A Comparison of Road Traffic Crashes along Mountainous and Non-Mountainous Roads in Sabah, Malaysia

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Abstract

Constrained topography and complex road geometry along rural mountainous roads often represent a demanding driving situation. As a result, traffic crashes along mountainous roads are likely to have different characteristics to crashes on roads in flatter areas; however, there is little research on this topic. The objective of this study is to examine the characteristics of road traffic crashes on rural mountainous roads and to compare these with the characteristics of crashes on non-mountainous roads. This paper explores and compares general crash characteristics including crash type, crash severity, roadway geometric features and environmental factors, and road user/vehicle characteristics. Five years of road traffic crash data (2008-2012) for Sabah were obtained from the Malaysian Institute of Road Safety Research. During this period, a total of 25,439 crashes occurred along federal roads in Sabah, of which 4,875 crashes occurred in mountainous areas. Categorical data analysis techniques were used to examine the differences between mountainous and non-mountainous crashes. Results show that the odds ratio of 'out-of-control' crashes and the crash involvement due to speeding are respectively about 4.2 times and 2.8 times higher on mountainous than non-mountainous roads. Other factors and crash characteristics that increase the odds of crashes along mountainous roads compared with non-mountainous roads include horizontal curved sections compared with straight sections, single-vehicle crashes compared with multi-vehicle crashes and weekend crashes compared with weekday crashes. This paper identifies some of the basic characteristics of crashes along rural mountainous roads to aid future research on traffic safety along mountainous roads.

Introduction

Mountainous roads have complex road geometry and limited 'right of way' compared with roads in flatter areas. One of the most dominant topographical features of mountainous areas is sloped surfaces which make it challenging for designers and engineers to construct roads according to engineering standards. Combinations of vertical and horizontal alignment coupled with risky roadside environments such as cliffs and embankments make driving in these areas more demanding. Rautela and Pant (2007) reported that mountainous roads have a higher fatality index (the ratio of fatalities to road injuries) compared to roads in flatter areas, implying that crashes along mountainous roads are more severe. Lin, Jinhai, and Yan (2013) argued that crash black-spots commonly exist on mountainous roads due to their complicated road geometry and topographical conditions. Therefore, it could be hypothesised that traffic crash characteristics along mountainous roads are different from other areas; however, there is scant research on this topic.

Many factors are associated with road traffic crashes, including traffic conditions, roadway geometric features, environmental factors and driver/vehicle characteristics. Many researchers have argued that the effect of these factors on crash occurrence and injury severity vary across various locations. For instance, using a disaggregate approach Qin, Ivan, and Ravishanker (2004) demonstrated that the relationships between crashes and traffic

volumes are different across different locations such as road segments and intersections. Milton, Shankar, and Mannering (2008) argued that the injury-severity outcomes are likely to be different across geographical locations. For motorcycle crashes, Haque, Chin, and Debnath (2012) demonstrated that the crash characteristics vary across location types such as intersections, expressways and other urban or suburban roads away from intersections. In a similar way, crash characteristics in urban and rural areas were compared to identify the impact of geographic differences on crash outcome, and specific interventions were suggested for rural and urban areas separately (M. D. Li, Doong, Chang, Lu, & Jeng, 2008).

In recent years, there have been some studies on road safety along mountainous roads (Ahmed, Huang, Abdel-Aty, & Guevara, 2011; Y. Chen, 2014; Yu, Abdel-Aty, & Ahmed, 2013; Zhang, Tang, & Kang, 2012; Zhou, Chen, & Xiang, 2014). Different approaches have been attempted to examine the factors influencing crash occurrence and injury severity of traffic crashes on mountainous roads. Yu et al. (2013) developed Bayesian random effect models to investigate mountainous freeway hazardous factors including geometric characteristics, weather conditions and traffic status, and found that precipitation is one of the significant determinants of traffic crashes along mountainous roads. Ahmed et al. (2011) reported that steep downgrades significantly increase crash risk along mountainous freeways, whereas the presence of wider medians reduces crash risk. Recently, Y. Chen (2014) analysed the fundamental attributes of severe crashes on mountainous highways using a cluster analysis technique and found that four key factors including long downhill sections, brake-fade, curves and poor visibility significantly influence crashes on mountainous roads. Note that brake-fade is the reduction in stopping power that can occur due to repeated or sustained application of the brakes, especially in high load or high speed conditions (Rhee, 1974). Although there is some research on mountainous road safety, much more remains to be known about how crashes along mountainous roads are different from those along roads in flatter areas.

