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A model of latent class multinomial logit to investigate motorcycle accident injuries

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Abstract

The analysis of road traffic accidents will be more complicated with the existence of heterogeneity in the raw data of traffic accident. This study conducts a specific attention to unobserved heterogeneity issues by classifying homogeneous attributes of two different accident data classes. A latent class approach was used to investigate the contributing factors and their influences of motorcycle accident injury outcomes. The data set from 2010 to 2015 consisting 1061 motorcycle accident injuries on Denpasar-Gilimanuk and Denpasar-Singaraja national road networks in Tabanan Regency, Bali were employed as the case study. This study found that male motorists and head on collisions significantly influencing fatal motorcycle injuries. In addition, collisions between motorcycle and the other types of motor vehicles, day time accidents, male motorists at fault, right angle and head on collisions significantly associated with serious motorcycle accident injuries. This result may represent many primary factors which considerably diverge across a traffic accident injury observation. The contributing factors identified in this study were further discussed and some countermeasures for reducing the motorcycle accident injuries were proposed.

Keywords: Accident injuries, Latent class analysis, Motorcycle, National road network

1. Introduction

Road traffic accidents result from an array of factors related to the elements of the transport system comprising of *human, vehicles, roads, the environmental* and road users [1]. Therefore, it is not always possible to gain access to all relevant data that could potentially take in to account when identifying the causes for traffic accidents. In addition, significant accident data may not be reported to and collected from the police or the law enforcement agencies. These data are classified to as unobserved factors or unobserved heterogeneity [2-4].

If both of these unobserved and observed factors are statistically correlated, then model parameters may be predicted inaccurately. For instance, age is a significant factor to influence a traffic accident injury[3]. However, considering only age in the model estimation, it consequently represents many primary factors which considerably diverge across a traffic accident injury observation. The reason is because road users with the same age may have dissimilarities within these unobserved factors [3]. Age may be acting as a proxy variable for many underlying factors that are likely to vary considerably across accident-injury observations because people of the same age are likely to have differences in these unobserved factors [3]. These differences may be correlated with many underlying factors that are likely to affect accident-injury severity such as physical health, susceptibility of bones to breakage, body positioning at the time of accident and reaction times that may affect (either reduce or increase) the severity of the accident [3]. On the assumption that age has similar influence on a traffic accident injury for all road users, consequently the developed model is considerably limited. This may influence conclusions taken from the parameter estimate of the age-variable as well as other parameters in the model. Many statistical methods can be used to cope with this problem however, many scientists previously disregarded this problem [3].

Heterogeneity probably come from these unobserved factors when constructing motorcycle accident injury models as a function of observed factors, causing biased parameters and inaccurate interpretations [2-4]. In addition, numerous factors are discovered to influence motorist injury severity. In addition, the random parameters illustrate that these effects diverging among accidents and road users [5].

Several studies conducted both in developed and developing countries have utilised the latent class regression methods to analyse road traffic accident injuries. A past study carried out in the US [6] employed a latent class multinomial logit model to address unobserved heterogeneity by identifying two distinct accident data classes with homogeneous attributes. Another study performed in the US [7] used a mixed logit model to investigate the factors that affect accident severity outcomes

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in a collision between a motorcycle and another vehicle. A past study in Belgium segmented a heterogeneous motorcycle accident data into various classes and injury analysis was carried out for each class. The results of these class-based analyses are compared with the results of a full-data analysis [8].

Latent class is an approach for addressing heterogeneity. Instead of having the heterogeneity vary across individual observations, the estimation approach seeks to identify groups of observations with homogeneous variable effects within each group. This approach is semi-parametric because it does not impose a parametric assumption on the distribution of parameter heterogeneity. In addition, the approach still requires a parametric model structure such as negative binomial and logit model [8].

One way to account for the heterogeneous nature of the data is to use a latent class clustering approach. For example. to identify the main factors that contribute to an accident casualty within each subgroup of accidents, the association rule algorithms for each one of the latent classes is used. To identify factors associated with the accident severity, different types of analysis such as the binary, multinomial and mixed logit model may be employed. The latent class logit model (LCM) is in some respects a semiparametric variant of the Multinomial logit that resembles the mixed logit model. It is somewhat less flexible than the mixed logit model in that it approximates the underlying continuous distribution with a discrete one, however, it does not require the analyst to make specific assumptions about the distributions of parameters across individuals [9].

