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Exploring the effects of roadway characteristics on the frequency and severity of head-on crashes: Case studies from Malaysian Federal Roads

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ABSTRACT

Head-on crashes are among the most severe collision types and of great concern to road safety authorities. Therefore, it justifies more efforts to reduce both the frequency and severity of this collision type. To this end, it is necessary to first identify factors associating with the crash occurrence. This can be done by developing crash prediction models that relate crash outcomes to a set of contributing factors. This study intends to identify the factors affecting both the frequency and severity of head-on crashes that occurred on 448 segments of five federal roads in Malaysia. Data on road characteristics and crash history were collected on the study segments during a 4-year period between 2007 and 2010. The frequency of head-on crashes were fitted by developing and comparing seven count-data models including Poisson, standard negative binomial (NB), random-effect negative binomial, hurdle Poisson, hurdle negative binomial, zero-inflated Poisson, and zero-inflated negative binomial models. To model crash severity, a random-effect generalized ordered probit model (REGOPM) was used given a head-on crash had occurred. With respect to the crash frequency, the random-effect negative binomial (RENB) model was found to outperform the other models according to goodness of fit measures. Based on the results of the model, the variables horizontal curvature, terrain type, heavy-vehicle traffic, and access points were found to be positively related to the frequency of head-on crashes, while posted speed limit and shoulder width decreased the crash frequency. With regard to the crash severity, the results of REGOPM showed that horizontal curvature, paved shoulder width, terrain type, and side friction were associated with more severe crashes, whereas land use, access points, and presence of median reduced the probability of severe crashes. Based on the results of this study, some potential countermeasures were proposed to minimize the risk of head-on crashes.

1. Introduction

Every year, more than 400,000 crashes occur in Malaysia, leading to approximately 7000 deaths and as much as nine billion ringgit in losses to the country's economy (RMP 2011). Of these crashes, head-on collisions account for about 12% of all reported crashes, while they are responsible for nearly 17% of fatal crashes (IRTAD 2011). A head-on collision occurs when a vehicle crosses a centreline or median either intentionally or unintentionally and collides with an opposing vehicle with an impact angle of zero (Gårder, 2006). As stated in other studies (Cerrelli, 1997; Abdelwahab and Abdel-Aty, 2004; Zhang and Ivan, 2005; Conroy et al., 2008; Bham et al., 2012), head-on crashes are among the most severe collision types and are of great concern to road safety authorities. For example, Wegman (2004) reported that head-on crashes are responsible for nearly 25% of fatal crashes occurring on rural roads in OECD member countries. According to U.S. statistics on traffic accident fatalities for the year 2005, head-on crashes comprised only 2% of total crashes, but they accounted for 10.1% of fatal crashes (NHTSA 2007). These statistics justify the need for increased efforts to reduce both the frequency and the severity of this collision type by implementing cost-effective countermeasures. To do so, it is necessary to first estimate the safety effects of roadway elements on the occurrence of head-on collision, which can be performed by developing crash prediction models that relate crash outcomes to a set of roadway geometric and environmental characteristics (Kumara and Chin, 2003). The outcomes of these models can assist transportation engineers and researchers in reducing the number of crashes. Among other techniques, statistical models are widely used to determine the critical factors associated with crash occurrence and to identify accident prone-locations. In this domain, there is a large body of research that has focused on road safety

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modelling. With respect to head-on collisions, a number of studies have attempted to isolate factors that are significantly associated with the crash occurrence. For example, Abdelwahab and Abdel-Aty (2004) evaluated the effect of increased percentage of light truck vehicles (LTVs) on head-on fatal crashes. Time series models were used to forecast the future fatality trends of head-on crashes based on a crash database obtained from the Fatality Analysis Reporting System (FARS) over the period of 1975–2000. The researchers forecasted that the annual deaths in head-on crashes would have increased over a 10-year period since the year 2000, and would have reached 5324 by 2010, representing an 8% increase since the year 2000. Overall, the modelling results showed that head-on fatal crashes were affected by the increased percentage of LTVs in traffic.

