REPORT OF RESEARCH RESULTS

(a) Title: The interdependent relationship between at-fault and non-at-fault status and motorcycle-involve crash severities.

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(c) Summary

This study investigates the interdependent relationship between fault-status and injury severity among motorcycle riders involved in rear-end crashes in Thailand. This research employs a bivariate probit model and an XGBoost model for simultaneous estimation of injury severity and at-fault status. Integrated data from the Department of Highway's Accident Information Management System and the Traffic Information Movement System provide a sample of 1,549 crashes from 2011 to 2015. The bivariate probit model results reveal significant factors influencing injury severity, including rider age, gender, road characteristics, rider behavior, and traffic conditions. Riders younger than 55 years old, female riders, and those on roads with depressed medians or higher traffic volume are less likely to suffer severe injuries. Conversely, drunk riding, nighttime crashes on unlit roads, and a higher percentage of trucks increase the risk of severe injuries. The XGBoost model confirms these findings, with traffic volume, the percentage of trucks, and nighttime crashes on unlit roads being the most influential predictors of injury severity. For at-fault status, younger riders and those using safety equipment are more likely to be at-fault. This novel approach adds valuable insights for policymakers and researchers in motorcycle safety.

(d) Aim of Research

The research aims to address the gap in understanding the interdependent relationship between motorcycle riders' at-fault status and injury severity in rear-end crashes in Thailand. It seeks to identify the key factors influencing both outcomes and to account for potential endogeneity between them. The study compares the performance of a bivariate model, which simultaneously estimates the effects of various factors on both injury severity and at-fault status, and the XGBoost model, a machine learning approach that captures non-linear relationships and interactions among variables for enhanced predictive accuracy. The objective is to provide a comprehensive analysis of the factors influencing motorcycle crash severity and to improve safety interventions.

(e) Method of Research & Progression

Data collection: The data for this study is compiled from three sources, focusing on motorcycle riders involved in rear-end crashes on Thai highways between 2011 and 2015. The primary dataset comes from the Department of Highway Accident Information Management System (HAIMS) and includes detailed accident information such as location, road characteristics, environmental factors, and driver attributes, recorded by highway district officials. The dataset was rigorously screened to include only rear-end accidents with complete information, resulting in 4,554 cases. Further filtering yielded a final sample of 1,549 motorcycle riders. To determine fault status, crash diagrams were used to identify motorcycle riders as either "at-fault" or "not-at-fault" based on their sequence in the crash (sequence 2 for at-fault, sequence 1 for not-at-fault). The dataset consists of 43 categorical variables and 2 numerical variables, with 1,549 motorcycle riders. Among them, 37.5% (581 riders) suffered serious injuries or fatalities, while the rest experienced property damage only (PDO) or minor injuries. The analysis indicates that 914 riders were at fault, with 299 involved in serious or fatal crashes, while 635

were not at fault, with 282 of them still experiencing severe outcomes. The data highlights the significant impact of fault status on injury severity in rear-end motorcycle crashes.

Methods: To achieve the research objective, this study employed a Bivariate Random Parameter Probit model to simultaneously analyze the factors influencing motorcycle crash injury severity and those associated with the fault status of the motorcyclists. Additionally, two separate XGBoost models were trained for each outcome and interpreted using SHAP to compare with the Bivariate model. These approaches aim to determine if a significant correlation exists between crash injury severity and the fault status of the motorcyclists.

(f) Results of Research

Table 1 presents the results from the bivariate random parameters probit model, while Figure 1 shows the results from the XGBoost models. Both methods demonstrate consistent findings; however, the bivariate model exhibits slightly superior performance compared to the XGBoost model.

Table 1. Result of Bivariate Model.

