scientific reports

Check for updates

OPEN

A study of motorcycle riders related to speeding behavior in Thailand's Industrial zones

Manlika Seefong[1], Panuwat Wisutwattanasak[2], Chamroeun Se[2], Kestsirin Theerathitichaipa[1], Sajjakaj Jomnonkwao[1], Thanapong Champahom[3], Vatanavongs Ratanavaraha[1] & Rattanaporn Kasemsri[4]✉

Despite the considerable efforts to address traffic crashes, overspeeding in industrial zones remains a primary cause in Thailand. In order to effectively against this challenge (overspeeding), the deep-rooted factors influencing speeding behaviors, particularly drivers' risky behaviors, must be understood. Thus, this study employs the theory of planned behavior (TPB) and the framework comprising three basic Es (Education, Engineering, and Enforcement) and additional Es (Emergency response), i.e., the 3Es + Es framework, to examine these deep-rooted factors while considering the riders' sociodemographic data. Additionally, we performed structural equation modeling to investigate the factors influencing speeding behaviors, with key findings revealing that Engineering factors significantly account for overspeeding. Conversely, we revealed that attitude, subjective norm, and perceived behavioral control (which are essential TPB components) significantly influence riders' intentions to exhibit safe behavior, resulting in reduced speeding. Additionally, our examination of latent factors based on riders' sociodemographic data revealed that age, marital status, income, riding experience, crash history, and traffic tickets are significant factors that determine speeding habits. Specifically, we observed that single riders and those with less than five years of riding experience were less likely to exhibit safe riding behaviors. Overall, our findings would benefit Thailand's road-safety authorities, as we specifically proposed appropriate policies and empirical guidelines for Thailand's industrial zones, which are prone to high crash rates. This could effectively reduce speeding among motorcycle riders and mitigate traffic crashes.

Keywords Structural equation modeling, Theory of planned behavior, 3Es + Es, Speeding behavior, Motorcycle rider

Injuries and fatalities due to overspeeding represent significant traffic hazards globally. It is concerning that approximately 50% of severe traffic crashes are attributable to overspeeding[1]. Similar to many countries, Thailand is also plagued by severe traffic challenges. The latest report of the World Health Organization (WHO) in 2023 revealed that Thailand has a road-accident-death rate of approximately 25.4 per 100,000 population[2]. Although the situation has improved slightly, Thailand still falls far short of its road-accident–fatality-reduction targets and may still be a leading Asian country in terms of traffic crashes[3]. Moreover, owing to Thailand's deeply worrying statistics, WHO has ranked the country as number 1 globally for motorcycle-related road-accident-attributable deaths, with an estimated rate of 24.3 per 100,000 population in 2018[2]. This poses a significant concern for road-safety agencies striving to mitigate traffic crashes.

The overall statistic (22.11%) encompasses the injury and fatality rates among road users in Thailand's industrial zones[4]. Emphasizing statistical disclosure underscores the prevalence of traffic crashes as well as the driving risks in these zones, characterized by complex driving conditions in dense traffic, which favor speeding and significantly increase crashes[5]. It is well-established that vehicle speed directly influences the risk of rear-end collisions with other vehicles[6], as high speeds preceding crashes could escalate the likelihood of crash[6]and injury severities as well as fatality rates[2,7]. These facts pose significant concerns, particularly for motorcycle riders, who

[1]School of Transportation Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. [2]Institute of Research and Development, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. [3]Department of Management, Faculty of Business Administration, Rajamangala University of Technology Isan, Nakhon Ratchasima 30000, Thailand. [4]School of Civil Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. ✉email: kasemsri@sut.ac.th

are among the primary casualties in industrial-zone traffic crashes[8]. In turn, these concerns warrant detailed scrutiny to uncover the deep-seated truths about the factors influencing speeding behaviors, particularly risky-riding behaviors, to effectively proffer control and prevention methods for mitigating the traffic crashes.

Several studies have revealed that human driving behavior is primarily a significant factor that contributes to traffic crashes[9]. Fundamentally, aberrant driving behaviors refer to risky behaviors that do not intentionally harm the driver or other drivers[10]. However, negligence and disregard for safety result in risky behaviors that may endanger drivers, passengers, pedestrians, and other road users[11]. Although most accidents stem from unsafe behaviors, they can be addressed and prevented[12,13]. Thus, we acknowledge that a comprehensive review and understanding of data on factors influencing speeding behaviors is one strategy for mitigating traffic crashes. Moreover, the selection of an appropriate model for accurately predicting driving/riding behavior is crucial, and one such model is the theory of planned behavior (TPB). TPB is a widely deployed psychological model for examining behavioral beliefs and intentions based on attitudes (positive/negative-behavior assessment), subjective norms (perceived social pressure regarding behavior), and perceived behavioral control (perception of ease/difficulty in controlling behavior) in each component. The model leverages these parameters to comprehensively study human behavior based on the consequences of such behavior[14].

Notably, there is currently a collaborative learning effort to address long-term safety concerns. The development of a framework that emphasizes collective responsibility toward road safety and traffic-crash mitigation has resulted in the discard of the conventional approach, which emphasizes holding individuals responsible for traffic crashes. The new framework proposes that everyone in society is responsible for the safety system and traffic-crash mitigation in such a society[15]. This safety-concept framework comprises the three basic Es (Education, Engineering, and Enforcement) and additional Es (Emergency response), known as 3Es + Es. However, the framework has neither been explored nor thoroughly examined. Particularly, the studies on the behaviors of motorcycle riders have mainly explored TPB[16]and socio-demographic factors[7] to clarify the research gaps. To resolve this limitation, this study was aimed at investigating the synergistic effect of the conventional model (TPB) and the new frameworks (3Es + Es) as well as exploring the socio-demographic data of motorcycle riders to underscore the criticality of elucidating the factors influencing motorcycle riders' speed behavior in attempting to mitigate traffic crashes.

Therefore, to ensure that crucial deep insights and discoveries are not neglected, we investigated factors influencing motorcycle riders' speeding behaviors in areas with high accident rates in Thailand, e.g., the industrial zones, using the three key models: (1) the 3Es + Es safety framework, (2) the TPB model, and (3) socio-demographic data. Additionally, employing a statistically robust structural equation modeling (SEM) approach for accurate prediction, we gathered valuable and useful deep data for road-safety organizations. Our effort will facilitate policy-making as well as the establishment of appropriate standards for the effective mitigation of traffic crashes.

Literature review

Table 1 presents a review of the extant studies (spanning 2005–2023) on the factors influencing speeding behaviors. Thus, 27 studies were reviewed; these studies predominantly examined these factors using data obtained from general drivers. The data were obtained through questionnaire surveys based on various conceptual frameworks. These frameworks included the following: TPB, socio-demographic, PRECEDE, driver behavior questionnaire (DBQ), IF-THEN, Homel's, norm-activation model (NAM), social learning theory (SLT), and prototype/willingness model (PWM), as well as social, cultural, road environment, attitude, personality traits, and risky-driving behaviors. The review revealed that the TPB framework is the most frequently used owing to its accuracy, as a psychological model, to effectively predict behavior. However, no study has examined the synergistic effect of the TPB and 3Es + Es frameworks on investigating the factors influencing speeding behaviors while also incorporating the sociodemographic data. As most studies mainly integrated the road-safety concept of the 3Es framework with the evaluation of road policies to examine similar standards across countries, this approach facilitates the gathering and refinement of effective road-safety programs[15,17–20]. Over the past decade, various methodologies, including exploratory factor analysis (EFA), regression analysis, hierarchical multiple regression analysis, hierarchical regression analysis, linear network autocorrelation models (LNAM), principal component analysis (PCA), descriptive and inferential statistics, SEM, analysis of variance (ANOVA), ordered probit model, multiple regression analysis, and binary logistic regression, have been employed. Among them, SEM has attracted the most attention owing to its advantages, such as its capability of simultaneously assessing various types of relationships between variables and rigorously examining and comparing similarities and differences between two or more groups[21].