A past study conducted in China estimated a new model to estimate real time traffic accident risk in accordance to some highly chosen on traffic flow' characteristics. The results of the study demonstrated that the general accuracy of the latent class logit model is higher than the traditional logistic regression model [10]. Overall, these past studies recommended that the latent class approach is favorable method to model traffic accident severity outcomes.

In the meantime, traffic accidents in Bali frequently occurred on roads that are part of the national road network such as Denpasar-Gilimanuk and Denpasar-Singaraja road networks in Tabanan Regency. The Denpasar-Gilimanuk and Denpasar-Singaraja national roads each stretch from east to west and north-south of the island of Bali. The total length of these two national roads is 65.73 km at the end of 2018 [11].

With regard to traffic accident data, motorcycle accidents dominated more than 70% of total traffic accidents in Bali [12]. Tabanan Regency is one of the districts with a high number of accidents, namely 1364 accidents during 2011-2015 with 67.59% occurring on the national road network [12]. This figure was a reported accident however in fact it may be more than that because the community often does not report traffic accident occurrences to the authorities. The national road network of Denpasar-Gilimanuk is important as it is connecting freight and passenger transport between Bali and Java islands. In addition, the road network Denpasar-Singaraja is important as it links between the southern and northern parts of Bali island. The length of distance travelled along the road with various geometric conditions passing through the short sight distance and small curve radius makes the high number of accidents [13] and consequently accident-prone areas scattered along the Denpasar-Gilimanuk and Denpasar-Singaraja road networks within Tabanan Regency.

The analysis of road traffic accidents will be more complicated with the existence of heterogeneity in the raw data of traffic accident. This study, therefore, uses a latent class approach to investigate the contributing factors and their influences of motorcycle accident injury outcomes using Denpasar-Gilimanuk and Denpasar-Singaraja national road networks in Tabanan Regency as the case study. This study describes a detailed discussion of unobserved heterogeneity in the context of motorcycle accident data and analysis. This is in line with one of the main goals of traffic accident analyses is to distinguish key factors that influence traffic accident casualty.

2. Methods

Figure 1 shows the stages of the use of latent class multinomial logit to investigate motorcycle accident injuries. Motorcycle accident data are obtained from the accident data report of the Bali Regional Police in 2016 [12]. A predictor variable from accident data set will then be selected statistically according to its variable proportion. Predictor variables which are not proportionally significant at the 10% level will not be used in the model construction. Predictor variables that pass the selection will then be used in the preparation of the latent class model.

The number of appropriate latent classes is subsequently determined. For example, the relevant appropriate number of latent class would be either 1, 2, 3, 4 or more classes. The statistical criteria used to determine the number of classes are Bayesian Information Criterion (BIC) and Adjusted BIC (ABIC), Lo-Mendell-Rubin likelihood ratio test (LMR LRT), the bootstrap likelihood ratio test (Bootstrap LRT) and the p-value for both Pearson χ^2 and Likelihood Ratio χ^2 [8, 14].

After obtaining the appropriate number of latent classes, the inclusion of each predictor variable on each latent class is carried out. The magnitude (t-statistic) of significant predictor variables is used as the reference to determine the group classification [6]. Each of significant predictor variable is allocated to only one latent class. Subsequently, the estimate of the significant predictor variable per class for each type of injury is determined with the value of each coefficient. The exponential value of each coefficient value is used to estimate the the probability of significant predictors for each type of injury.

2.1 Latent class multinomial logit

Due to the complexity of highway accidents which involve complex interactions among human, vehicle, roadway, traffic and environmental elements, it is impossible to have access to all of the data that could potentially determine the likelihood of a highway accident or its resulting injury severity. The latent class multinomial logit model has the advantage of having the possibility of common parameters among unobserved groups/classes of motorcycle accident observations. It does not require a parametric assumption relating to the distribution of unobserved heterogeneity in motorcycle accident data. In addition, the unseen (latent) subgroups within motorcycle accident data can be identified using responses from a set of variables [15]. The class membership specifications can be simplistic with few explanatory variables which providing little insight into class distinctions. Identifying many groups that may exist in the motorcycle accident data however, can be computationally cumbersome and the procedure makes the assumption of parameter homogeneity within the identified group [4].

