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Investigation of time and weather effects on crash types using full Bayesian multivariate Poisson lognormal models

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ABSTRACT

Previous research shows that various weather elements have significant effects on crash occurrence and risk; however, little is known about how these elements affect different crash types. Consequently, this study investigates the impact of weather elements and sudden extreme snow or rain weather changes on crash type. Multivariate models were used for seven crash types using five years of daily weather and crash data collected for the entire City of Edmonton. In addition, the yearly trend and random variation of parameters across the years were analyzed by using four different modeling formulations. The proposed models were estimated in a full Bayesian context via Markov Chain Monte Carlo simulation. The multivariate Poisson lognormal model with yearly varying coefficients provided the best fit for the data according to Deviance Information Criteria. Overall, results showed that temperature and snowfall were statistically significant with intuitive signs (crashes decrease with increasing temperature; crashes increase as snowfall intensity increases) for all crash types, while rainfall was mostly insignificant. Previous snow showed mixed results, being statistically significant and positively related to certain crash types, while negatively related or insignificant in other cases. Maximum wind gust speed was found mostly insignificant with a few exceptions that were positively related to crash type. Major snow or rain events following a dry weather condition were highly significant and positively related to three crash types: Follow-Too-Close, Stop-Sign-Violation, and Ran-Off-Road crashes. The day-of-the-week dummy variables were statistically significant, indicating a possible weekly variation in exposure. Transportation authorities might use the above results to improve road safety by providing drivers with information regarding the risk of certain crash types for a particular weather condition.

1. Introduction

Adverse weather and consequent conditions have a significant impact on road surface friction (due to precipitation), vehicle performance on the road (due to snow, ice or wind) and the driver (due to impaired visibility during inclement weather), which often increases the risk of crash occurrence. Statistics show that 15–20% of fatal crashes, 21–22% of injury crashes and approximately 25% of Property Damage Only (PDO) crashes occur during adverse weather condition (FHWA, 2013; RTA, 2005; Transport Canada, 2000). Andrey et al. (2001) estimated that weather related crashes in Canada cost around $1 billion per year. A number of empirical studies found an increased safety risk during adverse weather conditions. For instance, Andrey and Yagar (1993) and Andrey et al. (2001) found that precipitation was associated with more than a 70% crash increase; Suggett (1999) found snowy conditions increase injury risk by 70%; Knapp (2001) found that crash rates increased by approximately 1000% during severe winter storms.

Given the magnitude of the problem, investigating the relationship between crash risk and weather effects has received substantial attention from researchers and practitioners over the last few decades (Agüero and Jovanis, 2007; Jovanis and Chang, 1986; Jovanis and Delleur, 1983; Shankar et al., 1995). For instance, several researchers have assessed the effect of weather elements, i.e., snow fall (Andrey, 2010; Eisenberg and Warner, 2005; Hermans et al., 2006; Khattak and Knapp, 2001), rain fall (Abdel-Aty and Pemmanaboina, 2006; Usman et al., 2012; Yu et al., 2013), wind speed (Jung et al., 2011; Usman et al., 2012), temperature (Bergel et al., 2013; Brijs et al., 2008; El-Basyouny and Kwon, 2012), on

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crash occurrence (Ahmed et al., 2012; Brijs et al., 2008; Usman et al., 2012; Yu et al., 2013), whereas other researchers investigated these effects on crash severity (Andrey, 2010; Bergel et al., 2013; Eisenberg, 2004; El-Basyouny and Kwon, 2012). While the above studies are useful in understanding the effect of adverse weather, it is not always possible to identify suitable countermeasures based on the results of these studies. A particular safety countermeasure is often useful in reducing certain crash types; for example, a protected left turning phase is used to reduce Left-Turns-Across-Path crashes. Thus, in terms of identifying countermeasures, modeling crash type is more informative and useful to transportation authorities than modeling crash occurrence or severity. Further, literature also suggests that modeling crash types has the potential to provide better explanatory power than overall total crash modeling (Shankar et al., 1995).

Therefore, it is of paramount importance to understand the impact of weather elements on various crash types. To this end, the main objective of this study is to investigate the impact of different weather elements on seven crash types that were determined based on daily weather and crash data gathered over five years (2006–2010) for the entire City of Edmonton, Alberta, Canada. The onset of major snow or rain events was also considered to assess the impact of sudden weather change on crash type. As daily traffic data (e.g., vehicle-kilometer traveled) was not available, the day-of-the-week was used as proxy for exposure in this study. It has been shown in the literature that the days of the week can reasonably be used as a proxy variable for exposure when real traffic exposure is missing (Brijs et al., 2008; Shankar et al., 1995).