Variable	**Injury severity component**			**At-fault status component**		
	Coefficient	Standard Error	p-Value	Coefficient	Standard Error	p-Value
Constant	1.071	0.446	0.016	-0.608	0.299	0.042
Age_26	-0.299	0.150	0.046	1.738	0.155	0.000
Age_26_35	-0.361	0.160	0.024	1.017	0.158	0.000
Age_36_45	-0.289	0.163	0.076	0.400	0.161	0.013
Age_46_55	–	–	–	-0.457	0.185	0.014
Gender	-0.131	0.077	0.088	–	–	–
Safety_equip	–	–	–	0.155	0.078	0.047
Reg_Sec_highway	-0.332	0.139	0.017	–	–	–
Intra_Province_highway	-0.467	0.155	0.003	–	–	–
Main_Road	-0.312	0.157	0.047	–	–	–
Paralell_Road	-0.445	0.245	0.070	–	–	–
Two_lane	0.439	0.170	0.010	–	–	–
Four_lane	0.417	0.134	0.002	–	–	–
Depressed_median	-0.421	0.177	0.017	–	–	–
Slope	0.439	0.231	0.057	–	–	–
Median_opening	0.230	0.128	0.072	–	–	–
Drunk	0.408	0.201	0.042	–	–	–
Night_unlit	0.488	0.115	0.000	–	–	–
lnAADT	-0.071	0.034	0.040	–	–	–
Truck_percent	0.009	0.004	0.016	–	–	–
Disturbance correlation ρ	0.169	0.047	0.0004			
Model fit statistic						
AIC (independent model)	2037.8 (injury component) + 1582.2 (at-fault component) = 3620					
AIC (interdependent model)	3609.4					

The disturbance correlation (coefficient: 0.169, p-value: 0.0004) is positive and statistically significant, indicating the presence of common unobserved factors that simultaneously influence both injury severity and at-fault status. This finding highlights the importance of employing a bivariate probit model to account for the interdependence between the two outcomes.

Age: Younger riders (<26, 26-35, and 36-45 years) show lower injury severity than those aged 46-55, likely due to better physical resilience, quicker reactions, and recent safety training. However, younger riders are more often at fault due to inexperience, risk-taking, and distractions (e.g., mobile phone use).

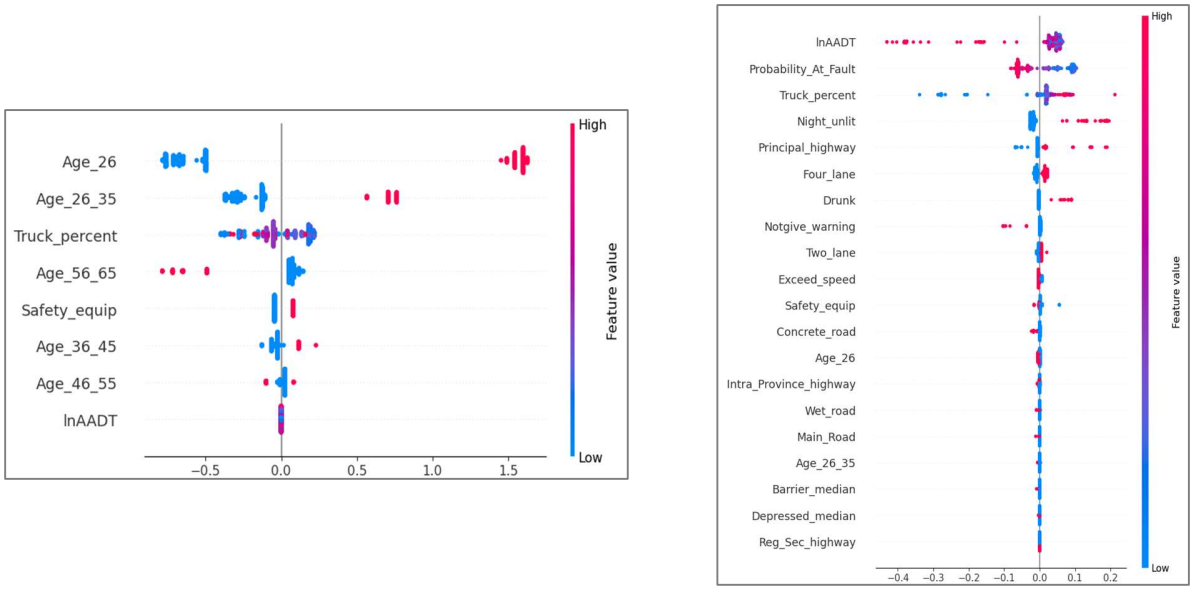
Gender: Female riders have a lower injury severity effect than males, possibly due to smaller body sizes and more cautious riding behavior. Females may also prefer lighter motorcycles, reducing crash impact.