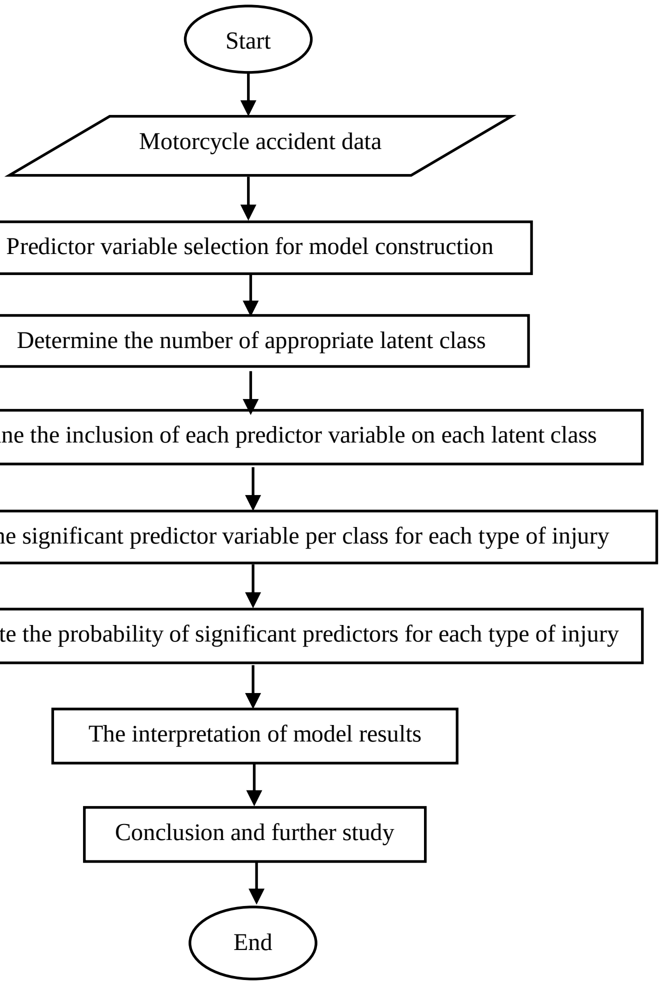

Figure 1 Diagrammatic chart of research method**.**

2.2 Latent class modelling framework

Three discrete casualty levels are considered: fatal, serious and slight injuries. The model in this study is set up by defining a function that determines the probability of motorcycle accident-injury outcomes as [15]

$$S_{in} = \beta_{in}X_{in} + \varepsilon_{in} \tag{1}$$

where,

S_{in} : the probability of motorcycle accident-injury will be in casualty category i in accident n
β_i : a vector of estimate parameters for injury-level i
X_{in} : a vector of the independent variables
ε_{in} : a disturbance terms that is assumed to be extreme-value distributed arising to the multinomial logit form

Motorcycle accident injuries drivers can be categorised into C distinct classes and that each of these classes will have their own parameter values. Having allocated motorcycle accident injury to specific classes, the class-specific unobserved heterogeneity can be acquired without making distributional assumptions as is needed when estimating traditional random parameters models. The resulting outcome probabilities are [15]:

$$P_n(i|C) = \frac{\exp\,(\beta_{ic}X_{in})}{\sum_{\forall C}\exp\,(\beta_{ic}X_{in})} \tag{2}$$

where,

$P_n(i|C)$: The probability of injury level i, for accident n, which is a member of unobserved class c.

The multinomial logit form also determines the unconditional class probabilities $P_n(i|C)$ by as:

$$P_n(C) = \frac{\exp\,(\alpha_c Z_n)}{\sum_{\forall C}\exp\,(\alpha_c Z_n)} \tag{3}$$

where,

Z_n : A vector of independent variable that establish class c probabilities for accident n.
α_c : a corresponding vector of estimated parameters

For detailed discussions on Latent Class Analysis multinomial Logistic Regression the reader is referred to [6, 15].

