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A Bayesian analysis of multi-level spatial correlation in single vehicle motorcycle crashes in Ohio

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ABSTRACT

Estimation of frequency for single-vehicle motorcycle crashes may be difficult due to challenges associated with underreporting of single-vehicle crashes and the unavailability of motorcycle-specific data. To help address these difficulties, this study focuses on modeling single-vehicle motorcycle crashes in Ohio using a full Bayesian negative binomial model with mixed effects, creating a model structure that accounts for some of the uncertainty inherent in the data. The fixed effects considered in this study incorporate geometric, administrative, and traffic information into the model while considering the limitations of motorcycle data, such as a lack of consistent, descriptive measures of motorcycle-specific traffic. The same data set is analyzed with varying levels of information describing the areas closest to each township. The Deviance Information Criterion and spatial correlation coefficient show that township level spatial random effects significantly improve the estimate of the parameters. The results show that a researcher can apply this methodology to single vehicle motorcycle crashes to find the influence of similar parameters in a given region.

1. Introduction

As a result of a proactive approach, the national number of motor vehicle fatalities in the United States has been decreasing steadily since 2005. According to the National Highway Transportation Safety Administration's Fatality Analysis Reporting System (FARS, 2011), the number of fatalities decreased by over 22% between 2005 and 2009. Unfortunately, motorcycle fatalities became increasingly overrepresented in the overall motor vehicle fatalities during the same time period, increasing from 10.5% in 2005 to 13.2% in 2009, peaking in 2008 at 14.2% of overall fatalities. The motorcycle fatality trends are similarly observed at state level, as in 2008, a total of 15.9% of fatalities in Ohio were motorcycle related (FARS, 2011; ODPS, 2011). Because single-vehicle crashes accounted for 43.8% of all motorcycle crashes in Ohio between 2008 and the summer of 2011 (ODPS, 2011), these types of crashes warrant further investigation.

Recent research, such as Jonsson et al. (2007) and Ivan (2004), has asserted that single- and multi-vehicle crashes are better described when modeled separately. In an analysis of this assertion, Geedipally and Lord (2010) showed a split approach is beneficial by employing separate models for single- and multi-vehicle crashes in comparison to a single model for all crashes using Texas highway data. Modeling only single-vehicle crashes provides an avenue to more closely investigate the causative factors of single-vehicle motorcycle crashes. The mechanisms that induce single-vehicle crashes are different from those that cause multi-vehicle crashes, and thus modeling single-vehicle motorcycle crashes separately at a regional level from crashes that involve more than one vehicle provides a researcher with a tool set to identify the specific factors that increase the frequency of this type of crash (Savolainen and Mannering, 2007; Yau, 2004).

2. Literature review

Many approaches may be taken to analyze data effectively to reduce the severity and frequency of motorcycle crashes. Some studies are undertaken specifically to identify the factors of injury severity using discrete outcome models (Pai and Saleh, 2008; Quddus et al., 2002; Savolainen and Mannering, 2007; de Lapparent, 2006). Discrete outcome models estimate the probability of various crash outcomes given crash characteristics. Consider Tables 1 and 2, which show injury severity trends of Ohio motorcycle crashes based on various circumstances. Unlike negative binomial models, discrete outcome models may include behavioral characteristics, where negative binomial models are unable to utilize this information, since it is unknown how many vehicles successfully traversed a route despite poor behavior. For example, alcohol and drug use is shown to have a heavy impact on the frequency and severity of all types of vehicle crashes (Begg et al., 2003; Creaser et al., 2009; Branas and Knudson, 2001; Huang and Lai, 2011),

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Table 1
Distribution of injury severity in Ohio motorcycle crashes based on crash type.

Injury severity	Single vehicle motorcycle crash		Non-collision		Rear-end		Head-on		Angle		Sideswipe-same direction		Sideswipe-opposite direction	
Property damage only	2599	39.7%	2328	18.1%	2460	64.0%	329	44.2%	3065	55.2%	536	54.7%	205	55.4%
Possible injury	580	8.9%	1092	8.5%	315	8.2%	60	8.1%	476	8.6%	63	6.4%	31	8.4%
Non-incapacitating injury	2013	30.8%	5226	40.6%	545	14.2%	154	20.7%	984	17.7%	170	17.3%	60	16.2%
Incapacitating injury	1181	18.0%	3049	23.7%	290	7.5%	109	14.7%	624	11.2%	84	8.6%	41	11.1%
Fatality	170	2.6%	448	3.5%	29	0.8%	51	6.9%	107	1.9%	15	1.5%	5	1.4%
Unknown	6543	–	717	5.6%	72	1.9%	41	5.5%	301	5.4%	112	11.4%	28	7.6%
Total			12,858	–	3845	–	744	–	5557	–	980	–	370	–

Table 2
Distribution injury severity in single vehicle Ohio motorcycle crashes based on the most harmful event.

