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A correlated random parameter approach to investigate the effects of weather conditions on crash risk for a mountainous freeway

Rongjie Yu [a,d,*], Yingge Xiong [b], Mohamed Abdel-Aty [c]

[a] School of Transportation Engineering, Tongji University, Shanghai 20092, China
[b] School of Civil Engineering, Purdue University, West Lafayette, IN 47907-2051, United States
[c] Department of Civil, Environmental and Construction Engineering, University of Central Florida, Orlando, FL 32816-2450, United States
[d] Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, SiPaiLou #2, Nanjing 210096, PR China

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ABSTRACT

Freeway crashes are highly influenced by weather conditions, especially for a mountainous freeway affected by adverse weather conditions. In order to reduce crash occurrence, a variety of weather monitoring systems and Intelligent Transportation Systems (ITS) have been introduced to address the weather impact. However, the effects of weather conditions on crash occurrence have not been fully investigated and understood. With detailed weather information from weather monitoring stations, this study seeks to investigate the complex effects of weather factors, such as visibility and precipitation, on crash occurrence based on safety performance functions. Unlike conventional traffic safety studies which deal with crash frequency, crash rates per 100 million vehicle miles travelled were adopted as the dependent variable in this study. Three years of weather related crash data from a 15 mile mountainous freeway on I-70 in Colorado were utilized. First, a fixed parameter Tobit model was estimated to unveil the effects of explanatory variables on crash rates. Then, in order to characterize the heterogeneous effects of weather conditions across the homogeneous segments, a traditional random parameter Tobit model was developed. Furthermore, for the purpose of monitoring the intricate interactions between weather conditions and geometric characteristics, a multivariate structure for the distribution of random parameters was introduced; which result in a correlated random parameter Tobit model. Likelihood ratio test results demonstrated that the correlated random parameter Tobit model was superior to the uncorrelated random parameter and fixed parameter Tobit models. Moreover, visibility and precipitation variables were found to have substantial correlations with geometric characteristics like steep downgrade slopes and curve segments. Results from the models will shed lights on future applications of weather warning systems to improve traffic safety.

1. Introduction

Crashes are complex events, which are affected by geometric characteristics, weather conditions, driving behaviors, and traffic conditions. Among the different sources of crash contributing factors, weather conditions' effects on crash occurrence

* Corresponding author at: School of Transportation Engineering, Tongji University, Shanghai 20092, China.
E-mail address: yurongjie@tongji.edu.cn (R. Yu).

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have been a hot research topic in recent traffic safety studies (Chang and Chen, 2005; Caliendo et al., 2007; Yu et al., 2013). According to the Federal Highway Administration (FHWA), weather contributed to over 22% of the total crashes in 2001 (Goodwin, 2003). Moreover, based on the fatal crash data from Fatality Analysis Reporting System (FARS), Abdel-Aty et al. (2010) concluded that inclement weather of rain, snow, fog and smoke resulted in a total of 31,514 fatal crashes between 2000 and 2007 in all 50 states, the District of Columbia, and Puerto Rico. Fog, snow, and rain will result in a sudden reduction in visibility and slippery roadway pavement surfaces, which will lead to an increased risk of crash occurrence.

Recently, a variety of weather monitoring and Intelligent Transportation Systems (ITS) systems (e.g. variable speed limit system) have been introduced to reduce the weather influences on crash occurrence. For example, a Variable Speed Limit (VSL) system in Wyoming adjusts the speed limits according to the weather and roadway surface conditions (Layton and Young, 2011). Moreover, in the Netherlands, the displayed speed limits are decided based on visibility conditions captured by 20 visibility sensors along the motorway (Waller et al., 2009). However, speed limits are changed based on human decisions (speed limits in Wyoming were decided by the Highway Patrol) and threshold values set up based on engineering experience (the Netherlands). No systematic study of how traffic safety was affected by weather conditions was conducted. In this study, with the benefits of detailed real-time weather data archived by existing weather monitoring systems, weather conditions' effects on crash occurrence are thoroughly investigated.