Notably, only five accessible studies have specifically reviewed the studies on motorcycle riders' behaviors in Southeast Asia. The extant studies mainly examined riders' behaviors using TPB, PRECEDE, and Homel's models as well as other factors, such as attitude, behavior, road characteristics, motorcycle characteristics, speed, throttle, brake usage, distance, riding experience, and age. These studies applied statistical models, such as SEM, logistic regression, binary logistic regression, LNAM, and hierarchical multiple regression to analyze these factors, effectively predicting motorcycle-riding behaviors across various parameters[16,22–24]. However, these studies did not comprehensively capture the basic road-safety concept of the 3Es + Es framework, and this oversight might have resulted in the negligence of certain key insights.

Regarding the existing research gap, Table 1 reveals that the extant studies on the factors influencing speeding behavior mostly surveyed general drivers using the TPB framework as their primary survey method, with SEM being the most popular technique. However, no study has examined the factors influencing motorcycle riders' speeding behaviors by analyzing the interaction between the TPB and 3Es + Es frameworks using SEM statistical methods. Based on the foregoing, this study is among the first to consider the interaction between the TPB theoretical framework and 3Es + Es in investigating the factors affecting motorcycle riders' speeding behaviors.

Paper	Country	Year	Factor					Method
			Target group	TPB	Sociodemography	3Es + Es	Others	
Elliott et al.[25]	England	2005	General Drivers	•				Hierarchical multiple regression analysis
Warner & Åberg[26]	Sweden	2006	General Drivers	•				SEM
Mehmood[27]	United Arab Emirates	2009	General Drivers	•				Multiple regression analysis
Forward[28]	Sweden	2010	General Drivers	•				Hierarchical regression analysis
Cestac et al.[29]	France	2011	Yung Drivers	•	•			Hierarchical regression analysis
SUKOR et al.[23]	Malaysia	2011	Motorcycle Riders	•				SEM
Chorlton et al.[30]	United Kingdom	2012	Motorcycle Riders	•				Regression analysis
Cristea et al.[31]	France	2013	General Drivers	•	•			Hierarchical regression analysis
Dinh et al.[32]	Japan	2013	General Drivers	•	•			Hierarchical regression analysis
Scott-Parker et al.[33]	Australia	2013	Young Drivers				SLT and PWM	Hierarchical multiple regressions
Choon et al.[24]	Malaysia	2014	Motorcycle Riders				Speed, Throttle, Brake, Weekly Travel Mileage, Distance, Riding Experience, and Age	SEM
Chumpawadee et al.[34]	Thailand	2015	Young Motorcycle Riders	•			PRECEDE Model	Descriptive and inferential statistics
Brewster et al.[35]	Scotland	2015	General Drivers	•			IF-THEN	ANOVAs
Rowe et al.[36]	United Kingdom	2016	Motorcycle Riders	•				EFA
Atombo et al.[37]	Ghana	2016	General Drivers	•			DBQ	Regression analysis
Jovanović et al.[38]	United States	2017	Motorcycle Riders	•				PCA
Manan et al.[22]	Malaysia	2017	Motorcycle Riders				Road Characteristics, Motorcyclist Riding Behavior, Motorcycle Characteristics, and Motorcyclist Characteristics	Logistic regression
Javid et al.[39]	Oman	2019	General Drivers		•		NAM	SEM
Mohamad et al.[40]	Malaysia	2019	General Drivers	•			Attitude	Binary logistic regression
Hong et al.[7]	Thailand	2020	Motorcycle Riders		•			LNAM
Javid & Al-Hashimi[41]	Oman	2020	General Drivers	•				SEM
Javid et al.[42]	Pakistan	2021	General Drivers				NAM, Social, Cultural, and Road Environment	EFA and SEM
Muntafi[16]	Indonesia	2022	Young Motorcycle Riders	•				Hierarchical multiple regression analysis
Qaid et al.[6]	Indonesia	2022	General Drivers	•			Homel's Model	SEM
Javid et al.[43]	Pakistan	2022	General Drivers		•			Ordered probit model
Tanglai et al.[44]	Thailand	2022	Van Drivers		•		Personality Traits, Attitude Toward Traffic Safety, and Risky-Driving Behaviors	Hierarchical regression analysis
Alizadeh et al.[45]	Iran	2023	General Drivers	•				SEM

Table 1. Reviewing studies on factors influencing speeding behavior from previous studies. Note:factors considered; TPB, theory of planned behavior; EFA, exploratory factor analysis: LNAM, linear network autocorrelation models; PCA, principal component analysis; DBQ, driver behavior questionnaire; SEM, structural equation modeling, SLT, social learning theory; PWM, prototype/willingness model; NAM, norm-activated model.

Based on the literature review, we explored the factors influencing speeding behavior using the TPB (attitude, subjective norm, and perceived behavioral control) and 3Es + Es frameworks (education, engineering, enforcement, and emergency response). Additionally, we examined latent factors based on demographic data. Our findings will enhance the understanding of key in-depth factors influencing speeding behavior and provide valuable information and measures for policymakers aiming to effectively and contextually reduce speed-related traffic crashes. To achieve our goals, we proposed the following hypotheses for the TPB framework:

• **hypothesis 1** • (H1): Positive safety attitudes increase the intention of practicing safe behaviors, facilitating reduced-speeding behaviors.

• **hypothesis 2** • (H2): Reference groups exhibiting safe riding behavior increase the intention of practicing safe-riding behaviors, facilitating reduced-speeding behavior.

- **hypothesis 3** • (H3): Low perceived behavioral control over risky behaviors increases the intention of practicing safe-riding behaviors, facilitating reduced-speeding behavior.

Similarly, we proposed the following hypotheses for the 3Es + Es framework:

- **hypothesis 4** • (H4): Education results in reduced-speeding behavior.
- **hypothesis 5** • (H5): Safe road design (Engineering) facilitates reduced-speeding behavior.
- **hypothesis 6** • (H6): Law enforcement leads to a reduction in speeding behavior.
- **hypothesis 7** • (H7): Effective emergency response facilitates reduced-speeding behavior.

Methods
Questionnaire structure
The survey questionnaire comprised three sections. The first section examines the social and demographic information of the respondents, such as their gender, age, marital status, education level, income, occupation, riding experience, crash history, and traffic tickets. These pieces of information effectively highlight the individual differences among the respondents. The second section assesses the respondents' behavioral beliefs and intentions based on TPB comprising attitudes, subjective norms, and perceived behavioral control as well as the 3Es + Es framework comprising education, engineering, enforcement, and emergency response. The questions in this section were evaluated on a seven-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = neutral, 5 = somewhat agree, 6 = agree, 7 = strongly agree). The final section evaluates the respondents' speeding behaviors. The questions were evaluated on a six-point Likert scale (1 = never, 2 = almost never, 3 = sometimes, 4 = fairly often, 5 = often, 6 = always). This section can effectively explain the individual differences among the speeding experiences of the riders.

