ARTICLE IN PRESS

Accident Analysis and Prevention xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Crash risk analysis during fog conditions using real-time traffic data

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ARTICLE INFO

Keywords:
Real-Time traffic flow data
Real-time weather data
Fog
Logistic regression
Real-time crash risk
Ramps

ABSTRACT

This research investigates the changes of traffic characteristics and crash risks during fog conditions. Using real-time traffic flow and weather data at two regions in Florida, the traffic patterns at the fog duration were compared to the traffic patterns at the clear duration. It was found that the average 5-min speed and the average 5-min volume were prone to decreasing during fog. Based on previous studies, a "Crash Risk Increase Indicator (CRII)" was proposed to explore the differences of crash risk between fog and clear conditions. A binary logistic regression model was applied to link the increase of crash risks with traffic flow characteristics. The results suggested that the proposed indicator worked well in evaluating the increase of crash risk under fog condition. It was indicated that the crash risk was prone to increase at ramp vicinities in fog conditions. Also, the average 5-min volume during fog and the lane position are important factors for crash risk increase. The differences between the regions were also explored in this study. The results indicated that the locations with heavier traffic or locations at the lanes that were closest to the median in Region 2 were more likely to observe an increase in crash risks in fog conditions. It is expected that the proposed indicator can help identify the dangerous traffic status under fog conditions and then proper ITS technologies can be implemented to enhance traffic safety when the visibility declines.

1. Introduction

The effects of weather events on traffic operations and safety have become a more important issue, and visibility reduction due to fog is a major concern. In recent years, the number of the fatal crashes involving fog shows a decreasing trend. However, there are still about 300–400 fog related fatal crashes happening every year in the United States (Hamilton et al., 2014). It has been shown that low visibility conditions have significant impact on the road traffic flow. However, reaction to the low visibility conditions is quite different by drivers. For example, some of the drivers would decrease their speed, while others would not during the low visibility conditions (Al-Ghamdi 2007). Different reactions to the low visibility may result in a variation in traffic flow.

Previous studies have found that there are more severe injury crashes and multi-vehicles crashes during fog (Abdel-Aty et al., 2011). Abdel-Aty et al. (2014) explored the relationship between reduced visibility and traffic flow characteristics. The study concluded that the variation of both headway and speed, and the average headway are higher while the average speed is lower in reduced visibility conditions. Abdel-Aty et al. (2012b) examined the relationship between the traffic data and the reduced visibility crashes. The data was collected from loop/radar detectors and Automatic Vehicle Identification (AVI) sensors. The model has good prediction accuracy of the reduced visibility crash occurrence. Ahmed et al. (2014) developed a Bayesian logistic regression model using six years' (2005–2010) of crash and weather data from eight airports in Florida. The results show that crash risk can be predicted using the visibility conditions within 5 M radius from the center of the airports. Huang et al. (2010) conducted a hotspots analysis for the low visibility related crashes in Florida. They found that the morning hours in December to February are more likely to experience fog-related crashes, while head-on and rear-end crashes are the two most prevalent types of crashes. They also concluded that the road with higher speeds, undivided road segments and road without sidewalk are more prone to have crashes under reduced visibility conditions. In addition, low visibility related crashes are more likely to occur on two-lane rural roads.

There are some studies that have been conducted to examine the relationship between weather and crashes (Edwards 1999; Golob and Recker 2003). Theofilatos and Yannis (2014) offered a review of the current studies about the effects of weather characteristics on road safety. The review pointed out that there is a trend of using real-time data to conduct the traffic safety impact analysis. However, most of the previous studies focused on the effects of precipitation, snow and some other weather conditions, but few have addressed the low visibility conditions. Yu et al. (2013) analyzed the hazardous factors on a

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http://dx.doi.org/10.1016/j.aap.2017.05.004
Received 20 July 2016; Received in revised form 13 February 2017; Accepted 5 May 2017
0001-4575/

mountainous freeway, and suggested that the weather conditions, especially precipitation, have significant impacts on crash occurrence. Li et al. (2015) attempted to identify the weather-sensitive-hotspots in order to find better locations to place the environmental sensor stations.

Meanwhile, the increasing use of the multi-type of data has made the combined effect analysis more possible. There are many factors that may have influences on the crash likelihood or the crash severity. Wang et al. (2015) examined the crashes that happened on the expressway ramps and the results indicate that visibility is a significant factor for both single- and multi-vehicle crash occurrence. There are also some efforts to develop reduced visibility related crash prediction models. Hassan et al. (2013) developed a prediction model based on random forests and matched case-control logistic regression model. They concluded that the higher occupancy rate of the downstream at 10–15 min before the crashes would increase the low visibility crash likelihood. Xu et al. (2013) analyzed the crash likelihood in rain and fog conditions. The results indicate that the reduced visibility crashes are highly related to the speed difference between the upstream and downstream.