Most harmful event	Event	Percent occurrence (%)	PDO	Possible injury	Non-incapacitating injury	Incapacitating injury	Fatality
Motor vehicle in transport	3134	44.7	1870	254	459	260	51
Overturn/rollover	1518	21.6	147	102	745	438	38
Other non-collision	355	5.1	161	33	96	35	2
Ditch	269	3.8	40	24	128	60	5
Animal – deer	209	3.0	59	22	80	37	0
Ran off road right	155	2.2	21	31	57	36	1
Other fixed object (wall, building, tunnel, etc.)	133	1.9	14	5	62	35	7
Guardrail face	127	1.8	9	5	50	45	15
Parked motor vehicle	118	1.7	59	10	15	8	0
Curb	101	1.4	7	8	46	31	3
Tree	69	1.0	9	2	23	23	9
Embankment	68	1.0	8	8	26	19	1
Ran off road left	54	0.8	11	7	19	12	1

and helmet use is shown to reduce injury severity, despite the movement by state administrations away from universal helmet laws for riders (Coben et al., 2007; Houston and Richardson, 2008; Mayrose, 2008; McCartt et al., 2011). It is notable that Ohio does not require riders over 18 years old to wear helmets after they have a full motorcycle endorsement (ORC 4507, 2012). Additionally, in Ohio, a motorcycle is defined as any vehicle, other than a tractor, with a seat or saddle and no more than three wheels on the ground (ORC 4511, 2012).

Since motorcycles compose a lesser portion of vehicle miles traveled (VMT), data that are commonly employed to describe overall vehicle crashes and traffic are not as consistently available in a motorcycle specific setting. For instance, while overall average daily traffic (ADT) is often shown to correlate strongly with vehicle crashes, motorcycle-specific ADT is not consistently available, especially at a reasonable level of analysis across an entire state. As a result of this limitation, general traffic ADT is frequently considered in the prediction of motorcycle crashes. For example, Haque et al. (2010) conducted a study which included overall ADT in an analysis of motorcycle crashes at signalized intersections, while Paulozzi (2005) conducted a study which used registration and motorcycle VMT.

The use of hierarchical, also known as multilevel, Bayesian analysis modeling is widespread in safety research. For example, Song et al. (2006) considered several Bayesian multivariate spatial models using Texas crash data to estimate crash rates. Wang et al. (2009) applied a hierarchical model with a spatial random effects term to assess the impact of traffic congestion on crash frequency on the M25 Freeway in London. A hierarchical Bayesian model with site specific random effects is used to estimate crash frequency in Utah by Schultz et al. (2011), whereas Abdalla (2005) employes a hierarchical Bayesian model to analyze the effectiveness and use of safety belts in United Arab Emirates.

Hierarchical models at a regional level are effective ways to optimize the implication of data that are often available at an administrative level into an organized summary of the factors and the magnitude of their effects on vehicle crashes (Quddus, 2008; Eksler and Lassarre, 2008). For crashes involving motorcycles, Haque et al. (2010) developed hierarchical models to explain the extra variation in motorcycle crashes at signalized intersections and demonstrated that crashes occurring at the same intersection tend to be more similar.

Spatial random effects terms are often deployed alongside uncorrelated random effects terms to prevent the inference of undue spatial correlation (Mitra, 2009; Quddus, 2008). Guo et al. (2010) used conditional autoregressive spatial effects to model corridor-level spatial correlations in Florida. Aguero-Valverde and Jovanis (2006) used Bayesian hierarchical methods with spatial and temporal effects to model county level crash frequency in Pennsylvania. In a separate study, Aguero-Valverde and Jovanis (2010) investigated the effectiveness of various spatial random effects methods in multi-level data, applying the spatial effects to the first level of analysis by specifying the spatial correlation at the roadway segment level. Despite the amount of research done in both spatial analysis and motorcycle safety, little to no research specifically addresses spatial analysis of motorcycle crashes. However, this approach is ideal for motorcycle data because this approach allows the researcher to include more descriptive predictors of motorcycle crashes.

3. Research objectives

The objective of this study is to develop a model to predict single-vehicle motorcycle crashes in Ohio at a regional level. Although some types of motorcycle specific data are largely unavailable, such as motorcycle-specific ADT or VMT, the predictors in this model are selected to capture aspects of motorcycle activity and the demographics of each region. The hierarchical negative binomial model with mixed effects that is developed in this study suits the availability of data by including two regional levels of predictors and spatial correlation, which reduces model error caused in part by unobserved factors. This approach reduces the impact of