Accident Analysis and Prevention 89 (2016) 62–73

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

A hybrid finite mixture model for exploring heterogeneous ordering patterns of driver injury severity

Lu Ma[a], Guan Wang[a], Xuedong Yan[a,*], Jinxian Weng[b]

[a] MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, PR China
[b] College of Transport and Communications, Shanghai Maritime University, Shanghai 201306, PR China

ARTICLE INFO

Article history:
Received 20 June 2015
Received in revised form
13 December 2015
Accepted 10 January 2016

Keywords:
Highway safety
Mixture model
EM algorithm
Injury severity
Heterogeneous ordering pattern

ABSTRACT

Debates on the ordering patterns of crash injury severity are ongoing in the literature. Models without proper econometrical structures for accommodating the complex ordering patterns of injury severity could result in biased estimations and misinterpretations of factors. This study proposes a hybrid finite mixture (HFM) model aiming to capture heterogeneous ordering patterns of driver injury severity while enhancing modeling flexibility. It attempts to probabilistically partition samples into two groups in which one group represents an unordered/nominal data-generating process while the other represents an ordered data-generating process. Conceptually, the newly developed model offers flexible coefficient settings for mining additional information from crash data, and more importantly it allows the coexistence of multiple ordering patterns for the dependent variable. A thorough modeling performance comparison is conducted between the HFM model, and the multinomial logit (MNL), ordered logit (OL), finite mixture multinomial logit (FMMNL) and finite mixture ordered logit (FMOL) models. According to the empirical results, the HFM model presents a strong ability to extract information from the data, and more importantly to uncover heterogeneous ordering relationships between factors and driver injury severity. In addition, the estimated weight parameter associated with the MNL component in the HFM model is greater than the one associated with the OL component, which indicates a larger likelihood of the unordered pattern than the ordered pattern for driver injury severity.

1. Introduction

Traffic injury severity is an important safety concern of the transportation system. Although many countries have reported a decrease in road traffic injuries and deaths, the numbers remain at an unacceptable level (WHO, 2015). It clearly underscores the requirement for understanding the influence of various factors on the severity of injury sustained by crash-involved motor vehicle occupants, and for providing insights and suggestions on improving the safety of the transportation system and preventing future accidents.

Past injury-severity studies have merits in terms of the development of econometrical approaches for properly modeling injury severity as well as understanding the patterns of influence of factors. Specifically, injury-severity models have been enhanced with features of Bayesian inferences (Huang et al., 2008), random effects (Aziz et al., 2013), multivariate statistics (Abay et al., 2013), etc. Empirical analyses have found that injury severity is affected by accident characteristics (Zhu and Srinivasan, 2011), individual characteristics (Castro et al., 2013), roadway characteristics (Mergia et al., 2013), atmospheric conditions (Yasmin and Eluru, 2013) etc. However, the continuing debates (Eluru, 2013; Sasidharana and Menéndez, 2014) on the ordering patterns of injury severity indicate the limited understanding of its distributional characteristics and inadequate flexibility in terms of capturing its complex ordering patterns.

Generally, the crash injury severity for a particular person can be categorized as one of the following: no injury (O), possible injury (C), non-incapacitating injury (B), incapacitating injury (A) and fatal injury (K). It is undeniable that crash data are inherently of an ordinal nature, with severity increasing consistently from level O to K. However, in fact the boundaries between adjacent categories of injury severity are ambiguous and could lead to the misreporting of injury severity (Rosman, 2001; Tsui et al., 2009). For example, a reported possible injury could be a non-incapacitating

---

* Corresponding author.
E-mail addresses: lma@bjtu.edu.cn (L. Ma), 14120888@bjtu.edu.cn (G. Wang), xdyan@bjtu.edu.cn (X. Yan), jxweng@shmtu.edu.cn (J. Weng).

http://dx.doi.org/10.1016/j.aap.2016.01.004
0001-4575/

injury or not an injury at all under certain circumstances. The misreports can occur due to the incorrect judgments of police officers as well as inadequate considerations of post-crash factors (Bigdeli et al., 2010), including emergency rescue action, pre-hospital and hospital medical care, personal physical condition etc. These factors are difficult to take into consideration at the time of being recorded by the police. In addition, some factors such as seat belt usage and airbag deployment may not unambiguously increase or decrease injury severity levels (Patil et al., 2012). Therefore, the reported injury-severity level could misinterpret the actual harm suffered by a person in an accident, and hence invalidate the ordinal sequence of the above-defined severities.

In order to examine the complexity of the ordering patterns as well as enhance the flexibility of the econometrical structures for injury-severity modeling, this study develops a finite mixture model using component distributions from a hybrid of more than one family. This is referred to as the hybrid finite mixture (HFM) model in this paper. In this approach, a multinomial logit (MNL) process and an ordered logit (OL) process are combined to fit the data simultaneously. The main objective is to capture heterogeneous ordering patterns and impacts of variables by assuming that samples are probabilistically generated from a nominal data process or an ordinal data process.

