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Modeling crash frequency and severity with spatiotemporal dependence

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ABSTRACT

This study proposes a novel multinomial generalized Poisson model with error components and spatiotemporal dependence (ST-EMGP) to analyze multi-period crash frequency and severity data. The proposed model not only simultaneously models crash frequency and severity, but also accommodates spatial and temporal dependence (spatiotemporal dependence) by specifying a spatiotemporal function. To demonstrate the applicability of the proposed model, a case study is conducted on five consecutive years' (2004–2008) crash data of Taiwan's Freeway No. 1. Estimation results show that ST-EMGP model performs better than the models without considering spatiotemporal dependence in terms of adjusted likelihood ratio index, consistent Akaike information criterion and log–likelihood test. Additionally, the estimated ST-EMGP model shows that spatial and temporal dependences exist and correlate mutually. Spatial dependence may overstate its impact magnitude, but underestimate its impact range when temporal dependence is ignored. According to the distribution and regression results of spatiotemporal effects, temporal effects are higher in crash frequency and are mainly affected by traffic characteristics; while spatial effects are higher in severe crash severity levels and are mainly affected by geometric configuration. Obviously, the proposed model can successfully elucidate the sources of spatiotemporal dependence as well as their effects on crash frequency and severity.

1. Introduction

To improve traffic safety, numerous statistical models have been developed to identify the factors that contribute to crash frequency and severity. Identifying these factors can then lead to effective countermeasures. Two potential dependences are usually ignored during crash modeling, which may bias estimation. First, most studies have identified risk factors for either crash frequency or severity, ignoring the interdependence between these two. This interdependence is obvious when one notes that segments with heavy traffic tend to have a higher crash frequency but fewer severe crashes. Second, to obtain empirical data collective models, a subjective spatial (*e.g.*, every 1 km) and temporal (*e.g.*, every year) segmentation of a study network and period is generally employed, possibly leading to spatial and temporal dependence among samples, violating the assumption of sample independence. The correlation among neighboring segments or consecutive periods of a

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segment, or a combination of the two, could lead to intertwined disturbances and estimation efficiency losses (Lord and Mannering, 2010).

To incorporate the dependence between crash frequency and severity, numerous accident models have analyzed crash frequency and severity to account for their relationships with unobserved factors among crash counts by severity level (*e.g.*, Ma and Kockelman, 2006; Park and Lord, 2007; Ma et al., 2008; Aguero-Valverde and Jovanis, 2009, Chiou and Fu, 2013). Interested readers can see Mannering and Bhat (2014) for a comprehensive introduction to the jointly modeling of crash frequency and severity.

As to the accommodation of spatial dependence, many studies have also be conducted, such as Miaou and Song (2005), Quddus (2008a), Guo et al. (2010), Hadayeghi et al. (2010), Aguero-Valverde (2013), Castro et al. (2012, 2013), Narayanamoorthy et al. (2013), Wang and Kockelman (2013), and Chiou et al. (2014). Spatial dependence effects include the spatial spillover effect from the characteristics of continuity in some observed variables (*e.g.*, roadway configuration and traffic flow patterns among neighboring road segments) and the spatial correlation effect of common unobserved factors for any two adjacent segments. Those interested in additional spatial research issues can refer to Anselin et al. (2005). Moreover, a recent study by Wang et al. (2012) comprehensively reviewed spatial model applications in road safety research.

Investigating crash varieties by spatial characteristics across time periods remains rare in accident studies (Aguero-Valverde and Jovanis, 2006; Wang and Abdel-Aty, 2006; Castro et al., 2012; Ponicki et al., 2013). Two recent studies (Lord and Mannering, 2010; Savolainen et al., 2011) showed that indicator variables, such as weather, time, and day, can markedly increase model precision because these factors have significant temporal effects on both crash frequency and severity. Mohammadi et al. (2014) and Lord and Persaud (2000) demonstrated that the variance of estimated parameters of crash frequency models would be under-estimated if temporal effects have not been well-accounted. Additionally, Quddus (2008b) compared the settings of different time-series count models, indicated that a time trend should address integer-valued autoregressive processes; otherwise, the temporal effect would be confined to non-negative integer-valued data, such that when the mean of counts is relatively low, the influence of a serial correlation is difficult to determine. That is, to elucidate the relationship between spatial and temporal dependence, the relationships among surrounding spatial segments and the correlation between consecutive periods (serial correlation) must be modeled simultaneously.

Previous studies (Chiou and Fu, 2013; Chiou et al., 2014) attempted to account for these dependences. First, Chiou and Fu (2013) applied a novel multinomial generalized Poisson model with error components (EMGP) to model crash frequency and severity. This model employs a generalized Poisson distribution for the marginal probability of crash frequency, and a conditional multinomial distribution for the conditional counts in each severity level. Crash frequency and severity sub-models are then estimated simultaneously by accommodating common unobserved error components and described risk factors according to their descriptive accident components (*i.e.*, severity and frequency) in an integrated framework. Chiou et al. (2014) developed two spatial-EMGP models that incorporate spatial dependence based on the EMGP model. The spatial error-EMGP model incorporates spatial error in its structure of spatial auto-regression and spatial moving average to capture spatial correlation effects. The spatial exogenous-EMGP model uses spatial dependence functions composed of two state-parameterized functions associated with traffic and geometric composite variables to accommodate spatial dependence and explain sources of spatial dependence. The result showed that spatial dependence among neighboring segments exists, and improves estimation accuracy by considering spatial dependence. Additionally, comparisons also showed the spatial exogenous-EMGP model performs better than the spatial error-EMGP model at modeling spatial dependence due to its better statistical capability, and correlation results can be interpreted more easily.

This study develops a spatiotemporal dependence function to account simultaneously for spatial and temporal dependence. The proposed spatiotemporal function is an extension of the spatial dependence function that incorporates spatial and temporal dependence of yearly crash counts by specifying both spatial (size) coefficients (Bhat et al., 1998; Bekhor and Prashker, 2008) and serial correlation error terms (Train, 2003; Srinivasan and Mahmassani, 2005). The EMGP model is estimated along with the spatiotemporal dependence function, namely, the multinomial generalized Poisson model with spatiotemporal error components (ST-EMGP). The ST-EMGP model attempts to represent and analyze crash counts and propensities over time for different severity levels. The modeling approach to spatial effects can be considered a mixture of spatial potential and latent variable approaches (Anselin, 2002).

In sum, the proposed model can simultaneously account for the dependence between crash frequency and severity and the spatiotemporal dependence so as to enhance model estimate accuracy and investigate the source and effect of these dependences. The remainder of this paper is organized as follows. Section 2 presents the proposed model. Section 3 addresses empirical data and their descriptive statistics. Section 4 presents estimation results along with implications. Section 5 compares elasticity effects of significant tested variables and the distribution of spatiotemporal effects, as well as their sources. Section 6 gives conclusions and suggestions for further research.

2. Model framework

This study attempts to develop a ST-EMGP model to analyze the correlation among crash frequencies by severity levels in the consideration of spatiotemporal dependence. The model derivation is introduced as follows.