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Occupant-level injury severity analyses for taxis in Hong Kong: A Bayesian space-time logistic model

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ABSTRACT

This study aimed to identify the factors affecting the crash-related severity level of injuries in taxis and quantify the associations between these factors and taxi occupant injury severity. Casualties resulting from taxi crashes from 2004 to 2013 in Hong Kong were divided into four categories: taxi drivers, taxi passengers, private car drivers and private car passengers. To avoid any biased interpretation caused by unobserved spatial and temporal effects, a Bayesian hierarchical logistic modeling approach with conditional autoregressive priors was applied, and four different model forms were tested. For taxi drivers and passengers, the model with space-time interaction was proven to most properly address the unobserved heterogeneity effects. The results indicated that time of week, number of vehicles involved, weather, point of impact and driver age were closely associated with taxi drivers' injury severity level in a crash. For taxi passengers' injury severity an additional factor, taxi service area, was influential. To investigate the differences between taxis and other traffic, similar models were established for private car drivers and passengers. The results revealed that although location in the network and driver gender significantly influenced private car drivers' injury severity, they did not influence taxi drivers' injury severity. Compared with taxi passengers, the injury severity of private car passengers was more sensitive to average speed and whether seat belts were worn. Older drivers, urban taxis and fatigued driving were identified as factors that increased taxi occupant injury severity in Hong Kong.

1. Introduction

Taxis are key public transport service providers in Hong Kong, offering a personalized point-to-point service for passengers. In 2014, taxis accounted for 12% of the boardings among all public transport modes, and the number of daily taxi boardings was 950 (Transport Department, 2014). Taxi drivers were found to have a higher risk of being involved in crashes, particularly fatal ones, as their exposure to risk is relatively greater (Baker et al., 1976; Johnson et al., 1999). The Transport Department (2014) reported that 233 out of 1000 taxis were involved in crashes in Hong Kong, second only to public light buses among all vehicular classes (compared to 15 for private cars). Both taxi-involved crash frequency and driver casualties have increased over the past decade. The number of taxis involved in crashes in 2014 was 4211 and the driver casualty rate 37.09%, both ranking second among all vehicle types apart from private cars (Transport Department, 2014). Taxi safety has become a severe problem in developed and motorized cities such as Hong Kong.

Taxis have been a subtopic of road safety studies since the 1990s, and the focus has mainly been on the psychological patterns of taxi drivers and factors affecting taxi crash risks. In a psychological sense, the unique driving behavior of taxi drivers has been attributed to aspects such as hazard perception, driving attitude and individual personalities (Burns and Wilde, 1995; Machin and De Souza, 2004; Rosenbloom and Shahar, 2007; Shams et al., 2011). Rosenbloom and Shahar (2007) surveyed male taxi drivers' and nonprofessional drivers' attitudes toward traffic violation penalties, and found that nonprofessional drivers regarded traffic violation penalties as more just and appropriate than did taxi drivers. The potential hazards associated with these psychological patterns, and the significant differences between the driving attitudes of taxi drivers and nonprofessional drivers, have been identified. Other significant factors related to taxi crash risks have been explored, such as fatigued driving (Dalziel and Job, 1997), use of safety measures (Routley et al., 2009; Sumner et al., 2014) and drivers' personal characteristics such as age, gender and income (Chin and Huang, 2009; La et al., 2013). The psychological, physical and behavioral features of taxi drivers have been found to be distinct from those of nonprofessional private car drivers, and different risk factors have

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been identified for taxi-involved crashes, but little research has been conducted to examine the crash-related injury severity for taxis.

Lam (2004) performed Pearson chi-square tests and logistic regressions to quantify the relationship between taxi drivers' injuries and several environmental factors. Demographic factors (age and gender) were also included. Factors such as driving late at night and driving without passengers were found to have a significant effect on taxi injury. Although the study quantitatively analyzed taxi drivers' injury issues, limitations in terms of both generality and methodology remain. First, only five environmental and two demographic factors were incorporated into the model, and the influence of other factors such as taxi operational attributes and traffic information were not investigated. Second, the effects of crashes on taxi drivers and passengers can be very different, and those on passengers have rarely been analyzed. In the taxi service, the driver controls the taxi and serves the passenger, and the passenger simply accepts the service passively. Thus, two separate analyses should be conducted on an occupant level for taxi drivers and passengers, to investigate the differences in factors that influence their injury severity levels. Third, basic logistic regression is unable to capture spatial and temporal heterogeneity and spatial correlations, which have been found to be significant in crash injury severity modeling (Klassen et al., 2014; Chen et al., 2015; Wei et al., 2017; Xu et al., 2016). A comprehensive study using a more rigorous modeling scheme and with more integrative information is therefore necessary for taxi injury severity analyses.