The objective of this paper was to examine the characteristics of road traffic crashes on rural mountainous roads and to compare these with the characteristics of crashes on non-mountainous roads. The scope of this research was limited to Sabah, Malaysia, but the research findings may be applicable to mountainous areas in other geographical regions. Sabah was selected as the study area because more than 60% of its area is mountainous. It also has the steepest roads in Malaysia, which include roads with vertical gradient more than 16%.

Methodology and Data

In Malaysia, roads have been mainly divided into two groups: urban and rural roads (REAM, 2002). Urban roads are subdivided into four categories, namely expressway, arterial, collector, and local road; and roads located in rural areas are subdivided into five categories, namely expressway, highway, primary road, secondary road, and minor road. Based on the road authority definition, federal roads are those constructed and maintained by the Ministry of Works in Malaysia through funding from the federal government. Federal roads are mainly rural highways which contribute to nearly 50% of injury crashes in Sabah (MIROS, 2014). This study compares the crash characteristics along federal roads in mountainous and non-mountainous areas. Five years of road traffic crash data from 2008 to 2012 were obtained from the Malaysian Institute of Road Safety Research – Roads Accident Analysis and Database System (M-ROADS). Topographical information was obtained from the Digital Terrain Model (DTM) provided by the Department of Survey and Mapping Malaysia.

Federal roads in mountainous and non-mountainous areas were identified using the global information system (GIS) software, ArcGIS. Maps of federal roads and topographical information were overlapped to identify boundaries of federal roads in mountainous and non-mountainous areas. Following the guide on geometric design of roads in Malaysia (REAM, 2002), mountainous roads were defined as those located in areas where the natural ground cross slope is more than 25%. Following this criterion, mountainous roads represented about 208 km (14.5%) out of 1,428 km Federal roads in Sabah (IDS, 2007). After identifying mountainous and non-mountainous roads, crash data were allocated to these two types of roads by using the 'route number' variable in the M-ROADS dataset. During 2008-2012, a total of 25,439 crashes occurred along federal roads in Sabah. Among them, about 19% (4,875) crashes were identified as occurring along roads in mountainous areas and the other 81% occurred along non-mountainous roads.

This study applied disaggregate-analysis techniques to examine the differences in crash characteristics between mountainous and non-mountainous roads. Two types of outcome variable were used in the analysis: 1) crash frequency; and 2) crash percentage. A number of explanatory variables were tested by the proposed technique, including collision type, crash severity, roadway geometric features, time and day of crashes, vehicle characteristics, driver attributes and driving manoeuvres prior to the crash. A series of chi-square tests in the form of contingency tables were conducted to compare the statistical differences between mountainous and non-mountainous road crashes across the range of explanatory variables. In addition, odds ratios—which provide a relative likelihood of occurrence of events for a given category in comparison with other categories—were calculated to measure effect size and the strength of the relationship between pairs of categorical variables (McHugh, 2009).

Results

Results are discussed based on the differences in general crash characteristics, environmental factors and driver/vehicle characteristics of crashes along mountainous and non-mountainous roads.

General Crash Characteristics

Table 1 presents a univariate analysis comparing crash characteristics between mountainous and non-mountainous roads. In the M-ROADS database, there are 39 variables representing general crash characteristics of every crash such as month of crash, day of the week, road geometry, intersection type and area type. Among them, four variables were found to be statistically significant in distinguishing crashes between mountainous and non-mountainous roads. These included horizontal alignment, collision type, crash type and injury severity. As shown in Table 1, the collision type variable has eight categories including rear-end, out-of-control, head-on, angle, side swipe, vehicle-pedestrian, overturn and other crashes. While rear-end crashes were the most frequent (nearly 38%) collision type along non-mountainous roads, 'out-of-control' crashes were the most common (about 48%) collision type along mountainous roads. Compared to rear-end crashes, the odds of 'out-of-control' crashes along mountainous roads were about 4.2 times (*95%CI: 3.89 – 4.60*) higher than on non-mountainous roads. The odds of head-on, side swipe and overturn crashes were also significantly higher along mountainous roads than non-mountainous roads, with the corresponding odds respectively about 3.6 times (*95%CI 3.09 – 4.23*), 3.1 times (*95%CI 2.64 – 3.64*) and 3.4 times (*95%CI 2.84 – 4.10*) higher. Differences in the likelihood of vehicle-pedestrian collisions and angle collisions were not statistically significant across mountainous and non-mountainous roads.