2.3 Data description

The Sustainable Development (SD) is an improvement of a traffic system at the current casualty levels into the considerably lower levels, with zero being ultimate aim to be handed over subsequent generations [16 -17]. Meanwhile, the Sustainable Development Goals (SDGs) associated with road safety targets is to stabilise and then reduce the forecast level of road traffic deaths around the world

Table 1 Motorcycle accident injuries data at the road networks**.**

Fatal Injuries	Serious Injuries	Slight Injuries	Total
330	340	391	1061

Table 2 Selecting variables for model construction.

Variable Description	X	N	p_i	95% Conf. level	
				Lower	Upper
Accident type					
PEDESTRIAN_ ACCIDENT 1 = Pedestrians involved in accident, 0 = Otherwise	167	1061	0.157	0.135	0.179
* MOTOR_VEHICLE_ACCIDENT 1 = Motor vehicle involved in accident, 0 = Otherwise	813	1061	0.234	0.208	0.259
Collision type					
OC 1 = Collision occurred due to driver/rider is out of control, 0 = Otherwise	171	1061	0.161	0.139	0.183
* RA 1 = Right angle collision, 0 = Otherwise	337	1061	0.318	0.290	0.346
*RE 1 = Rear end collision, 0 = Otherwise	192	1061	0.181	0.158	0.204
*HO 1 = Head on collision, 0 = Otherwise	271	1061	0.255	0.229	0.282
*OTHERS 1 = Collision occurred due to others (tailgating & run red light), 0 = Otherwise	482	1061	0.454	0.424	0.484
Accident cause					
*WW 1 = Accident occurred due to driver/rider was on the wrong way, 0 = Otherwise	273	1061	0.257	0.231	0.284
FY 1 = Accident occurred due to driver/rider failed to yield, 0 = Otherwise	163	1061	0.154	0.132	0.175
Temporal characteristic					
* TIME_OF_ACCIDENT 1= Day time, 0 = Night time	687	1061	0.648	0.619	0.676
Driver/Rider characteristic					
*AGE_16_25 1 = Driver/rider age at fault was between 16-25, 0 = Otherwise	365	1061	0.344	0.315	0.373
*AGE_26-60 1 = Driver/rider age at fault was between 26-60, 0 = Otherwise	648	1061	0.611	0.581	0.640
*GENDER 1 = Male driver/rider at fault, 0 = Female driver/rider at fault	926	1061	0.873	0.853	0.893
Vehicle Characteristic					
* MC 1 = Motorcycle was at fault in accident, 0 = Otherwise	767	1061	0.723	0.696	0.750
LV 1 = Light vehicle was at fault in accident, 0 = Otherwise	177	1061	0.167	0.144	0.189
HV 1 = Heavy vehicle was at fault in accident, 0 = Otherwise	117	1061	0.110	0.091	0.129

Notes: N = sample size; X = number of occurrence (yes =1)
* Statistically significant at the 10% level (the 90% confidence limits)

(https://sustainabledevelopment.un.org/sdgs). The goals of the Decade of Action for Road Safety 2011-2020 include:

a. SDG 3.6 By 2020 halve the number of global deaths and injuries from road traffic accidents

b. SDG 11.2 By 2030 provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older person.

According to Global Status Report on Road Safety [17], number of victims killed in road accidents in Indonesia is 0.01% (31,282 people) out of total population of 261,115,456 inhabitants in 2016. In addition, 74% and 16% of the total accident victims who killed in road accidents were motorcyclists and pedestrians respectively. Table 1 shows motorcycle accident injuries taking into account of three severity groups such as killed, serious and slight injuries, during period between 2010 and 2015 on the road networks of Denpasar-Gilimanuk and Denpasar-Singaraja within Tabanan regency, Bali. Of those all motor vehicle injuries, nearly 63% comprise of motorcycle KSI (Killed or Serious Injuries).

Killed or Seriously Injured (KSI) is a standard metric for safety policy, particularly in transportation and road safety. Killed is human casualties who sustained injuries which caused death less than 30 days after the accident. Confirmed suicides are excluded. The UK definition of serious injury covers injury resulting in a person being detained in hospital as an in-patient, in addition all injuries causing fractures, concussion, internal injuries, crushing, burns, severe cuts, severe general shock which require medical treatment even if this does not result in a stay in hospital as an in-patient. Slight injury is an injury of a minor character such as a sprain (including neck whiplash injury), bruise or cut which are not judged to be severe, or slight shock requiring roadside attention. This definition includes injuries not requiring medical treatment [18].