Respondents
In this study, we interviewed motorcycle riders with riding experience around industrial zones in Thailand. The target participants were aged 18–60 years, as riders within this age range are characterized by enhanced physical capabilities, cognitive skills, perception, motor coordination, and readiness to respond to various situations[46,47]. Further, 2,000 samples were obtained, corresponding to the guideline of using more than five times the number of variables in the model, as reported in the literature[48,49]. To ensure the reliability and accuracy of SEM and the results, respectively, we used a sample size that was 40 times the number of variables in the model, which included 48 variables. Therefore, the utilized sample size was 1,920 samples, with a reserve of 80 samples to account for potential loss. During the survey, 2,000 participants cooperated and responded to all the questions. This number of participants was employed to ensure that the sample represented the motorcycle riders' population as accurately as possible. Notably, we used the data from all the 2,000 participants for the model analysis. During the survey, we explained the objectives and fundamental concepts to the participants to ensure they completely understood the details of the study and provided accurate and complete information. Significant ethical considerations were submitted and approved by the Ethics Committee of Suranaree University of Technology, Thailand. The committee considered the survey and deemed it low risk, as the data do not pose greater risks to the participants than what they face in their daily lives. Moreover, the questions did not include personal or identifiable information, thus canceling out the possibility of subjecting the participants to physical or psychological stress. Additionally, Our field data collectors invited participants to join the project through verbal invitations and provided them with information sheets. All participants were fully informed about the study and provided their consent by signing the informed consent form. (COE No.5/2567; January 30, 2024).

Data analysis
The analyses of the social and demographic data of the respondents are presented in Supplementary Table S1 online, alongside the analyses of the dependent and independent variables, which are displayed as descriptive information. The survey recorded a complete response rate; the data from the 2,000 respondents were available for analysis, as detailed in Supplementary Tables S2 and S3 online. In this study, EFA was used to evaluate the district variables to identify or categorize variables with similar relationships and accurately determine the components that explain the main factors. The analysis included verifying the Kaiser–Meyer–Olkin (KMO) measure of the sampling adequacy and the ability of the components to explain variance. Additionally, confirmatory factor analysis was used to verify the quality of the latent-construct measurement. The analysis involved examining the composite reliability (CR) as well as the average variance extracted (AVE) before analyzing the factors influencing speeding behaviors by SEM. The model-fit was tested using the following statistics: X^2/df, ratio of the chi-square to degrees of freedom; CFI, comparative fit index; TLI, Tucker–Lewis index; RMSEA, root mean square error of approximation; and SRMR, standardized root mean square residual. The statistics were calculated to ensure accurate results and reliable conclusions[50]. All the analyses were conducted using the statistical software, Mplus version 7.0.

Results
Exploratory factor analysis of district variables
We performed EFA of the 3Es + Es framework and TPB models to reduce the latent factors and consolidate them into main factors reflecting different components. Supplementary Table S4 online presents the results of EFA of

the TPB model comprising 14 items. The KMO-test value was 0.805, explaining up to 79.494% of the variance. These factors were classified into four groups: (1) Attitude (SA1–SA3), (2) Subjective Norm (SS4–SS6), (3) Perceived Behavioral Control (SP7–SP11), and (4) Intention (SB12–SB14). Regarding the 3Es + Es framework also comprising 14 items, with a KMO-test value of 0.899, explaining up to 79.968% of the variance, these factors generated Cronbach's alpha values of 0.733–0.944. These factors were classified into four groups: (1) Education (SE15–SE17), (2) Engineering (SG18–SG21), (3) Enforcement (SF22–SF24), and.

(4) Emergency response (SM25–SM28). These factors generated Cronbach's alpha values of 0.863–0.921. All the statistics fell within acceptable ranges, as per the literature[51–53].

Confirmatory factor analysis

In this section, the importance of each item was examined and explained to confirm the possibility of using the indicators as components in each factor (Supplementary Table S5 online). All the loading values exceeded 0.05, with each item being statistically significant at a 99% confidence level, thus indicating that the model achieved accuracy and consistency[54]. Furthermore, all the factors exhibited composite reliability (CR) values of over 0.7, and the AVE values of all the factors exceeded 0.05, falling within an acceptable range. Studies have recommended that CR and AVE values must be ≥ 0.7 and 0.05, respectively, to ensure statistical reliability. These statistics confirmed that SEM could be used to appropriately analyze all the factors[54].

Factors in the theory of planned behavior model

The Attitude factor was measured using indicators SA1–SA3. The analyses of the three variables revealed that they were components of the Attitude Toward the Behavior factor with a p-value of < 0.000. The loading values ranged from 0.692 to 0.818. Notably, SA2 exhibited the highest loading factor regarding Attitude, indicating the following: "I believe that speeding may result in running pedestrians/animals over" ($\gamma = 0.818$, $t = 40.648$).

The Subjective Norm factor was measured using indicators SS4–SS6. The analyses of these three variables revealed that they were components of the Subjective Norm factor with a p-value < 0.000. The loading values ranged from 0.637 to 0.746. Notably, SS6 exhibited the highest Subjective Norm loading factor, indicating the following: "The people around me advise me not to drive faster than the legal speed limit" ($\gamma = 0.746$, $t = 59.780$).

The Perceived Behavioral Control factor was measured using indicators SP7–SP11. The analyses of these five variables revealed that they were components of the Perceived Behavioral Control with a p-value of < 0.000. The loading values ranged from 0.729 to 0.949. Notably, SP9 displayed the highest loading factor regarding Perceived Behavioral Control, indicating the following: "I can drive faster than the legal speed limit even under unfavorable weather conditions, such as rain, fog, or heat" ($\gamma = 0.949$, $t = 175.501$).

Behavioral Intentions were measured using indicators SB12–SB14. The analyses of these five variables revealed that they were components of Behavioral Intentions with a p-value of < 0.000. The loading values ranged from 0.708 to 0.887. Notably, SB14 exhibited the highest Behavioral Intentions loading factor, indicating the following: "I will advise my family and those around me to not exceed the legal speed limit" ($\gamma = 0.887$, $t = 63.603$).

3Es + Es factor

The Education factor was measured using indicators SE15–SE16. The analyses of the three variables revealed that they were components of the Education factor with a p-value of < 0.000. Their loading values ranged from 0.649 to 0.889. Notably, SE17 exhibited the highest Education loading factor, indicating the following: "I believe that raising awareness in the community about the risks of speeding would help reduce speeding" ($\gamma = 0.889$, $t = 83.571$).

The Engineering factor was measured using indicators SG18–SG21. The analyses of the four variables revealed that they were components of the Engineering factor with a p-value of < 0.000. The loading values ranged from 0.596 to 0.904. Notably, SG19 exhibited the highest Engineering loading factor, indicating the following: "I believe that installing warning and speed-limit signs would help reduce speeding" ($\gamma = 0.904$, $t = 99.351$).

The Enforcement factor was measured using indicators SF22–SF24. The analyses of the three variables revealed that they were components of the Enforcement factor with a p-value of < 0.000. Their loading values ranged from 0.822 to 0.883. Notably, SF23 exhibited the highest Enforcement loading factor, indicating the following: "I believe that strict traffic discipline enforced by police would help reduce speeding" ($\gamma = 0.883$, $t = 101.909$).

The Emergency-Response factor was measured using indicators SM25–SM28. The analyses of the four variables revealed that they were components of the Emergency-Response factor with a p-value of < 0.000. Their loading values range from 0.772 to 0.869. Notably, SM26 exhibited the highest loading Emergency-Response factor, indicating the following: "I believe that quick access to crash scenes by organizations when crashes occur due to speeding would reduce injuries and fatalities" ($\gamma = 0.869$, $t = 92.213$).