Unobserved heterogeneity is an issue in most road safety research cases, identified by both crash frequency and injury severity analyses. Correlations with observed factors, if not addressed in the model, will thus result in biased interpretations of the estimated parameters (Mannering and Bhat, 2014). Spatial and temporal variables can address unobserved heterogeneity, and are commonly studied (Xu et al., 2014; Behnood and Mannering, 2015; Chen et al., 2015; Xu and Huang, 2015; Xu et al., 2017). To explicitly address both spatial and temporal effects, a Bayesian hierarchical model with autoregressive priors is an effective approach (Chen et al., 2015; Mannering and Bhat, 2014; Shaheed et al., 2016), as the designated error terms can simultaneously account for heterogeneity, spatial correlation and space-time interaction.

In this study, Bayesian hierarchical logistic models were established for Hong Kong taxi drivers and passengers, to estimate the possibility of them being killed or severely injured (KSI) in a taxi-involved crash. Environmental and demographic factors and traffic characteristics were collected from 2004 to 2013 and included as independent variables in the models, which were then tested for any unstructured random effect, a spatial correlation term, a temporal random effect and a space-time interaction. The model with the smallest deviance information criterion (DIC) value was selected as optimal, and the corresponding estimated posterior distributions of the parameters were discussed. Finally, the optimal models for taxi injuries and private car injuries were compared, with private cars as a benchmark for all vehicular classes.

2. Data

The datasets used in this study were obtained by integrating three comprehensive databases: the zoning system of Hong Kong, a traffic information system (TIS) database and a global positioning system (GPS) database. The primary information available and the corresponding variables extracted from each database are discussed below.

2.1. Introduction of databases

2.1.1. Zoning system

The Planning Department of Hong Kong established a zoning system with two levels, DB26 and PDZ454, based on the Territory Survey of 2011, which is commonly used for transport planning and modeling. On the DB26 level, the whole territory of Hong Kong is divided into 26 broad districts according to the land use and development features, and therefore similar traffic characteristics are expected within each district. We selected the DB26 level as the spatial panel when considering the spatial correlation and spatial heterogeneity of the occupants' injury severity.

The territory was further divided into 406 traffic analysis zones (TAZs) to enable detailed urban planning activities, consisting of 18 cross-boundary zones and 388 normal zones, which form the PDZ454 level zoning system (Meng et al., 2017). In the occupant-level injury severity models, the zonal average speeds and annual travel times of various vehicular classes in the 406 TAZs were used to represent the zonal traffic operation condition.

2.1.2. Crash database

The TIS database was established by the Transport Department of Hong Kong in collaboration with the Hong Kong Police Force (Wong et al., 2007). It records the vehicle attributes (vehicle class, license, age, etc.), environmental characteristics (time, location, lighting condition, weather, etc.) and casualty information (age, sex, seat occupied, etc.) of reported crashes. The TIS crash data from 2004 to 2013 was extracted, and the casualties divided into four categories: taxi driver casualties, taxi passenger casualties, private car driver casualties and private car passenger casualties. Over the studied period, 30,110 casualties in taxis were recorded (18,004 drivers and 12,106 passengers), and 37,220 casualties in private cars (21,202 drivers and 16,018 passengers). The distribution of the casualties, categorized by casualty role and severity for taxis and private cars, is shown in Table 1. To establish occupant-level injury severity models, each casualty's demographic information, the attributes of the vehicle carrying the casualty, and environmental characteristics of the crash were extracted and used as explanatory factors (see Tables 2–5 for the list of factors for each category of casualties).

Three occupant injury severity levels—killed, severely injured and slightly injured—were defined in the database. The first two levels were combined as KSI casualties, as the fatality rate of traffic crashes in Hong Kong is extremely low (Transport Department, 2015). As only the individuals injured in a crash were recorded in the database, the lowest

Table 1
Distribution of driver and passenger casualties in taxis and private cars.

Severity	Taxi			Private car		
	Driver	Passenger	**Total**	Driver	Passenger	**Total**
KSI	2,438 (8.1%)	1,764 (5.9%)	**4,202 (14.0%)**	2,358 (6.3%)	2,648 (7.1%)	**5,006 (13.4%)**
Slight injury	15,566 (51.7%)	10,342 (34.3%)	**25,908 (86.0%)**	18,844 (50.6%)	13,460 (36.2%)	**32,214 (86.6%)**
Total	**18,004 (59.8%)**	**12,106 (40.2%)**	**30,110 (100%)**	**21,202 (56.9%)**	**16,108 (43.3%)**	**37,220 (100%)**