Following a past study [19] on reduction of design variables, Table 2 shows that some independent variables are overlooked due to their small proportion ($p_i = \frac{X\ (number\ of\ occurrence)}{N\ (sample\ size)}$). Based on the test, there were six variables excluded from the model development stages, for instance accident type (with pedestrians), collision types (out of control and rear end collisions), accident cause (failed to yield), vehicle types (heavy and light vehicles). As the result, there were ten variables included in the model construction consisting of accident type (with vehicles), day time, age of 17-25 years at fault, age of 26-60 years at fault, male motorists at fault, collision types (right angle and head on), accident cause (others and wrong way) and motorcycles at fault.

There are relevant explanations for these variable inclusions in the model construction. Age and gender were apparently considered as the most important motorcyclist-specific factors that influence both severity and frequency of motorcycle accidents [6]. This previous study discovered that older motorcyclists have higher probability than younger motorcyclists to be severely injured as they are considered to have slower reaction time, reduced sensory, less perceptual ability and less physical strength to motorcycle accidents. On the other hand, older motorcyclists were more likely to have

Table 3 Criteria to retain number of latent classes

LCA Models	BIC	ABIC	*p*-value for LMR	*p-value* for Bootstrap	*p-value for Pearson* χ^2	*p-value for likelihood Ratio* χ^2
2-Class (2-Class vs. 1-Class)	11237.848	11342.155	< 0.001	< 0.001	< 0.001	< 0.001
3-Class (3-Class vs. 2-Class)	10357.680	10516.623	< 0.001	< 0.001	< 0.001	0.486
4-Class (4-Class vs. 3-Class)	10022.645	10236.225	< 0.001	< 0.001	0.150	1.000

Table 4 The latent classes

Variable Description	Latent class 1		Latent class 2	
	β	t-statistic	β	t-statistic
Accident type–with vehicles	0.681	40.511	**0.996**	284.636
Time (day time)	**0.657**	38.312	0.623	21.444
Age at fault (16-25 years)	0.336	19.485	**0.365**	12.269
Age at fault (26-60 years)	**0.614**	34.525	0.603	20.012
Gender (male at fault)	0.863	69.561	**0.899**	49.673
Collision type – right angle	**0.422**	23.599	0.035	3.213
Collision type – head on	0.042	5.258	**0.834**	37.303
Cause of accident – others	**0.622**	35.761	---	---
Cause of accident–traffic violations	---	---	**0.954**	56.835
Vehicle types at fault–motorcycle	**0.748**	47.728	0.655	22.849
β = parameter				

more riding experience that was a significant risk factor related with motorcycle accidents.

Age of the casualty is associated with physical characteristics, reaction times and risk-taking behavior of the road users in which may influence their accident injury severity. Age, however, may be used only as a substitute for these unobserved and unmeasured factors. The influence of age on accident injury severities, therefore, may diverge across road users at the same age. Further, age is frequently included in a model' variable. This causes the heterogeneous effects of age can be even more declared [4]. In terms of gender, there are obviously physical and physiological distinctions between men (code =1) and women (code = 0). In addition, there is considerable differences among road users at the same gender including height, weight, physical health and other factors that are definitely unobserved to the researcher [4].

In terms of collision types, right angle was significantly included in the model variable as many of the accidents happened at the road network junctions [20] and typically in Bali that many motorcyclists pulled into main road at any time without waiting. Meanwhile head-on collision was more likely to occur because these road networks were two-lane two-direction of single carriageways.

3. Model development and results

Subsequently, these ten predictor variables are used to determine the number of appropriate latent classes using the software of M-Plus version 7.4. Statistically, there have been multiple criteria to retain number of latent classes include:

a. Bayesian Information Criterion (BIC) and Adjusted BIC (ABIC). These were used to choose the number of clusters in the final model. These statistical figures measure the model fit and simultaneously correct for the model's complexity in which a more parsimonious model is better or a lower score is better. [8].

b. Lo-Mendell-Rubin likelihood ratio test (LMR LRT). This test compares the improvement in fit between neighbouring class models and provides a p value that can be used to determine if there is a statistically significant improvement in fit for the inclusion of one more class [14].

c. The bootstrap likelihood ratio test (Bootstrap LRT). the BLRT provides a p value that can be used to compare the increase in model fit between the class models [14].

d. The p-value for both Pearson χ^2 and Likelihood Ratio χ^2 are the standard component to establish the fit of a given model [14].