Structural equation modeling

The results of the model-fit test and SEM obtained by exploratory analysis are shown in Fig. 1; Table 2. The results revealed that the model appropriately fit the data, with the following statistics: $\chi 2/df = 2.04$, $CFI = 0.964$, $TLI = 0.961$, $RMSEA = 0.027$, and $SRMR = 0.047$. A comparison of these statistics with those of previous studies revealed that they fell within acceptable ranges[51].

The parameter-estimation results of the structural model revealed the factors influencing risky-riding behaviors that result in overspeeding, as presented in Table 3; Fig. 1. We observed that both sets of components effectively clarified speeding behaviors during riding. The first set was related to the TPB factors, where the results indicated that Attitude ($\gamma = 0.28$, $t = 7.442$), Subjective Norm ($\gamma = 0.116$, $t = 4.747$), and Perceived Behavioral Control ($\gamma = -0.136$, $t = -5.618$) influenced the riders' intention to engage in safer riding behaviors,

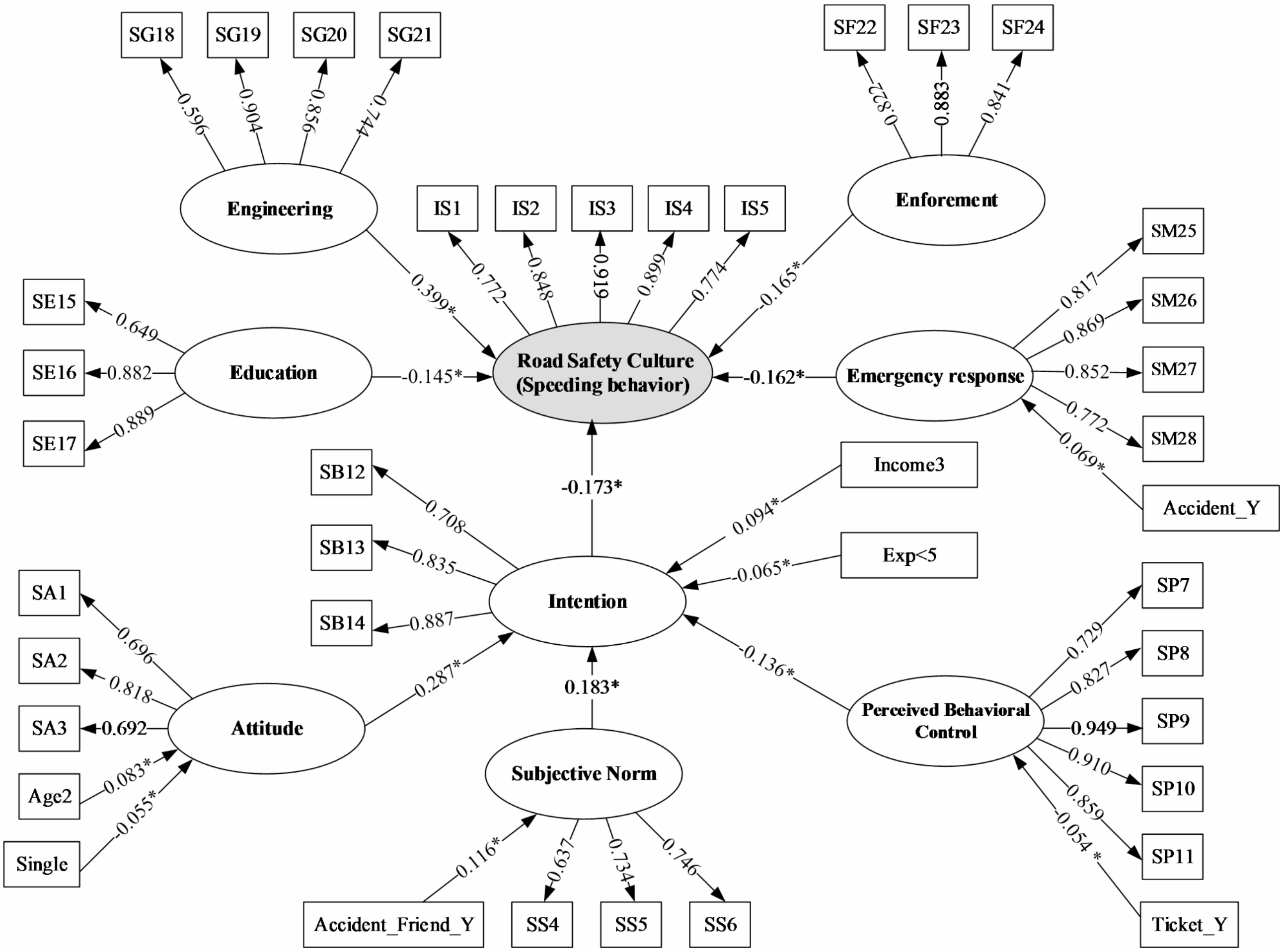

Fig. 1. Structural Model of the Factors Influencing Risky Speeding Behavior.

	X^2/df	CFI	TLI	RMSEA	SRMR
Index values	2.04	0.964	0.961	0.027	0.047
Critical values	< 3[48,55]	> 0.95[53,56]	> 0.95[57]	< 0.05 [58]	< 0.08[53,59]

Table 2. Goodness-of-fit of SEM. * X^2/df, ratio of the chi-square to the degrees of freedom; CFI, comparative fit index; TLI, Tucker–Lewis index, RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual.

resulting in a significant reduction in their speeding behaviors. The second set comprised the 3Es + Es factors, where the results indicated that Education (γ = −0.145, t = −21.385), Enforcement (γ = −0.165, t = −26.577), and Emergency Response (γ = −0.162, t = −26.158) significantly contributed to reduced-speeding behaviors. Conversely, Engineering (γ = 0.399, t = 13.647) significantly increased the riders' speeding behavior. Additionally, the deep dive resulted in the evaluation of the social and demographic factors of the riders, which acted as latent variables, The results revealed that the riders aged between 26 and 35 years exhibited increased attitude to practice safer riding behaviors (AGE2:γ = 0.083, t = 2.374). Moreover, the single riders exhibited decreased attitude toward safer riding behaviors (Single:γ = −0.055, t = −2.187), those with an income of 20,001–30,000 baht demonstrated increased intentions to engage in safer behaviors (Income:γ = 0.094, t = 3.836). The riders with less than five years of experience displayed decreased intention to engage in safer riding behaviors (Ex < 5:γ = −0.065, t = −2.775), whereas those with crash histories believed that efficient emergency-response agencies could contribute to increased safety (Accident_Y:γ = 0.069, t = 3.047). The riders whose relatives or acquaintances have crash histories believed that adhering to safe riding behavior increases safety (Accident_Firend_Y:γ = 0.116, t = 4.376). Finally, the riders who have received tickets exhibited significantly reduced risky-riding behaviors (Ticket_Y:γ = 0.116, t = 4.376). The results of the model parameter evaluation reveal several key factors that influence speeding behavior, which in turn lead to targeted interventions aimed at avoiding and reducing risky behaviors to promote a road safety culture.