Fatal and serious injury, slight injury, and property damage only crashes represented respectively about 5.8%, 2.4%, and 91.8% of crashes along mountainous roads. Similar shares of injury crashes were also observed among non-mountainous road crashes. Therefore, only the odds of a slight injury crash were statistically significantly different between mountainous and non-mountainous roads. In general, crashes along mountainous roads were slightly more severe as the fatality index (ratio of fatalities to road injuries) for mountainous roads was 0.21 whereas the fatality index for non-mountainous roads was only 0.18.

Among crash types, single-vehicle crashes were the most frequent crash type in mountainous areas, representing about 64.4% of all crashes along mountainous roads. Compared to multi-vehicle crashes, the odds of single-vehicle crashes along mountainous roads were about 2.6 times (*95%CI 2.44 – 2.78*) higher than for non-mountainous roads. Moreover, the single-vehicle crashes represented about 97% of out-of-control crashes.

The horizontal alignment of roads appeared to have more influence along mountainous roads than non-mountainous roads. Nearly 55% of crashes along mountainous roads occurred along roads with a horizontal curve, whereas only 16% of crashes in flat areas occurred along a road bend. The corresponding odds ratio suggested that the presence of horizontal curves, compared to straight road segments, increased the likelihood of crashes as much as 6.5 times (*95%CI 6.08 – 7.02*) along mountainous roads compared to non-mountainous roads.

Table 1. General crash characteristics

Variable	Mountainous, n (%)	Non-Mountainous, n (%)	OR (95% CI)	χ^2, *p*-value
Collision Type				
Rear-end*	900 (18.5)	7708 (37.5)	1.00	
Out-of-control	2317 (47.5)	4697 (22.8)	4.23 (3.89 – 4.60)	1204.893, p < 0.01
Head-on	271 (5.6)	642 (3.1)	3.62 (3.09 – 4.23)	282.901, p < 0.01
Angle and right angle side	546 (11.2)	4438 (21.6)	1.05 (0.94 – 1.18)	0.829, p = 0.36
Side swipe	248 (5.1)	686 (3.3)	3.10 (2.64 – 3.64)	206.287, p < 0.01
Vehicle-pedestrian	50 (1.0)	448 (2.2)	0.96 (0.71 – 1.29)	0.087, p = 0.77
Overturn	187 (3.8)	469 (2.3)	3.42 (2.84 – 4.10)	191.765, p < 0.01
Others	356 (7.3)	1476 (7.2)	2.07 (1.81 – 2.36)	115.017, p < 0.01
Crash Severity				
Property damage only*	4474 (91.8)	18765 (91.3)	1.00	
Slight injury	118 (2.4)	657 (3.2)	0.75 (0.62 – 0.92)	7.861, p < 0.01
Fatal & serious injury	283 (5.8)	1142 (5.6)	1.04 (0.91 – 1.19)	0.318, p = 0.573
Crash Type				
Multi-Vehicle *	1695 (34.8)	11948 (58.1)	1.00	
Single-Vehicle	3139 (64.4)	8485 (41.5)	2.61 (2.44 – 2.78)	862.435, p < 0.01
Unknown	41 (0.8)	131 (0.6)	1.18 (0.83 – 1.68)	0.863, p = 0.35
Horizontal Alignment				
Straight*	2071 (45.2)	13748 (84.4)	1.00	
Bend	2507 (54.8)	2546 (15.6)	6.54 (6.08 – 7.02)	2983.346, p < 0.01

* Reference category

Environmental factors

Table 2 presents the results of disaggregate analyses which compared environmental factors such as time of the day, day of the week and seasonal variations between mountainous and non-mountainous road traffic crashes. As reported in Table 2, night time crashes represented about 38% of mountainous crashes. Compared to day time crashes, the odds of night time crashes along mountainous roads were about 18% (*95%CI 1.10 – 1.25*) higher than on non-mountainous roads. Compared to weekdays, weekend crashes were slightly overrepresented

along mountainous roads, with the corresponding odds about 10% (*95%CI 1.02 – 1.17*) higher. In terms of seasons of the year, crash occurrences between mountainous and non-mountainous roads were not significantly different across dry and wet seasons. However, in terms of school seasons, the odds of crashes along mountainous road were about 20% (*95%CI 1.12 – 1.29*) higher during school holidays.