Zhang and Ivan (2005) assessed the effects of roadway geometric characteristics on the frequency of head-on crashes on two-lane rural roads in Connecticut. A negative binomial regression model was applied to estimate the crash outcomes as a function of road traits. Based on the modelling results, five variables were found to be significantly associated with head-on crashes: average annual daily traffic (AADT), speed limit, sum of absolute change rate of horizontal curvature, maximum degree of horizontal curve, and sum of absolute change rate of vertical curvature. Of these factors, posted speed limit and AADT were negatively associated with head-on crashes while the others had a positive effect. Gårder (2006) analysed head-on crashes that occurred on two-lane rural highways in Maine during the period 2000–2002. The analysis results showed that most of the head-on crashes were attributed to driver error and violations such as distraction/inattention, excessive speeds, fatigue, and alcohol/drug use. In addition, higher speed limits, more travel lanes, wider shoulder widths, and higher AADT were found to contribute to crash severity. Ye et al. (2009) developed a multivariate Poisson regression approach to model crash frequencies by collision type using crash data for 165 rural intersections in Georgia. The modelling results showed that posted speed limit and traffic volume on both the major and minor roads had a positive effect on the number of head-on crashes. Using crash data for rural, two-lane highways in Minnesota, Geedipally et al. (2010) estimated the proportion of crashes by collision type that occurred during the 5-year period between 2002 and 2006. The results showed that head-on crashes were affected by AADT, truck percentage, and shoulder width. Bham et al. (2012) analysed single and multivehicle collisions using data collected on urban highways in Arkansas from 2005 to 2007. A multinomial logistic regression model was applied to determine the impacts of several factors on crash outcomes for six collision types. Slowing or stopping and driving under the influence of alcohol were found to be significantly associated with head-on collisions. In addition, the authors noted that head-on collisions contribute to a higher risk of severe injuries compared to other crash types.

However, the number of studies focusing on head-on crashes is still limited when compared to those devoted to total or other collision types. This may be due to the lack of detailed data and the rarity of head-on crashes that, together, could be a barrier to accurately identifying the potential causes of crash outcomes. This study attempts to fill that gap and extends the related literature by analyzing head-on crashes. The objective of this study is to evaluate the effects of various roadway geometric design, the environment, and traffic characteristics on the frequency and the severity of head-on collisions. Seven count-data regression models including Poisson, standard negative binomial (NB), random-effect negative binomial (RENB), hurdle Poisson (HP), hurdle negative binomial (HNB), zero-inflated Poisson (ZIP), and zero-inflated negative binomial (ZINB) regression models were developed and compared to model the crash frequency. A random-effect generalized ordered probit model (REGOPM) was applied to model the severity, given that a head-on crash had occurred. To accomplish the objective of this study, 4 years of crash records (2007–2010) and data on the roadway geometry, and environmental and traffic attributes were collected on 543 km of Malaysia federal roads on which the rate of traffic crashes are considerably higher than on other road types (e.g., expressways, state roads, and municipal roads). This paper is organised as follows: the second section describes the case studies and characteristics of the data used. The third section explains the methodology applied to model the head-on crash frequency and severity. The results of the comparison analysis and an interpretation of the parameter estimation are then presented in the fourth section. The fifth and final section summarizes the findings and presents the conclusion.

2. Study area and data collection

This study is a part of more comprehensive research conducted to investigate the impacts of road site-specific characteristics on traffic crashes by collision type (e.g., head-on, rear-end, pedestrian, etc.). As noted earlier, Malaysian federal road network was selected as the study area. This road system is among the most important transport systems throughout the country. However, it experiences the highest rate of traffic crashes compared to other road types where it accounts for over 40% of all accident fatalities nationwide (IRTAD 2011). Among the candidate federal roads, those finally selected were on conditioned that data on roadway characteristics, traffic flow, and crash information were available and complete. Based on the conditions, the study area finally consisted of 543 km sections from five federal roads including Malaysia federal road 2 (F2), Malaysia federal road 3 (F3), Malaysia federal road 4 (F4), Malaysia federal road 67 (F67), and Malaysia federal road 76 (F76) located in the states of Perak, Kedah, Kelantan, Pahang, and Terengganu in Peninsular Malaysia. The road segments considered are representative sample to Malaysia federal road system in which most of its roadways pass through rural and semi-urban areas.

To investigate the effects of road geometric, environmental, and traffic characteristics on head-on crash frequency and severity, required data were collected from three sources: Malaysia Institute of Road Safety Research (MIROS), Highway Planning Unit (HPU), and Royal Malaysia Police (RMP). The first database, which obtained from the MIROS, originally collected from the Malaysian Pilot study by International Road Assessment Programme (IRAP) carried out in 2007. The database includes a list of road geometric and environmental characteristics such as curvature, land use, shoulder width, number of lanes, etc. The second database, collected from the HPU, contains traffic data for a 4-year period from 2007 to 2010, including average daily light-vehicle traffic (LVT) and average daily heavy-vehicle traffic (HVT). The third database consists of crash data including location and time of crashes occurred on the considered segments between 2007 and 2010. The data were collected from the MIROS based on data originally provided by the Royal Malaysia Police crash database. Merging these three databases provided the study with a data set containing four years (2007–2010) of crashes along with site-specific road and traffic characteristics for the considered road segments. More than one year of crash records was used to reduce the variability of the crash frequency from year to year. With these data at hand, the next step is to divide the study area into homogeneous segments. To do this, the study sections were split into homogeneous segments in terms of traffic flow, land use, and cross-sectional characteristics such as shoulder width, the number of lanes, and median. After the segmentation process, the 543 km sections were segregated into 448 homogeneous segments with the length ranged between 1 km and 7 km, and an average of 1.2 km. For a specific variable on each segment, the characteristic with the largest proportion was determined as the