Variable	Coefficient	S.E.	t–Stat	*p*-Value
TPB Factor				
Attitude ⟶ Behavioral intentions	0.287	0.039	7.442	0.000
Subjective Norm ⟶ Behavioral intentions	0.183	0.038	4.747	0.000
Perceived Behavioral Control ⟶ Behavioral intentions	−0.136	0.024	−5.618	0.000
3Es + Es Factor				
Education ⟶ Speed	−0.145	0.007	−21.385	0.000
Engineering ⟶ Speed	0.399	0.029	13.647	0.000
Enforcement ⟶ Speed	−0.165	0.006	−26.577	0.000
Emergency response ⟶ Speed	−0.162	0.006	−26.158	0.000
Behavioral intentions ⟶ Speed	−0.173	0.008	−22.311	0.000
Demography				
Age2 ⟶ Attitude	0.083	0.035	2.374	0.018
Status (Single) ⟶ Attitude	−0.055	0.025	−2.187	0.029
Income ⟶ Behavioral intentions	0.094	0.024	3.836	0.000
Experience (< 5 Y) ⟶ Behavioral intentions	−0.065	0.023	−2.775	0.006
Accident_Y ⟶ Emergency response	0.069	0.023	3.047	0.002
Accident _Firend_Y ⟶ Subjective Norm	0.116	0.026	4.376	0.000
Ticket_Y ⟶ Perceived Behavioral Control	−0.054	0.025	−2.184	0.029

Table 3. Parameter estimation for the structural model.

Discussion

Theory of planned behavior factors

A positive attitude toward safety increases riders' intentions to engage in safe riding, resulting in a decrease in riding speed and supporting H1. Several studies have indicated that attitude could significantly predict traffic-rule-violation and speeding behaviors[54,60]. Riders with a positive attitude toward safety might more likely exhibit good intentions toward safe riding behavior[10]. Conversely, riders with a negative attitude toward safety might engage in unsafe riding. These findings align with previous findings that riders with positive attitudes toward speeding tend to exhibit high-speeding behaviors[61]Concurrently, riders to engage in risky-riding behaviors are more likely to do so when others agree to and accept their behaviors[62].

Individuals who belong to reference groups with safe-riding behavior patterns are more likely to exhibit an increased intention to engage in safe-riding behaviors, resulting in decreased riding speed and supporting H2. This is consistent with the findings of previous studies, indicating that observing the safe-riding behaviors of other riders could significantly reduce the risky-riding intentions of a rider[63]. Regarding risky-riding behaviors, the attitudes and behaviors of others primarily account for riders' traffic violations[10]It is plausible that individuals who believe that most people around them would accept certain behaviors are motivated and feel the social pressure to exhibit such behaviors. Conversely, those who believe that most people around them would not accept certain behaviors lack the motivation to conform to such behaviors, thus creating a self-regulatory mechanism that steers them away from those behaviors[64]. Furthermore, a comparison with previous similar studies in Southeast Asia suggests that subjective norms significantly influence intentions and can effectively predict traffic violation behaviors[16,54,65,66]. This observation may indicate that cultures with similar contexts tend to exhibit comparable driving behaviors, and such findings may reflect broader regional trends.

Perceived behavioral control influences the intention to engage in safe-riding behaviors, resulting in a decrease in the riding speed and supporting H3. This finding contradicts those of other studies that observed that individuals who perceived themselves as having control over low-risk behaviors are more confident in frequently overspeeding[16]. Additionally, if such individuals are influenced by situational facilitators for risk (e.g., driving on less congested roads, at night, alone, in a hurry, on roads with distant police checkpoints, or roads with fewer surveillance cameras), they tend to exhibit increased risky speeding behaviors[54]. Despite conflicting with the findings of the extant studies, our findings are supported by a notion that riders are less inclined to exhibit risky-riding behaviors when they perceive that they can control low-risk behaviors and perceive a lack of resources or opportunities to engage in risky behavior[64]. Additionally, perceived behavioral control can also reflect broader regional trends, as previous studies in Southeast Asia have indicated that this factor is a significant predictor of behavior[16,54,66,67].

3Es + Es factors

Education results in decreased riding-speed intentions, thus supporting H4. This finding is consistent with those of the extant studies that providing safety knowledge to riders can significantly reduce their risky behaviors and injury rates[68] Specifically, providing knowledge through web-based instructions (WBI) can significantly reduce risky speed-related behaviors (braking and cornering) by up to 73.93%.[69] Providing appropriate education can change riders' attitudes toward speeding, helping them to prioritize safety and adhere more to speed limits.

Engineering increases riders' intentions to engage in high riding speed, and this contradicts H5 as well as the findings of the extant studies that indicated that safe engineering designs play a role in reducing riding speeds[54,70]. For instance, measures, such as road narrowing could reduce riding speeds by up to 35%,[1]along with the creation of dedicated lanes for motorcycles[54], among other engineering interventions. The findings can be explained by a psychological phenomenon known as Risk Compensation[71]. This phenomenon suggests that drivers tend to adjust their behavior to offset perceived risks when roads appear to be safer. Drivers may feel more confident in their ability to handle higher speeds, leading to risk-taking behaviors such as driving at excessive speeds. Moreover, road designs that unintentionally encourage higher speeds (such as highways with wide lanes, dedicated acceleration lanes, smooth curves, and clear signage) might inadvertently promote higher overspeeding. Although these designs are aimed at mitigating the risk of high-speed traffic crashes, they can also induce the misperception of the danger of overspeeding among riders, thereby increasing their risky-riding behaviors.

Enforcement results in decreased riding speed, thus supporting H6. This finding aligns with those of several studies that revealed that law enforcement measures could significantly influence speed reduction among riders[72,73]. Specifically, the presence and enforcement of laws over time have been shown to modify rider behavior and can significantly increase spatial effectiveness[74,75]. Thus, law enforcement coupled with strict penalties for speeding can deter speeding behaviors. Moreover, the presence of visible law enforcement officers can effectively deter overspeeding.

Emergency Response decreases driving speeds, and this supports H7. This finding is consistent with those of previous studies that revealed how emergency-response systems facilitate speed reduction and increase overall road safety[76,77]. Prompt medical assistance and the application of traffic strategies in emergency responses, such as using speed-detection equipment[78,79], monitoring high-risk areas[80,81], and campaigns to raise awareness about the risks of speeding[82], play significant roles in preventing overspeeding. Therefore, their roles are crucial to creating a safe driving environment that can reduce traffic crashes and mitigate the impact of unforeseen events.

Riders' demographic factors

Riders aged 26–35 years exhibited increased attitudes toward safety. This finding is consistent with those of previous studies that found younger riders (under 26 years old) tended to exhibit more adventurous-riding attitudes resulting in risky behaviors resulting in lower injuries and fatalities compared with their older counterparts[3]. As riders aged 26–35 years are predominantly in the workforce to generate income, they might be significantly affected by crashes. This age group tends to prioritize safe riding and reduced risks[51]. Riders in this group prioritize safety to mitigate the impact of crashes on their lives.

Single riders exhibit decreased attitudes toward safety. This finding confirms previous findings, where unmarried riders tended to exceed the speed limits and engage in riskier behaviors compared with their married counterparts[43,61]. Married riders might feel more responsibility and consider their family members, and these might force them to prioritize safety and avoid risks on the road to protect their well-being and livelihood[83].

Riders with monthly incomes of 20,001–30,000 baht exhibit increased intentions to engage in safe-riding behaviors. This aligns with the findings of the extant studies, indicating that riders with lower incomes (14,000–19,000 baht or less) tend to use motorcycles more often[84]. This group often faces higher financial stress, thus displaying increased stress levels, and loss of attention while riding, and these might result in riskier riding behaviors. However, we confirmed that riders with moderate to high incomes exhibited increased intentions to engage in safe-riding behaviors. These individuals experience lower financial stress compared with those with lower incomes, and financial problems do not force them into stress-induced risky behaviors. This is further supported by an extant study revealing that riders with lower incomes often experience higher financial stress, which significantly influences their risky-riding behaviors[85].

