were from July 2013 to December 2015 but did not included April 2014 because the traffic data were not available during that month. The studied segments were classified into four types according to the Highway Capacity Manual 2010 (National Research Council, 2010): merge, diverge, weaving, and basic segments. The influence