Safety Equipment: Safety gear use is associated with being at fault but shows a slight negative effect on injury severity, likely due to risk compensation. Despite riskier behavior, the protective benefits of helmets and gear slightly outweigh the risks.

Road Characteristics: Urban roads (secondary highways, intra-province highways) reduce injury severity, while two-lane, four-lane, and slope roads increase severity due to limited sight distances and sudden stops. Depressed medians lower injury severity by providing a safer roadside environment compared to barrier or raised medians.

Rider Behavior: Drunk riding and nighttime crashes on unlit roads significantly increase injury severity. Alcohol impairs judgment and coordination, while poor visibility on unlit roads delays hazard perception and emergency response.

Traffic Characteristics: Higher traffic volume (lnAADT) slightly reduces injury severity as riders are more alert and travel speeds are lower in congested conditions. Conversely, a higher truck percentage increases severity due to trucks' longer stopping distances and greater impact force in collisions.



(a) (b)

Figure 1. (a) SHAP result for fault-status component and (b) SHAP result for injury severity component.

(g) Future Areas to Take Note of, and Going Forward

Based on the findings of this study, several practical policy recommendations can be made to enhance motorcycle safety in Thailand, particularly concerning rear-end crashes. First, it is crucial to implement targeted training programs for younger riders that emphasize hazard perception, defensive riding, and risk management. Since younger riders are more likely to be at fault due to inexperience and risk-taking behaviors, these programs could reduce their involvement in crashes. Another key recommendation is the installation of better lighting on rural and unlit roads, as nighttime crashes on unlit roads significantly increase injury severity. Improving road lighting would enhance visibility and reduce the likelihood of severe crashes. Additionally, while promoting the use of safety gear among motorcyclists, there is a need to educate riders about risk compensation, as the false sense of security provided by safety equipment can lead to riskier behaviors, increasing the likelihood of being at fault in crashes. Stricter enforcement of drunk riding laws, particularly during nighttime and in rural areas, would also help mitigate the risk of severe injuries caused by impaired judgment. Public awareness campaigns should also focus on the dangers of riding near trucks, as the study highlights that a higher percentage of trucks on the road increases injury severity in motorcycle crashes due to the size and weight disparity.

Although most riders involved in these crashes are licensed, this may reflect poor or non-existent training and substandard licensing practices, common in LMICs like Thailand. Thus, while educational campaigns and training programs for young riders are often proposed, these efforts in isolation are unlikely to be sufficient to substantially reduce at-fault crashes. Broader policy reforms are needed for more impactful results. Stricter licensing requirements and raising the minimum riding age would likely have a greater impact. One particularly effective measure is the implementation of Western-style Graduated Licensing Schemes (GLS), which have been shown to reduce crash rates among novice riders. GLS gradually builds riding experience through supervised stages and could significantly reduce at-fault crashes by incorporating restrictions, such as limiting nighttime riding for young, inexperienced riders. Reducing exposure to high-risk conditions, such reforms could help curb nighttime crash rates and improve young rider safety.

(h) Means of Official Announcement of Research Results

This research paper has passed the editor screening and is currently "Under Review" in the International Journal of Injury Control and Safety Promotion (Web of Science and Scopus Q1).