Riders with less than five years of riding experience tended to ride faster or have a higher intention to engage in risky behaviors compared with those with more years of experience. This finding is consistent with those of the extant studies, indicating that riders with less experience have fewer coping mechanisms for stress-induced risky behaviors and unexpected events[85]. These findings indicated that less experienced riders often exhibit a decreased intention to engage in safe-riding behaviors.

Riders with crash histories believed that efficient emergency response enhances safety. This new finding from this study indicated that riders who have directly encountered severe incidents might become more aware of the risks associated with their behaviors, and this would reduce risky-riding intentions[86]. Moreover, witnessing effective emergency responses to crashes might highlight the consequences of unsafe riding, thereby promoting safer riding behaviors.

Relatives and bystanders involved in crashes often believe that adopting safe-riding behaviors referenced by role models would increase safety. This finding is a discovery from this study. Perceiving crashes involving close individuals can exert intense emotional impacts related to pain or even the loss of loved ones. These perceptions can motivate riders to show respect or concern, especially toward supportive and exemplary riders. Such an environment might support their commitment to safer riding practices to avoid such losses. This finding is supported by those previously reported, indicating that riders would engage in certain behaviors if they perceived positive behaviors along with pressure and motivation from social environments to display such behaviors and if they believe that they can do so successfully[64].

Riders who have received traffic tickets generally believe they need to reduce their risky-riding behaviors. This finding is supported by those previously reported, that speeding tickets are the most widely deployed tool for deterring overspeeding among riders[87]. Receiving citations can reduce riders' overconfidence in their ability to control their risky behaviors, and receiving tickets serves as a stimulus for riders to reassess their riding behaviors and face the unnecessary expenses associated with traffic violations. This may lead them to become more mindful and attentive to safer riding behaviors.

Conclusions

In this study, we combined the TPB and 3Es + Es frameworks analyzed by EFA to examine the factors influencing motorcycle riders' speeding behaviors in Thailand's industrial zones. We identified several crucial factors that can determine riders' intentions to engage in speeding. Interestingly, we confirmed that Engineering factors significantly influenced speeding behaviors. Additionally, Attitude, Subjective Norm, and Perceived Behavioral Control emerged as crucial TPB factors that influence riders' intentions to exhibit safer riding behaviors, resulting in reduced-speeding behaviors. However, to obtain deeper insights, we investigated latent factors based on the socio-demographic data of the riders. The significant influential factors included age, marital status, income, riding experience, crash history, and traffic tickets. Notably, the single riders exhibited reduced safety attitudes, and those with less than five years of riding experience tended to ride faster or displayed intentions to engage in less safe-riding behaviors. To maximize the benefits of the study, important policies and guidelines for managing and addressing risky-riding behaviors leading to overspeeding among motorcycle riders in industrial zones were proposed (Table 4).

Practical applications

Education and awareness

General promotion promoting the organization of educational programs and training within the community, integrating content related to (1) continuous awareness of the risks and consequences of consistently exceeding the legal speed limits can significantly reduce speeding behaviors. (2) An awareness of the risks and consequences of exceeding the legal speed limits under adverse weather conditions (rain, fog, or heat) can significantly reduce speeding behavior. (3) An awareness of technologies, such as warning signs and speed limiters can help reduce speeding behaviors. (4) Promoting good riding role models and encouraging positive attitudes toward speed usage among peers can significantly reduce speeding behavior.
(5) Sharing experiences from individuals who have encountered unexpected events related to the direct and indirect impacts of crashes can significantly reduce speeding behaviors. These initiatives may focus on providing knowledge through online teaching, as WBI can significantly reduce speeding behavior by up to 73.93%.[69]

Targeted promotion Promoting the organization of educational programs and training within specific groups of riders, including those under and over 26 and 35 years, respectively; single riders; riders with incomes of less than 20,001 baht, and riders with less than five years of experience is crucial. This process must incorporate content aimed at promoting attitudes and awareness regarding the risks and severe consequences of overspeeding. These groups are identified as having increased tendencies to exceed speed limits, thus making them the primary target for specialized safety-promotion efforts by safety organizations.

Engineering and infrastructural improvements Promoting the design of safer roads by considering speed-reduction measures alongside the consequences of speeding is crucial. Furthermore, promoting the installation of speed-camera devices in high-risk areas is another strategy for reducing the likelihood of speeding by riders[36]. Regular maintenance and upkeep are also crucial to preventing errors in road infrastructure and reducing risky behaviors among riders on the roads.

Legislation and enforcement promoting strict law enforcement via severe penalties that align with speeding offenses can significantly deter speeding behaviors. For instance, measures could include increasing penalties for repeat offenders by temporarily suspending their riding licenses and establishing speed enforcement checkpoints in high-risk areas. Law enforcement must focus on the visible presence of officers where riders can see them, as this effectively deters overspeeding[74].

Emergency response and post-crash care Efforts to continuously enhance efficient emergency-response capabilities are crucial, as such mechanisms play a role in preventing speeding and improving overall road safety. Additionally, providing timely medical assistance and implementing strategies for post-crash emergency response are vital to effectively reducing casualties and property damages[88]. For instance, training emergency medical services (EMS) personnel in both basic and advanced life-saving skills is vital. Equipping medical vehicles with comprehensive tools and life-saving devices ensures that injured individuals receive prompt assistance. Additionally, the development of advanced back-end systems, such as a unified communication platform, allows all relevant personnel to communicate through a single channel. This system enhances rapid inter-agency collaboration and improves decision-making accuracy in emergency situations. Moreover, the establishment of emergency service stations in high-risk areas or locations frequently associated with speed-related accidents plays a crucial role in providing timely assistance to injured individuals. Such localized support bridges critical response gaps, ensuring that emergency medical systems operate efficiently. However, listening to feedback from those who have directly experienced unforeseen events regarding the operational practices of emergency responders is another strategy for enhancing and improving emergency-response capabilities. This feedback mechanism is key to elevating the effectiveness of the emergency-response capabilities of safety organizations.

(+) Indicates a high possibility of exhibiting safe behaviors.
(−) Indicates a high possibility of exhibiting risky behaviors.
S = Short-range plan refers to a plan with a duration of up to one year.
I = Intermediate-range plan refers to a plan with a duration of one to five years.
L = Long-range plan refers to a plan with a duration of five years or more.