Based on the least of p-values for LMR, Bootstrap, Pearson $\chi^2$and Likelihood Ratio χ^2, two (2) latent classes shown in Table 3 are considered as the best model. This illustrates that initial analysis of latent class clustering may uncover concealed relationships among motorcycle accident injuries [8].

More specifically, the inclusion of each variable for the two classes is shown in Table 4. The magnitude of variables is used as the reference to determine the group classification [6]. These variables can be grouped into accident-specific characteristics including time of accident, accident characteristics as well as motorcyclist attributes.

In Latent Class 1 the predictors included were time of accidents (day time), adult motorists (age of 26-60 years at fault), right angle collision, other factors as the cause of accident and motorcyclists at fault. Meanwhile, Latent Class 2 comprised of accident type – with vehicles, young motorists (age of 17-25 years at fault), male motorists at fault, head on collision and traffic violations as the cause of accident. Using this classification, the influencing factors on motorcycle fatal, serious and slight injuries are examined.

The fatal injury is considered as the reference or the base category. The value of $\exp(\beta)$ for day time accident and right angle collisions on motorcycle serious injury for latent class 1 were 1.632 and 3.139 respectively which implies that the odds increased by 1.6 and 3.1 times. Hence, day time accidents and right angle collisions were 1.6 and 3.1 times more likely to influence motorcycle serious injury than fatal injury. In addition, accidents involving other vehicles in

Table 5 The estimation of latent class logit model

Variable Description	Latent class 1			Latent class 2		
	β	e^{β}	t-statistic	β	e^{β}	t-statistic
Defined for serious injury						
Accident type – with vehicles				0.986**	2.680	4.388
Time (day time)	0.490*	1.632	2.778			
Age at fault (16-25 years)				0.522	1.685	1.259
Age at fault (26-60 years)	-0.105	0.900	-0.265			
Gender (male at fault)				-0.333	0.717	-1.331
Collision type – right angle	1.144**	3.139	4.936			
Collision type – head on				-0.024	0.976	-0.083
Cause of accident – others	0.013	1.013	0.060			
Cause of accident – traffic violations				0.508	1.662	1.558
Vehicle types at fault – motorcycle	-0.045	0.956	-0.223			
Defined for slight injury						
Accident type – with vehicles				---		---
Time (day time)	---		---			
Age at fault (16-25 years)				3.532*	34.192	3.437
Age at fault (26-60 years)	---		---			
Gender (male at fault)				-3.652*	0.026	-2.631
Collision type – right angle	---		---			
Collision type – head on				-3.090**	0.046	-4.940
Cause of accident – others	2.736*	15.425	2.569			
Cause of accident – traffic violations				---		---
Vehicle types at fault – motorcycle	---		---			

Lo-Mendell-Rubin likelihood ratio test = 718.768 ; (p-value : 0.000)
LL(convergence) = -1554.606; LL(null) = -1926.886; McFadden ρ^2= 0.193
** significantly different from zero at the 0.001 level;
* significantly different from zero at the 0.05 level

Table 6 The probabilities of motorcycle injuries

Variable	Fatal Injury	Serious Injury	Slight Injury
Accident type – with vehicles	21.37%	57.27%	21.37%-
Time (day time)	27.53%	44.94%	27.53%
Age at fault in between 16-25 years old	2.76%	2.76%	94.47%
Gender (male at fault)	49.36%	49.36%	1.28%
Collision type – right angle	19.46%	61.08%	19.46%
Collision type – head on	48.89%	48.89%	2.22%
Cause of accident – others	5.74%	5.74%	88.52%

latent class 2 was 2.7 times more likely to influence motorcycle serious injury than fatal injury.