2. Literature review

Statistical analyses of crash injury severities have received tremendous attention for the last two decades, as researchers have sought to find appropriate econometrical structures as well as to reveal the patterns of influence of factors. A prevalent concern is the ordering patterns of crash injury severities, which are crucial for developing models in the form of regressions. The MNL model (e.g. Shankar and Mannering, 1996; Çelika and Oktay, 2014; Zhao and Khattak, 2015) and the ordered response model (e.g. Klop and Khattak, 1999; Zhu and Srinivasan, 2011; Zhao and Khattak, 2015) are recognized as the most basic econometrical structures, treating crash injury severity as unordered/nominal variables and ordinal variables respectively. Based on ordered or unordered models, specific data features have been taken into account, including individual unobserved heterogeneity (Malyshkina and Mannering, 2009; Xie et al., 2012; Xiong and Mannering, 2013; Xiong et al., 2014; Yasmin et al., 2014; Behnood et al., 2014; Cerwick et al., 2014; Shaheed and Gkritza, 2014), and effects of outcome-based samples (Hauer and Hakkert, 1989; Elvik and Myssen, 1999; Yamamoto et al., 2008; Ye and Lord, 2011; Patil et al., 2012). On the other hand, advanced analytical approaches were also developed, including random parameters (e.g. Yasmin and Eluru, 2013; Ye and Lord, 2014; Islama et al., 2014; Roque et al., 2015; Weiss et al., 2014; Zhao and Khattak, 2015), and multivariate distributions (Lee and Abdel-Aty, 2008; Eluru et al., 2010; Abay et al., 2013; Russo et al., 2014; Chiou et al., 2014). The readers could see Savolainen et al. (2011) and Mannering and Bhat (2014) for a more extensive and comprehensive review of the evolution of injury-severity models.

In the sequence of no injury, possible injury, non-incapacitating injury, incapacitating injury and fatal injury, the harmfulness of an accident seemingly increases. Therefore, studies may treat crash injury severity as an ordinal variable. However, the traditional ordered response model is problematic due to the strong assumption of constant coefficients across different categories of injury severity (Eluru et al., 2008) and the constraint on the shifts in thresholds to move in the same direction (Savolainen et al., 2011). For example, the deployment of airbag could decrease the probability of both the fatal and no-injury severities and increase the probability of other severities (Patil et al., 2012). Yet, such a behavior of data will be concealed under traditional ordered response models. Generalized ordered outcome models (e.g. Quddus et al., 2010) and partial proportional odds models (Sasidharana and Menéndez, 2014) improve the traditional ordered response model by allowing the coefficients to vary across different severity categories.

Past studies also recognize injury severity as unordered/nominal data. Although the MNL model can largely enhance the flexibility of capturing complicated influential patterns between factors and injury severity, it violates the ordinal nature of the dependent variable for certain cases (Abdel-Aty, 2003) and is susceptible to correlation of unobserved effects among different injury-severity levels (Savolainen et al., 2011). Nested logit models (e.g. Abdel-Aty and Abdelwahab, 2004; Patil et al., 2012) and ordered generalized extreme value models (e.g. Yasmin and Eluru, 2013) are useful for overcoming that issue.

Although both the unordered and ordered approaches have been enhanced with various statistical considerations, the understanding of the ordering patterns of crash injury severity is still limited. As mentioned above, the ordering patterns of the crash injury severity could be very complicated. Hence, it is interesting to treat the crash injury severity using features from both ordinal and nominal data generation processes. This study aims to account for the heterogeneous data generation process by developing an HFM model that contains both an unordered/nominal component and an ordered component. It should be noted that the zero-inflated ordered probit model (Jiang et al., 2013) can be considered a special case of the proposed model, treating it as the mixture of an ordered probit distribution and a degenerate distribution.

As has been emphasized (Malyshkina and Mannering, 2009; Xiong and Mannering, 2013; Zou et al., 2014), the mixture modeling approach can capture unobservable individual heterogeneity. Malyshkina and Mannering (2009) introduced a Markov switching MNL model, in which the severity level of each crash could be regressed simultaneously by two MNL models. Several other studies (Xie et al., 2012; Yasmin et al., 2014; Xiong and Mannering, 2013; Behnood et al., 2014; Shaheed and Gkritza, 2014) have also used mixture multinomial models for analyzing crash injury severities. On the other hand, injury severity has also been treated using two-component ordered probit/logit data-generating processes (Eluru et al., 2012; Xiong et al., 2014; Yasmin et al., 2014). Although these mixture models allow observations to come from multiple data-generating processes, the components of the model are restricted to a single family. This limitation could result in biased estimations and misinterpretations of factors.

Overall, the past literature has contributed to injury-severity analysis by accounting for various econometrical features of data. However, there are still debates on the ordering patterns of crash injury severities. This study seeks to propose an alternative model capturing unobserved heterogeneous relationships between driver injury severity and explanatory variables. The new approach allows the coexistence of both ordinal and nominal econometrical considerations for injury severity data, while enhancing the flexibility of the data-fitting structures.

3. Method

3.1. The hybrid finite mixture (HFM) model

A general framework of mixture models with K components is given by Eq. (1). The probability function $f(\cdot)$ is the weighted sum of K different density/mass functions $f_k(\cdot)$ using weight parameters