Table 2. Characteristics of crashes by time of the day, day of the week, and seasonal variations

Variable	Mountainous, n (%)	Non-Mountainous, n (%)	OR (95% CI)	χ^2, *p*-value
Time of day				
Day time*	3037 (62.3)	13573 (66.0)	1.00	
Night time	1838 (37.7)	6991 (34.0)	1.18 (1.10 – 1.25)	28.888, p < 0.01
Day of week				
Weekdays*	3411 (70.0)	14779 (71.9)	1.00	
Weekend	1464 (30.0)	5785 (28.1)	1.10 (1.02 – 1.17)	6.975, p < 0.01
Season of year				
Dry Season*	4013 (82.3)	16873 (82.1)	1.00	
Wet Season	862 (17.7)	3691 (17.9)	0.98 (0.91 – 1.07)	0.191, p = 0.66
School seasons				
School Days*	3711 (76.1)	16305 (79.3)	1.00	
School Holidays	1164 (23.9)	4259 (20.7)	1.20 (1.12 – 1.29)	23.549, p < 0.01

* Reference category

Driver and vehicle factors

Table 3 presents the distribution of crashes along mountainous and non-mountainous roads across various driver/vehicle factors. The age distributions of drivers involved in crashes along mountainous and non-mountainous roads were marginally different with young (less than 25 years old) and older drivers (more than 64 years old) being slightly overrepresented in crashes along non-mountainous roads. Female drivers were also less represented in crashes along mountainous roads, with the corresponding odds about 43% lower (*OR0.57, 95%CI 0.52 – 0.63*).

About 60% of drivers involved in crashes along mountainous roads were engaged in risky driving activities (e.g. speeding, dangerous overtaking, etc.) prior to the crash, while the corresponding percentage for non-mountainous roads was about 51%. Speeding was the most frequent risky driving behaviour among drivers involved in crashes along mountainous roads with the corresponding percentage about 32% of all mountainous road crashes. In the crash database, speeding is defined as driving over the posted speed limit. Compared to not-at-fault crashes, the odds of crash involvement due to speeding were 2.78 times (*95%CI 2.62 – 2.96*) higher along mountainous roads than non-mountainous roads. Risky driving behaviour like dangerous overtaking was also more evident among drivers involved in crashes along mountainous roads than non-mountainous roads, with the corresponding odds about 14% higher, but this estimate was only significant at 10% significance level. Other risky driving activities like ‘driving too close’ and ‘dangerous turning’ were more frequent among crash involved drivers along non-mountainous roads, with the corresponding odds respectively 25% (*OR 0.80, 95%CI 0.74 – 0.87*) and 70% (*OR 0.59, 95%CI 0.50 – 0.69*) higher than mountainous roads. Note that ‘driving too close’ and ‘dangerous turning’ are identified and recorded by the traffic police based on their evaluation of driving manoeuvers prior to a crash.

The distribution of crashes along mountainous and non-mountainous roads across vehicle types is presented in Figure 1. For both mountainous and flat areas, passenger cars represented most of the crashes. Four wheel drive (4WD) vehicles were overrepresented in crashes along mountainous roads representing about 29% of all crashes in mountainous areas. Compared to passenger cars, the odds of crash involvement for 4WDs were about 67% (*95%CI 1.57 – 1.78*) higher along mountainous roads than non-mountainous roads. Similarly, heavy vehicles were also overrepresented in crashes along mountainous roads, with the corresponding odds about 43% *(95%CI 1.32 – 1.55)* higher compared to passenger cars and non-mountainous roads. Small lorry and vans were also overrepresented in crashes along mountainous roads, with the corresponding odds about 72% (*95%CI 1.57 – 1.89*) and 13% (*95%CI 1.00 – 1.28*) higher. In contrast, motorcycles only represented about 1.7% of crashes along mountainous roads but 5.8% of crashes along non-mountainous roads, resulting in the odds of motorcycle crashes for non-mountainous roads about 3 times higher compared to passenger cars.