This study seeks to investigate the intricate effects of weather factors (e.g. visibility and precipitation) on crash occurrence, based on safety performance functions with the real-time weather data. Aggregate traffic safety evaluation models (e.g. safety performance functions) were developed to unveil hazardous factors that lead to crashes; a better understanding of crash mechanisms can be obtained. These studies aim at identifying the factors that affect the number of crashes within some geographical area over a certain time period; various methodological alternatives have been employed (Lord and Mannering, 2010). Among the luxuriant literatures on aggregate traffic safety studies, crash frequency per segment has been mostly recognized as the dependent variable. In this study, instead of crash frequency, crash rates were utilized and analyzed as it is consistent with crash reporting systems. For example, fatality and injury rates per 100 million vehicle miles traveled (VMT) were employed in the National Highway Traffic Safety Administration's (NHTSA) annual crash reports (NHTSA, 2012).

In addition, majority previous studies considered weather related variables as fixed parameters, which ignored the possible heterogeneous effects across segments and cross-correlation effects among the explanatory variables. These effects are critical and need to be considered in weather related traffic safety studies. For instance, it is intuitive that low visibility conditions will have distinct effects for vehicles travelling on steep slopes and flat segments; effects like these cannot be captured by the independent assumption of parameter distributions.

This study focuses on a 15 mile mountainous freeway suffering from adverse weather conditions and high crash rates. Instead of using crash counts as the dependent variable, crash rate per 100 million VMT is preferred. In addition to the geometric characteristic data, real-time weather data are employed to capture weather factors' (visibility and precipitation) effects on crash occurrence. As for the methodology, in order to account for the unobserved heterogeneity across segments and possible correlation effects between the explanatory variables, a correlated random parameter approach is adopted (to the best of our knowledge, this is the first time the correlated random parameter model was used in an aggregate traffic safety study). Totally three models are presented: (i) fixed parameter Tobit model, (ii) uncorrelated random parameter Tobit model, and (iii) correlated random parameter Tobit model. The best model with regarding to the goodness-of-fit and model estimation results will be identified; possible applications of modeling results on weather related freeway management will also be discussed.

This paper is divided into five sections. First, previous studies related to weather conditions in the aggregate traffic safety area and relevant modeling techniques like Tobit models have been discussed. The second section provides a brief description of the data preparation procedures, which is followed by the description of methodologies used in this study. The fourth section presents results of the models, discussions about the estimated coefficients, and models' goodness-of-fit. Finally, a summary of the work and results presented in this study are discussed.

2. Background

Driven by Tobin's (1958) innovation of Tobit model to describe a non-negative continuous dependent variable, Anastasopoulos et al. (2008) first introduced the Tobit model to analyze crash rates instead of focusing on crash counts of roadway segments. Crash rates were treated as a continuous variable that is left-censored at zero. Through investigating five years crash data from Interstate highways in Indiana, the authors concluded that Tobit regression models have substantial potential in analyzing the crash rates data. Later on, instead of looking at total crash rates, Anastasopoulos et al. (2012a) employed a multivariate Tobit model to analyze crash rates by injury severity levels. The multivariate Tobit model was estimated and compared to a multivariate negative binomial model; modeling results concluded that the multivariate Tobit model provided more precise parameter estimations with additional statistically significant variables. However, ordinary fixed parameter Tobit models failed to allow parameter estimates to vary across observations, which inevitably results in biased and possibly erroneous inferences (Lord and Mannering, 2010). In order to account for the unobserved heterogeneity among roadway segments, Anastasopoulos et al. (2012b) utilized a random parameter Tobit model to analyze crash data from urban Interstate roads in Indiana. Normal distributions for the random parameters were found to provide the best model fit. It was concluded that the random parameter Tobit model outperformed the fixed parameter Tobit model with a better model fit and additional significant variables.