Table 4 reveals the challenges of managing some policies and guidelines. These policies and guidelines may involve complex factors that are challenging in some areas owing to resource constraints or the lack of central

Policy	Variable	Indicator	Guidelines	Planning S	Planning I	Planning L	Responsible department
1) Education and Awareness (General promotion)	Education ⟶ Speed	(+)	Promoting community awareness regarding the risks and consequences of exceeding the legal speed limits.				1) Government Public Relations Department 2) Department of Land Transport 3) Department of Local Administration
	Engineering ⟶ Speed	(−)	Promoting awareness about technologies, such as warning signs and speed limiters, can contribute to reducing overspeeding.	✓			
	Behavioral intentions ⟶ Speed	(+)	Promoting consistent encouragement for peers to not exceed the legal speed limits.	✓			
	Attitude ⟶ Behavioral intentions	(+)	Promoting attitudes and awareness regarding the impacts of speeding can help prevent continuous traffic crashes involving pedestrians and animals.				
	Subjective Norm ⟶ Behavioral intentions	(+)	Promoting positive examples of responsible speed riding is key to fostering safer roads.	✓			
	Perceived Behavioral Control ⟶ Behavioral intentions	(−)	Promoting awareness of the risks of speeding under adverse weather conditions (such as rain, fog, or heat)				
	AF_Y ⟶ Subjective Norm	(+)	Promoting awareness of the consequences of crashes through the experiences of those who have encountered such unforeseen events can be a powerful strategy for educating the community.	✓			
1) Education and Awareness (Targeted promotion)	AGE2 ⟶ Attitude	(+)	Promoting a positive attitude toward the risks of exceeding the legal limit can be targeted at two specific groups: riders under and over ages 26 and 35 years, respectively.	✓			1) Government Public Relations Department 2) Department of Land Transport 3) Department of Local Administration
	STATUS1 (Single) ⟶ Attitude	(−)	Promoting a positive attitude toward the risks of exceeding the legal speed limit among single riders	✓			
	INCOME3 ⟶ Behavioral intentions	(+)	Promoting awareness of the consequences of exceeding the legal speed limit among riders with an income of less than 20,001 baht can be beneficial.	✓			
	EXPERIENCE (< 5 Y) ⟶ Behavioral intentions	(−)	Promoting awareness of the consequences of exceeding the legal speed limit among riders with less than five years of riding experience can be effective.	✓			
2) Engineering and Infrastructural Improvements	Engineering ⟶ Speed	(−)	Designing roads with the consideration of reducing riding speeds and the impact of speed enforcement can be beneficial.			✓	1) Department of Highways 2) Department of Rural Roads
			Installing speed-camera devices in high-risk areas can effectively deter speeding.		✓		1) Royal Thai Police 2) Department of Highways 3) Department of Rural Roads
			Regular maintenance of infrastructure is key to ensuring road safety.		✓		1) Department of Highways 2) Department of Rural Roads
3) Legislation and Enforcement	Enforcement ⟶ Speed	(+)	Establishing speed enforcement checkpoints in high-risk areas	✓			1) Royal Thai Police 2) Department of Highways 3) Department of Rural Roads
	TICKET_Y ⟶ Perceived Behavioral Control	(+)	Temporarily suspending their riding licenses		✓		
4) Emergency Response and Post-Crash Care	Emergency response ⟶ Speed	(+)	Training emergency medical services (EMS) personnel				1) Ministry of Public Health of Thailand 2) National Institute for Emergency Medicine 3) Emergency Medical System of Local Administrative Organizations
			Preparation for Emergency Medical Equipment		✓		
			The development of advanced back-end systems, such as a unified communication platform		✓		
			Establishing emergency service points in high-risk areas	✓			
	ACCIDENT_Y ⟶ Emergency response	(+)	Promoting feedback on the conduct of officials from individuals who have experienced unexpected events. This serves as a pathway to enhancing the emergency-response capabilities of safety organizations.	✓			

Table 4. Appropriate policies and guidelines proposed based on the findings using the model

support, as well as factors that cannot be directly controlled owing to budget limitations. However, these policies and approaches can drive results if they rely on cooperation among multiple parties, including the government, the private sector, and the general public, to bring about beneficial changes. Additionally, planning for various timeframes and designating responsible departments helps in setting clearer goals and policies. Short-range planning helps address the current problems or challenges and facilitates rapid changes. Intermediate-range planning aids sustainable development and problem-solving at a broader level. Long-range planning supports the creation of a vision and the setting of directions to prepare for future changes. Planning across these different timeframes ensures that road-safety efforts are systematic and capable of effectively managing challenges. Additionally, the monitoring and evaluating the outcomes of the measures by collecting crash data before and after implementation, this data will be utilized to assess the results and refine policies and measures for future improvements.

Limitation of the study

This study has offered valuable and novel insights in many aspects. However, it was accompanied by several limitations arising from its focus on examining the speeding behavior of motorcycle riders in industrial zones characterized by heavy traffic and road designs primarily tailored to accommodate trucks and commuter vehicles, such as motorcycles. Additionally, the study centers on riders within industrial areas, who are predominantly working-age individuals. This demographic may exhibit driving behaviors and commuting patterns distinct from those of riders in other areas. As such, applying the recommendations and policy measures derived from this study to other areas or regions with differing environmental conditions should be approached with caution. Future research should broaden the scope to encompass a diverse range of areas, such as urban zones, rural regions, and commercial districts, to compare driving behaviors across varied contexts. Moreover, to effectively mitigate road crashes, future studies should aim to expand their scope by exploring secondary factors or other causes influencing risky behaviors among motorcycle riders. These factors may include road infrastructure, technological advancements, innovations, and law enforcement practices. A more comprehensive understanding of these elements would support the development of tailored policies for different contexts, enabling policymakers to identify and implement more effective strategies for reducing road crashes.

Data availability

The data presented in this study are available on request from the corresponding author.

Received: 2 July 2024; Accepted: 28 November 2024
Published online: 02 December 2024