Table 3. Driver and vehicle factors

Variable	Mountainous, n (%)	Non-Mountainous, n (%)	OR (95% CI)	χ^2, *p*-value
Driver Age				
<15	103 (1.4)	878 (2.8)	0.46 (0.37 – 0.56)	57.493, p < 0.01
15-24	771 (10.3)	3914 (12.6)	0.77 (0.71 – 0.84)	37.789, p < 0.01
25-44*	4491 (60.1)	17534 (56.6)	1.0	
45-64	1989 (26.6)	8091 (26.1)	0.96 (0.91 – 1.02)	1.860, p = 0.17
>64	113 (1.5)	586 (1.9)	0.75 (0.61 – 0.92)	7.484, p < 0.01
Driver Gender				
Male*	4258 (87.3)	16365 (63.2)	1.00	
Female	597 (12.2)	4027 (25.2)	0.57 (0.52 – 0.63)	145.532, p < 0.01
Unknown	20 (0.4)	172 (11.6)	0.45 (0.28 – 0.71)	12.193, p < 0.01
Driver Errors				
Not at fault*	3175 (40.1)	15807 (48.6)	1.0	
Speeding	2497 (31.5)	4466 (13.7)	2.78 (2.62 – 2.96)	1091.885, p < 0.01
Driving too close	892 (11.3)	5521 (17.0)	0.80 (0.74 – 0.87)	28.284, p < 0.01
Dangerous turning	188 (2.4)	1591 (4.9)	0.59 (0.50 – 0.69)	45.447, p < 0.01
Dangerous overtaking	227 (2.9)	993 (3.1)	1.14 (0.98 – 1.32)	2.890, p = 0.09
Other offences	945 (11.9)	4130 (12.7)	1.14 (1.05 – 1.23)	10.124, p = < 0.01
Types of vehicle				
Passenger car*	3534 (47.3)	16624 (53.6)	1.0	
Four Wheel Drive	2170 (29.1)	6110 (19.7)	1.67 (1.57 – 1.78)	275.539, p < 0.01
Heavy Vehicle	1032(13.8)	3391(10.9)	1.43 (1.32 – 1.55)	80.703, p < 0.01
Van	367 (4.9)	1526 (4.9)	1.13 (1.00 – 1.28)	4.093, p = 0.04
Small lorry	174(2.3)	699(2.3)	1.17 (0.99 – 1.39)	3.318, p = 0.069
Motorbike	127 (1.7)	1789 (5.8)	0.33 (0.28 – 0.40)	150.349, p < 0.01
Other vehicles	27 (0.4)	278 (0.9)	0.46 (0.31 – 0.68)	15.745, p < 0.01
Unknown	34 (0.5)	586 (1.9)	0.27 (0.19 – 0.39)	61.382, p < 0.01

*Reference category

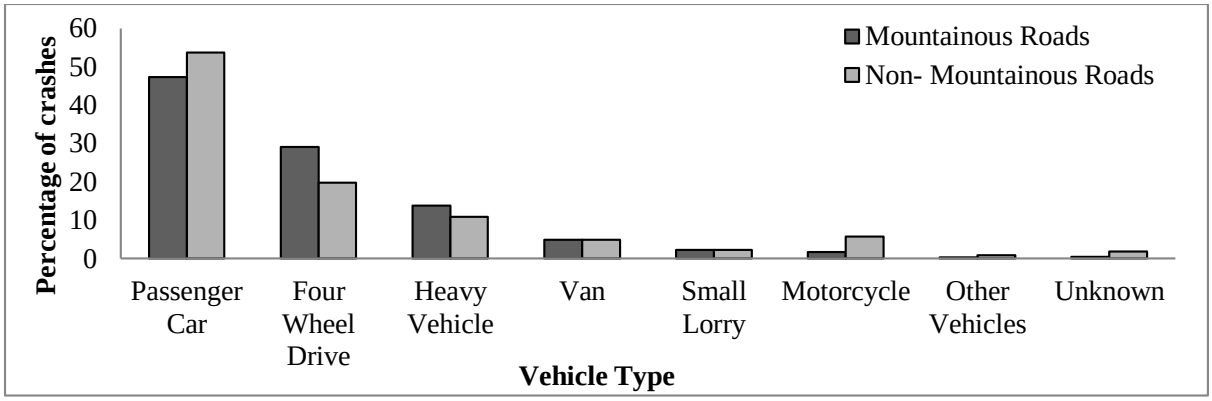

Figure 1. Percentage of crashes by vehicle type for mountainous and non-mountainous roads

Discussion and conclusion

This study examined the characteristics of crashes along mountainous roads and compared them with the characteristics of crashes along non-mountainous roads. The results have brought several new insights into the characteristics of crashes along mountainous roads which would be useful for designing countermeasures as well as targeting more focused in-depth research.