Although there have been many efforts undertaken to evaluate traffic safety during fog conditions, most of the previous research studies have been based on crash data analysis or driving simulator experiments. Even though driving simulators could be a good tool to explore the driver behavior in fog, it cannot provide information about the traffic flow condition under the reduced visibility conditions. As for the studies based on crash data, they heavily rely on crash cases. A long study period is usually needed to obtain enough crash cases. Also, most of the previous research studied the locations with higher crash frequency during fog. However, it is difficult to identify the locations that crash risks increase because of the nature of rare traffic crash occurrence during fog. The possible solution to overcome this issue is to analyze the traffic change at the fog durations and identify the potential increase of crash risk based on the traffic data. Then, the locations which may experience higher crash risk under fog conditions can be identified.

In this study, both weather and traffic data are collected and the changes of traffic flow under fog conditions are investigated. Based on the changes of traffic flow, a concept of crash risk indicator is suggested in order to explore the changes of crash risk during fog. Subsequently, a logistic regression analysis is conducted to identify the factors contributing to increasing crash risk during fog.

2. Data preparation

2.1. Study area

This study based on two types of data sources: (1) weather data and (2) traffic data. The data for the study is from November 2014 to April 2015, when fog conditions are frequently present in Florida. The weather data were collected from the National Climate Data Center (NCDC), which archives weather data from nationwide weather stations operated by the National Oceanic Atmospheric Administration (NOAA). Two weather stations were selected in this study, which are Tampa Executive Airport and Orlando Executive Airport (Fig. 1). According to previous research, both regions cover hotspots of fog-related crashes (Abdel-Aty et al., 2012a).

Previous research revealed that fog related data that was collected from the airports can be utilized to indicate the road weather conditions for adjacent areas within 5 M (5.8 statute miles) (Ahmed et al., 2014). Some of the traffic data was collected from LDs (loop and radar detectors) that are spaced at approximately 0.8 mile for about 7 miles and 11 miles of I-75 and I-4 in Tampa, respectively. The other traffic data was collected from Microwave Vehicle Detection System (MVDS) sensors spaced at 0.4 mile for about 10 miles of SR-408 (East-West Expressway) in Central Florida.

2.2. Traffic data and detector location information

The detector system provides traffic volume (vehicle count), average speed (mph), and occupancy (the percent time that the sensor is occupied). The traffic information was aggregated to 5-min intervals, and the standard deviation for each 5-min interval is calculated. In this study, there are a total of 43 detectors on I-75 southbound, I-4 westbound, and I-4 eastbound in Region 1, and 27 detectors on SR-408 in Region 2 for both eastbound and westbound directions. Thus, 70 detectors are included in this study. The three lanes that are closest to the median in both directions were used. Also, according to the Highway Capacity Manual (HCM, 2010), the influence area of ramp vicinities can be beyond 1500 ft. (0.3 mile). Thus, in this study, if a detector is located within 0.4 mile upstream/downstream of an off ramp/on ramp, the detector will be treated as within off ramp/on ramp vicinity.

2.3. Weather data and event

The weather data reported by the NCDC is not organized by a specific time interval, but the station will update the readings if there is a change in the weather conditions (e.g. fog, rain, etc.). The weather data include weather types, visibility (ranges from 0.25 to 10 miles), temperature, humidity, wind speed, etc. Thus, the fog event can be detected and the corresponding visibility distance can be obtained. According to the Highway Capacity Manual (HCM, 2010), fog will impact traffic when the visibility is lower than 1 mile. Thus, fog events were selected when a fog event was reported while the corresponding visibility was less than 1 mile. The fog events are based on the starting and ending times of the fog. If rain was present before the fog duration, the corresponding fog events would be removed in this study in order to exclude the effects of the wet pavement. Based on the above selection rules, 55.56 h of data in Region 1 and 32.25 h of data in Region 2 were selected in this study.

3. Preliminary analysis

In order to analyze the fog impact on traffic flow, each event observation has a corresponding control observation, which has the same time period, similar day (weekday/weekend), and a clear weather condition. In total, there are 210 samples in this study. Each sample's traffic information was collected for both case and control (fog and clear) durations.

The differences in traffic characteristics between the case group (fog) and control group (clear) are analyzed in order to understand the fog impact on traffic flow. Fifty-five percent of the samples' speeds decreased significantly (p-value = 0.10), which indicates that many drivers are prone to drive at a lower speed during fog. The results are consistent with previous research (Al-Ghamdi 2007). Also, there is a clear trend that drivers in the center lanes are more likely to decrease their speeds, where 67.1% of the samples' speeds decrease significantly at the 0.10 significant level. Meanwhile, 52.4% samples' volume decreases significantly at the fog duration. However, a difference between the two regions is observed, 74.2% and 14.8% of samples' volume decrease significantly in Region 1 and Region 2, respectively.

Fig. 2 provides an example of the volume-occupancy relationship for the innermost lane during both fog and clear conditions at SR-408. The congestion percentage in fog conditions was 7.9%, while the congestion percentage decreases to 5.2% in clear conditions. Thus, more congestion situations were observed during fog. Meanwhile, a regression analysis was conducted for fog conditions and clear conditions, separately. The R-Square values are 0.96 for fog conditions and 0.98 for clear conditions.

$$\text{Average volume during fog conditions} = = -0.23^{*}(\text{occupancy})^{2} + 11.82^{*}\text{occupancy} + 5.47$$