From a methodological viewpoint, various approaches, such as sequential logistic regression (Jung et al., 2010, 2011), negative binomial regression (Eisenberg, 2004; Eisenberg and Warner, 2005; Khattak and Knapp, 2001), discrete choice approach (Khattak et al., 1998), etc., have been advocated by other researchers to assess weather effects on crash occurrence and severity. However, most of the models do not explicitly account for the likely correlations among crash counts that may be caused by omitted variables, which can influence crash occurrence data at all levels of classification, or by ignoring shared information in unobserved error terms. To account for these correlations among seven crash types, multivariate Poisson lognormal (MVPLN) models (Chib and Winkelmann, 2001; Aguero-Valverde and Jovanis, 2009; El-Basyouny and Sayed, 2009; Park and Lord, 2007; Park et al., 2010) with multiple regression links under a Full Bayesian (FB) framework were used for this study. Other researchers used a multivariate Poisson (MVP) approach (Karlis, 2003; Karlis and Meligkotsidou, 2005) for the analysis of multivariate crash count data; however, the MVPLN regression is preferred: (i) it accounts for over-dispersion (extra Poisson variation), which is often observed in crash data; and (ii) it allows for a full general correlation structure. Since the classical estimation of the parameters of the MVPLN regression models is not straightforward, the Markov Chain Monte Carlo (MCMC) simulation method (Gilks et al., 1996) was used for model calibration. As WinBUGS (Lunn et al., 2000) is a flexible platform for the Bayesian analysis of complex statistical models using MCMC methods, this open-source statistical software was used for the estimation of the proposed MVPLN models.

2. Previous work

The development and application of models to investigate the relationships between weather and safety has been the subject of numerous studies. Ahmed et al. (2012) used a Bayesian logistic regression technique to assess crash occurrence with freeway geometry and real time weather and traffic data. They found that crash likelihood could double between the dry and snow seasons, because of the interaction between pavement conditions and steep grades. Yu et al. (2013) applied Bayesian random effect models to investigate hazardous factors on mountainous freeways using real-time weather and traffic data. Results indicated that weather elements, especially precipitation, play a key role in crash occurrence models. Qiu and Nixon (2008) conducted a meta-analysis showing that the crash rate increases during precipitation, with snow having a greater effect on crash occurrence than rain (snow can increase the crash rate by 84% and the injury rate by 75%). Compared with rates in non-adverse weather conditions, fatal crash rates increased 9% during snow, and 8% during rain. Shankar et al. (2004) employed a zero-inflated negative binomial model to examine the marginal impacts of road design, traffic and weather elements (i.e., precipitation, snowfall and temperature) on crash occurrence. Results suggested that weather effects play a statistically significant role in roadside crash occurrence.

Usman et al. (2012) used a disaggregated single level generalized negative binomial model and a multilevel Poisson lognormal model to quantify the safety effects of winter road maintenance activities at an operational level. They found that particular factors, such as visibility, precipitation intensity, air temperature, wind speed, exposure, the particular month of the winter season and storm hours, all have statistically significant effects on winter road safety. Marginal effects showed that a 1% increase from the mean values of precipitation and wind speed will cause the mean number of crashes to increase by 0.02% and 0.08%, respectively, with a 0.6% decrease in crashes for 1% increase in air temperature. Brijs et al. (2008) presented an integer auto regressive model to study the effect of weather conditions on daily crash counts. They found that rainfall is highly significant, and that an increase of precipitation intensity leads to a higher number of crashes. In terms of temperature, the relationship with crashes is negative, highly significant and non-linear, which indicates that lower temperatures result in a greater number of crashes. Khattak and Knapp (2001) used Poisson and negative binomial models to examine snow effects on interstate highway crashes. Results showed that crash rates significantly increase during snow events in cold regions. In addition, longer storm duration, higher snowfall intensity, higher wind speeds and greater traffic during snow events significantly contribute to higher crash frequency on interstate highways. Hermans et al. (2006) found that the presence of precipitation during the observation period increases the crash frequency. Furthermore, for black ice, very few results were found to be significant; however, they did indicate that the presence of black ice increases the number of crashes, while the presence of hail has an insignificant effect (Hermans et al., 2006).

Several researchers analyzed the effects of weather elements on crash severity. Some found a positive correlation between precipitation and crash severity (Brijs et al., 2008; El-Basyouny and Kwon, 2012; Jung et al., 2011; Qiu and Nixon, 2008), while others found a negative correlation (Andrey, 2010; Bergel et al., 2013). In terms of temperature, researchers found an inverse relationship between the mean temperature and both severe (injury and fatal) and PDO crashes (Bergel et al., 2013; El-Basyouny and Kwon, 2012). With regard to wind speed, increased wind speed is likely to decrease severe crashes (Jung et al., 2011). Snow days had fewer fatal crashes compared to dry days, but more non-fatal injury and PDO crashes; this risk is substantially high during the first snow day (Eisenberg and Warner, 2005). However, there is an ongoing discussion on the positive correlation between snowfall and crash risk (El-Basyouny and Kwon, 2012), as some studies noted an inverse correlation (Andrey, 2010; Veneziano et al., 2009).

In summary, many previous studies assessed weather effects on crash occurrence and severity. Nevertheless, there is a gap in the literature regarding the weather effects on crash type. This study attempts to investigate this relationship by applying multivariate