It was found that 'out-of-control' was the most frequent collision type and single-vehicle crashes were the most frequent crash type among crashes along mountainous roads compared to non-mountainous road crashes. Further, about 97% of 'out-of-control' crashes involved a single vehicle only. Mountainous roads often represent a demanding driving situation due to their constrained topography and complex road geometry. F. Chen and Chen (2013) also argued that mountainous roads with steep gradients and horizontal curves represent a unique situation and impose significant challenges to driving tasks. The second most frequent collision type along mountainous roads was rear-end crashes. While rear-end crashes may have a variety of contributing factors including roadway and traffic characteristics and driver factors, investigating their contributing factors on mountainous roads should be a worthwhile research pursuit. Other types of crashes such as vehicle-pedestrian collisions were less common along mountainous roads mainly because these roads are located in rural areas where there are fewer pedestrians. Similarly, angle or right-angle crashes were infrequent in mountainous areas because there are less intersections along rural mountainous roads.

The presence of a horizontal curve was more associated with crashes along mountainous roads than non-mountainous roads. It appears that horizontal curves represent a relatively risky situation in mountainous areas mainly because of the constrained topographical condition. In addition, a larger proportion of the road network in mountainous areas being curves represents a higher exposure along horizontal curves on mountainous roads compared to non-mountainous roads. Consistency of horizontal curves throughout the road bend is important to ensure comfortable and safe driving. Wang, Chen, Hu, and Pei (2010) reported that a road bend with a constant radius horizontal curve is safer than a road bend that consists of road curves with varying radii. M. Li, Wang, and He (2014) also reported that driving along mountainous road curves with different radii represents a dangerous situation mainly because drivers often fail to calibrate driving speed with the sudden change of road alignments. Due to constrained geometry and limitation of space, financial and technical resources, it is often challenging to construct roads following engineering standards. As a

result, many horizontal curves along mountainous roads have substandard designs compared to those in flat areas, which may contribute to high crash occurrence along mountainous roads.

Night time crashes were more frequent in mountainous areas than others. Mountainous roads in Sabah generally do not have street lighting. Complex road geometries of mountainous roads in dark conditions may make the driving task even complex, and drivers may face difficulties in negotiating roads with tight curves and steep slopes. It is not clear from this research how the night time environment makes the driving task complex in mountainous areas. Future research should target investigating the influence of various road geometrical elements on night time driving behaviour and safety. Given that night time represents an unsafe environment along mountainous roads, road authorities should target provision of street lights along these roads, at least in black spot areas.

The odds of road crashes along mountainous roads were found to be higher during weekends and school holiday seasons. This may simply reflect a higher exposure of traffic along mountainous roads during times when people travel longer distances for holidays or to visit family, friends and relatives. Further research on the relationship between weekend/school holiday exposure and road crashes should be useful in this regard. Despite previous research indicating precipitation can be influential for crash occurrences along mountainous roads, the difference in crash frequencies between wet and dry seasons was not significant in this research. Seasons of a year may not contain sufficient information to compare the influence of precipitation on road safety, and hence future research should include meteorological data and compare crash frequencies between mountainous and non-mountainous roads.

Young and older drivers had lower odds of involvement in crashes in mountainous areas compared with middle aged drivers. Similarly, female drivers were less involved in road traffic crashes along mountainous roads compared with male drivers. In the cultural context of Malaysia, middle-aged male drivers often choose to drive when they travel with the family, and this may be the case when they drive in mountainous areas which impose complicated driving tasks and require long distance travel. Therefore, the high crash involvement of middle-aged males along mountainous roads may be due to their high exposure in these areas. Other than that, it is well known that males are generally more involved in crashes than females at all ages (e.g. McGwin Jr and Brown (1999)). In addition, male drivers are generally noted to partake in higher risk driving.