Male motorists and head on collisions in latent class 2 were 97.4% and 95.4% less likely to affect motorcycle slight injury than fatal injury. Younger motorists in latent class 2 however, were 34.2 times more likely to influence motorcycle slight injury than fatal injury. In addition, others as the cause of accidents in latent class 1 were 15.4 times more likely to influence motorcycle slight injury than fatal injury.

As shown in Table 5, there have been the evidence of heterogeneity between the two classes of the models such as some of the parameters have the same sign across the two classes, opposite signs or the parameters are not significant. These suggest that heterogeneity exists between the two classes. Statistical methods that address unobserved heterogeneity are likely to be more complex from a model-estimation perspective. Many models that address unobserved heterogeneity are not often nested, therefore direct conventional statistical comparison between models is often not possible. For example, latent class approaches cannot be directly compared with a conventional method such as a likelihood ratio test. This often presents the analyst with difficult decisions that weigh model complexity and associated computational issues against the potential improvements in statistical fit [4].

Having computed the log of the odds for each class and each level of injury (fatal injury/FI, serious injury/SI and slight injury/SLI) shown in Table 5, the log of the odds is converted to a probability number with the following formulas [8, 15].

$$P(FI) = \frac{1}{e^{SI}+e^{SLI}+1}; P(SI) = \frac{e^{SI}}{e^{SI}+e^{SLI}+1}; P(SLI) = \frac{e^{SLI}}{e^{SI}+e^{SLI}+1};$$

Where: $e^{FI} = e^{0} = 1$.

The probabilities of motorcycle accident injuries are shown in Table 6. For example, motorcycle collided with vehicles so other variables are being held constant, giving that SI = 0.986*AccidentWithVehicles = 0.986*1 = 0.986. The percentage change (probability) of each injury will give P(serious injury) = 57.27%, P(fatal injury) = 21.37% and P(slight injury) = 21.37%. The probability of each injury based on the significant variables is summarised in Table 6.

4. Discussion

The probability of a fatal motorcycle injury is significantly associated with the motorcycle accidents involving male motorists at fault and head on collisions. In relation to the motorcyclist characteristics, male motorcyclists involved in a motorcycle accident along the road network of Denpasar-Gilimanuk and Denpasar-Singaraja were more likely to be more fatal injured compared to female motorcyclists. This result might be a reflection of the difference in riding style, experiences, risk perceptions, physical strength and behaviour between male and female motorcyclists [7]. Previous studies also showed that head on collision result in fatal motorcycle accident injuries [21-22]. A past study demonstrated that head on collisions between light vehicles and motorcycles with both vehicles traveling at 60 km/h (a relative speed at 120 km/h), resulting 55% risk of at least serious injury to the motorcyclists [22].

Motorcyclists younger than 25 years old were less likely to be fatal and serious injured in motorcycle accident compared to older motorcyclists, which is in line with past studies [6, 21]. This result, however, needs to be further investigated and compared to other national road networks in Bali as demographic information on motorcyclists shows a considerable increase in younger motorcyclists in recent years [12].

The probability of a serious motorcycle injury is significantly associated with the accidents involving motor vehicles, time of accident (day time), male motorists at fault, right angle collisions and head on collissions as the cause of accident respectively along the road network of Denpasar-Gilimanuk and Denpasar-Singaraja. Collisions among motorcycle, heavy and light vehicles significantly influenced serious motorcycle accident injuries. This might be of mixed traffic conditions in which motorcycle, heavy and light vehicles share the roadways together. Segregating motorcycle from other modes on this national road network such as providing special lane on the left side of the road may reduce this kind of accidents.

Previous studies have also outlined that segregating motorcycles from other traffic reduces the accident exposure and improves the safety of motorcyclists [23-25]. Motorcycle lanes are imperative in urban cities to bring down the effect of motorisation and mixed traffic. As the results, the lessened number of road traffic accident will cause road traffic safety achievement and is according to sustainable urban concept. While motorcycle lane is capable of reduce the number and severity of motorcycle-involved accidents, different levels of government agencies can implement other "push" and "pull" policy instruments to promote and encourage the use of public transport systems

In addition, collisions between motorcycle and the other types of motor vehicles may be indicated with various significant unobserved variables such as speeding, driving/riding with dangerous over-taking, riding without helmets and disrespecting the right of way [26]. In relation to these unobserved variables, associated and sustained road traffic safety education, therefore, need to be more implemented to take a part in rising people's awareness on road safety [27] particularly in Bali. According to the WHO, the Indonesian law enforcement performances scores (1 to 10 scoring system) for speed limit law, drink-driving law, motorcycle helmet law and seat-belt law are 8, 9, 9 and 8, respectively [17]. This indicated the excellent national law safety enforcement performances in Indonesia. Child restraint law however, has never been legally enforced.