With respect to driver actions, speeding and dangerous overtaking were significant factors among drivers involved in crashes along mountainous roads. Lin et al. (2013) also found that speeding was the main illegal driving action in mountainous areas. As reported by Lee, Nam, and Abdel-Aty (2015), low traffic volume in rural mountainous areas may encourage drivers to increase their speed. In addition, many tourist spots are located in mountainous areas in Sabah, which attracts weekend and holiday traffic along mountainous roads there. Illegal speeding and dangerous overtaking may be initiated by drivers driving in holiday mode—this merits further investigation. Due to dangerous driving actions or manoeuvres of drivers along mountainous roads which generally have complex road geometries, many researchers have suggested strict speed enforcement along mountainous highways (e.g. F. Chen and Chen (2013)).

As per the data from the Ministry of Transportation Malaysia in 2012, more than half of vehicles registered in Sabah are passenger cars (MOT, 2012). However the odds of crash involvement for 4WDs were much higher along mountainous roads in Sabah. 4WDs,

including sport utilities vehicles (SUVs), were also reported to be over involved in crashes in earlier research elsewhere (McGinnis, Davis, & Hathaway, 2001). Research from Keall, Newstead, and Watson (2006) highlighted that 4WDs are more liable to rollover crashes because of their design with a higher centre of gravity relative to the width of the wheel track. Recently, technology such as Electronic Stability Control (ESC) has been introduced to solve this problem (Chatzikomis & Spentzas, 2014), however much of the vehicle fleet in Sabah Malaysia does not yet have ESC. More research is also needed to investigate the performances of ESC along mountainous roads with tight curves and steep slopes. In addition, the exposure of 4WDs is higher along mountainous roads because people may simply prefer using a 4WD for traveling in mountainous areas. Other than 4WDs, the odds of crash involvement were also higher for small lorries and vans along mountainous roads compared with non-mountainous roads.

Heavy vehicles including rigid lorries, lorry trailers and buses represented a substantial 13.8% of crashes along mountainous roads. Their odds of crash involvements were higher along the mountainous than non-mountainous roads. Mountainous roads with steep slopes and tight curves represent an even more challenging situation to heavy vehicles due to their size and capability. Some research in the past attempted to examine the effects of heavy vehicles on mountainous road safety. For example, S. Chen, Chen, and Wu (2011) found that vertical alignments of roads and pavement surface condition influence the crash risk of trucks along mountainous roads. Yu, Xiong, and Abdel-Aty (2015) reported that the proportion of trucks in the traffic volume is negatively associated with crash rates. W. Li, Sun, and He (2010) reported that the crash risk of trucks is likely to increase with the increase in speed limits along the roads in mountainous areas. Heavy vehicles often face difficulties in maintaining driving speed both along upgrade and downgrade sections of a road with a steep slope. The slow speed of heavy vehicles often interrupts the flow of other traffic particularly along a road where no overtaking or relief lane is provided. In addition, continuous braking while travelling along a downgrade section may impose additional hazards for heavy vehicles, as continuous braking may cause brake-fade in which the braking capability of the heavy vehicle significantly reduces due to over-heating.

In Sabah, motorcycles are the second most common travel option after passenger cars (MOT, 2012). The odds of motorcycle crashes were found to be lower along mountainous roads. Motorcycles are cheaper, easy to ride and require little parking space, which makes them a good choice for middle and low income earners. However, motorcycles are less likely to be used for long distance travel and climbing up and down mountainous roads, and thus the exposure of motorcycles along mountainous roads is less.

This study has brought several new insights into the factors that influence crash occurrences along mountainous roads by analysing the crash data of the Malaysian Institute of Road Safety Research – Roads Accident Analysis and Database System (M-ROADS). To estimate and compare crash risk between mountainous and non-mountainous roads, odds ratios were calculated for a combination of various explanatory variables. Although this technique provided a good estimate of relative crash involvements, these estimates could be more reliable with exposure measures. As such, future research should focus on obtaining relevant exposure measures across various road traffic features and road users to estimate and compare the crash risk along mountainous roads as well as to identify road geometry and cross-section elements that may increase the crash risk along mountainous roads. Based on the findings of this study, potential countermeasures for mountainous roads may include lowering speed limits along high-risk road segments, providing or revising advisory speeds

on curves, better delineation along horizontal curves through improved pavement markings and retro-reflective road signs, and greater use of safety barriers. However, the suitability and effectiveness of these countermeasures should be thoroughly investigated before implementation.

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