Table 6 also demonstrates that right angle collisions were significant contributing factors to serious motorcycle accident injuries along the road network of Denpasar-Gilimanuk and Denpasar-Singaraja which having considerable numbers of both signalised and unsignalised junctions. This is in line with a past study conducted in Cambodia [26] which also found right angle collisions were contributing factor on motorcycle dominated-traffic accidents. Right angle collision occurred when vehicles arrive on perpendicular roads and collide. There are two main types of right-angle collisions – one where entering traffic has stopped, and one where entering traffic disregards a stop or signal for instance, motor vehicles pulled into main road traffic without looking.

Right angle collisions however, can be used as a proxy for these unobserved variables of geometric, traffic, and situational variables in which analysts do not observe and often cannot be measured. Right angle might indicate various significant variables on motorcycle accident injuries such as lane position, junction type, entry/exit points at the roadways, wet surface, presence of passenger, and maneuver of vehicles [27]. Therefore, the effect of right-angle collisions on injury severities may vary among individual motorists.

In order to reduce right-angle collisions, putting a Red Light Camera (RLC) at signalised junction the relative accident vulnerability (RCV) or accident-involved exposure of motorcycles at collisions is reduced [27]. In addition, reducing right-angle collisions at signalised junction may be conducted by utilising speed cameras at junctions (similar to RLC but captures speed violations during the green phase), installing dynamic signal warning flashers, removing unwarranted signal and increasing all red clearance' interval. Further, potential countermeasures for reducing right angle collisions at unsignalised junction may be conducted by constructing roundabout and acceleration lanes, clearing sight triangles, posting appropriate speed limit, eliminating skew and targeted enforcement [27].

Younger motorcyclists aged in between 16-25 years old significantly contributed to slight motorcycle accident injuries. This is relevant to a past study result that around half of road users involved in road accidents were young drivers. In addition, about 70 percent of motorcycle accidents were caused by young motorcyclists [26]. On the other hand, this indicated that younger motorists/motorcyclists are less likely to be fatal or seriously injured due to the faster reaction time and higher sensory and perceptual ability, as well as to the higher physical resiliency to motorcycle accidents compared to older motorists/motorcyclists [6]. In addition, motorcycle accidents caused by other factors significantly influenced slight motorcycle injuries by more than 15 times. These other factors may include variables of human behaviours, motor vehicle conditions, road and environment situations which specifically were not included in this study.

5. Conclusions

This study aims at investigating the contributing factors and their influences of fatal, serious and slight motorcycle accident injuries using a latent class approach. The case study is on Indonesian national road networks located in Tabanan Regency, Bali. This study found that the probability of a fatal motorcycle injury is significantly associated and increased when the motorcycle accidents involving male and older motorists, head on collisions and motorcycle at fault. Motorcycle accidents involving collisions between motorcycle and the other types of motor vehicles, time of accident (day time), motorcyclists younger than 25 years old, traffic violations and others as the cause of accident and right angle collisions are significantly associated and increased with the probability of a serious motorcycle injury.

Right angle collisions however, might indicate various significant variables on motorcycle accident injuries such as lane position, junction type, entry/exit points at the roadways, wet surface, presence of passenger, and maneuver of vehicles. Therefore, the effect of right-angle collisions on injury severities may vary among individual motorists.

Younger motorists/motorcyclists are less likely to get involved in fatal or seriously injured may be due to their faster reaction time and higher sensory and perceptual ability, as well as to the higher physical resiliency to motorcycle accidents compared to older motorists/motorcyclists. Further investigation is required to analyse the influence of age on fatal motorcycle accident injuries.

A further study is therefore needed to investigate and compare the contributing factors and their influence on motorcycle accident injury outcomes on the other national road networks in Bali. This is important to consider demographic information on motorcyclists shows a dramatic increase in younger motorcyclists in recent years.

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