References

1. Distefano, N. & Leonardi, S. Evaluation of the benefits of traffic calming on vehicle speed reduction. *Civil Eng. Archit.* **7**, 200–214 (2019).
2. World Health Organization. Global status report on road safety 2023. (2023).
3. Se, C., Champahom, T., Wisutwattanasak, P., Jomnonkwao, S. & Ratanavaraha, V. Temporal instability and differences in injury severity between restrained and unrestrained drivers in speeding-related crashes. *Sci. Rep.* **13**, 9756 (2023).
4. Ministry of Transport. *Accidents on the road network of the Ministry of Transport - MOT Data Catalog*, < (2023). https://datagov.mot.go.th/dataset/roadaccident
5. Seefong, M. et al. Big Data Analytics with the Multivariate Adaptive Regression splines to analyze key factors influencing Accident Severity in Industrial zones of Thailand: a study on Truck and Non-truck collisions. *Big Data Cogn. Comput.* **7**, 156 (2023).
6. Qaid, H. et al. Speed choice and speeding behavior on Indonesian highways: extending the theory of planned behavior. *IATSS Res.* **46**, 193–199 (2022).
7. Hong, V. et al. Socio-demographic determinants of motorcycle speeding in Maha Sarakham, Thailand. *PLOS ONE*. **15**, e0243930. https://doi.org/10.1371/journal.pone.0243930 (2020).
8. Department of Land Transport. *Transport Statistics*, < (2022). https://web.dlt.go.th/statistics/
9. Rashmi, B. S. & Marisamynathan, S. Factors affecting truck driver behavior on a road safety context: a critical systematic review of the evidence. *J. Traffic Transp. Eng. (English Edition)* (2023).
10. Yanuvianti, M., Coralia, F. & Qodariah, S. in *2nd Social and Humaniora Research Symposium (SoRes 2019)*. 308–311 (Atlantis Press).
11. Fitrianti, F. & Yanuvianti, M. Studi deskriptif mengenai perilaku mengemudi berbahaya pada pengguna sepeda motor usia 18–24 tahun di kota Bandung. *Fakultas Psikologi Unisba Bandung* (2013).
12. Dadipoor, S., Ranaei, V., Ghaffari, M., Rakhshanderou, S. & Safari-Moradabadi, A. Safe driving behaviors among taxi drivers: a predictive cross-sectional study based on the health belief model. *Archives Public. Health*. **78**, 82. https://doi.org/10.1186/s13690-020-00469-0 (2020).
13. Retting, R. A., Ferguson, S. A. & McCartt, A. T. A review of evidence-based traffic engineering measures designed to reduce pedestrian–motor vehicle crashes. *Am. J. Public Health*. **93**, 1456–1463 (2003).
14. Shruthi, M., Meundi, A. D. & Sushma, D. Determinants of helmet use among health-care providers in urban India: leveraging the theory of planned behavior. *J. Educ. Health Promotion*. **8**, 24 (2019).
15. Morimoto, A., Wang, A. & Kitano, N. A conceptual framework for road traffic safety considering differences in traffic culture through international comparison. *IATSS Res.* **46**, 3–13 (2022).
16. Muntafi, M. S. Speeding behavior among Young motorcyclists: the role of theory of planned behavior variables and willingness. *Psikostudia: Jurnal Psikologi*. **11**, 158–168 (2022).
17. Mwebesa, M. E., Yoh, K., Inoi, H. & Doi, K. A new approach to cross-sector cooperation in road safety through a comparison of policies in selected countries. *IATSS Res.* **42**, 197–206. https://doi.org/10.1016/j.iatssr.2018.08.001 (2018).
18. Abbas, K. Assessment & improvement of children road safety: a pyramid & honeycomb structure approach. *J. Transp. Technol.* **7**, 240–260 (2017).
19. Effah, E., Umaru, M. Y., Densua, D. F. N., George, G. & Kweku, A. K. Smart Road Accident Prevention System for Revenue Generation in Ghana. *Int. J. Comput. Sci. Inform. Secur. (IJCSIS)* (2023).
20. Mwebesa, M. E., Chou, C. C., Yoh, K. & Doi, K. A Cross-sector Framework to boost the Sustainable Implementation of Integrated Transport and spatial strategies to Improve Safety and mobility of Moto-taxi riders. *Front. Sustainable Cities*. **3**, 775011 (2021).
21. Dilalla, L. F. in *In Handbook of Applied Multivariate Statistics and Mathematical Modeling*. 439–464 (eds Howard, E. A., Tinsley, Steven, D. & Brown) (Academic, 2000).
22. Manan, M. M. A., Ho, J. S., Arif, S. T. M. S. T., Ghani, M. R. A. & Várhelyi, A. Factors associated with motorcyclists' speed behaviour on Malaysian roads. *Transp. Res. part. F: Traffic Psychol. Behav.* **50**, 109–127 (2017).
23. SUKOR, N. S. A. & Fujii, S. in *Proceedings of the Eastern Asia Society for Transportation Studies Vol. 8 (The 9th International Conference of Eastern Asia Society for Transportation Studies,*). 390–390 (Eastern Asia Society for Transportation Studies).). 390–390 (Eastern Asia Society for Transportation Studies). (2011).
24. Yuen, C. W., Karim, M. R. & Saifizul, A. Analysis of motorcyclist riding behaviour on speed table. *The Scientific World Journal* 236396 (2014). (2014).
25. Elliott, M. A., Armitage, C. J. & Baughan, C. J. Exploring the beliefs underpinning drivers' intentions to comply with speed limits. *Transp. Res. Part. F: Traffic Psychol. Behav.* **8**, 459–479. https://doi.org/10.1016/j.trf.2005.08.002 (2005).
26. Warner, H. W. & Åberg, L. Drivers' decision to speed: a study inspired by the theory of planned behavior. *Transp. Res. Part. F: Traffic Psychol. Behav.* **9**, 427–433. https://doi.org/10.1016/j.trf.2006.03.004 (2006).
27. Mehmood, A. Determinants of speeding behavior of drivers in Al Ain (United Arab Emirates). *J. Transp. Eng.* **135**, 721–729. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000049 (2009).

28. Forward, S. E. Intention to speed in a rural area: reasoned but not reasonable. *Transp. Res. Part. F: Traffic Psychol. Behav.* **13**, 223–232. https://doi.org/10.1016/j.trf.2010.04.002 (2010).
29. Cestac, J., Paran, F. & Delhomme, P. Young drivers' sensation seeking, subjective norms, and perceived behavioral control and their roles in predicting speeding intention: how risk-taking motivations evolve with gender and driving experience. *Saf. Sci.* **49**, 424–432. https://doi.org/10.1016/j.ssci.2010.10.007 (2011).
30. Chorlton, K., Conner, M. & Jamson, S. Identifying the psychological determinants of risky riding: an application of an extended theory of Planned Behaviour. *Accid. Anal. Prev.* **49**, 142–153 (2012).
31. Cristea, M., Paran, F. & Delhomme, P. Extending the theory of planned behavior: the role of behavioral options and additional factors in predicting speed behavior. *Transp. Res. Part. F: Traffic Psychol. Behav.* **21**, 122–132 (2013).
32. Dinh, D. D. & Kubota, H. Speeding behavior on urban residential streets with a 30km/h speed limit under the framework of the theory of planned behavior. *Transp. Policy*. **29**, 199–208. https://doi.org/10.1016/j.tranpol.2013.06.003 (2013).
33. Scott-Parker, B., Hyde, M. K., Watson, B. & King, M. J. Speeding by young novice drivers: what can personal characteristics and psychosocial theory add to our understanding? *Accid. Anal. Prev.* **50**, 242–250. https://doi.org/10.1016/j.aap.2012.04.010 (2013).
34. Chumpawadee, U., Homchampa, P., Thongkrajai, P., Suwanimitr, A. & Chadbunchachai, W. Factors related to motorcycle accident risk behavior among university students in northeastern Thailand. *Southeast. Asian J. Trop. Med. Public. Health*. **46**, 805–821 (2015).
35. Brewster, S. E., Elliott, M. A. & Kelly, S. W. Evidence that implementation intentions reduce drivers' speeding behavior: testing a new intervention to change driver behavior. *Accid. Anal. Prev.* **74**, 229–242 (2015).
36. Rowe, R. et al. Identifying beliefs underlying pre-drivers' intentions to take risks: an application of the theory of Planned Behaviour. *Accid. Anal. Prev.* **89**, 49–56 (2016).
37. Atombo, C., Wu, C., Zhong, M. & Zhang, H. Investigating the motivational factors influencing drivers intentions to unsafe driving behaviours: speeding and overtaking violations. *Transp. Res. Part. F: Traffic Psychol. Behav.* **43**, 104–121. https://doi.org/10.1016/j.trf.2016.09.029 (2016).
38. Jovanović, D., Šraml, M., Matović, B. & Mićić, S. An examination of the construct and predictive validity of the self-reported speeding behavior model. *Accid. Anal. Prev.* **99**, 66–76 (2017).
39. Javid, M. A. & Al-Roushdi, A. F. A. Causal factors of driver's speeding Behaviour, a case study in Oman: role of norms, personality, and exposure aspects. *Int. J. Civil Eng.* **17**, 1409–1419. https://doi.org/10.1007/s40999-019-00403-8 (2019).
40. Mohamad, F. F., Abdullah, A. S. & Mohamad, J. Are sociodemographic characteristics and attitude good predictors of speeding behavior among drivers on Malaysia federal roads? *Traffic Inj. Prev.* **20**, 478–483. https://doi.org/10.1080/15389588.2019.1612057 (2019).
41. Javid, M. A. & Al-Hashimi, A. R. Significance of attitudes, passion and cultural factors in driver's speeding behavior in Oman: application of theory of planned behavior. *Int. J. Injury Control Saf. Promotion*. **27**, 172–180. https://doi.org/10.1080/17457300.2019.1695632 (2020).
42. Javid, M. A., Ali, N., Abdullah, M. & Shah, S. A. H. Integrating the norm activation model (NAM) theory in explaining factors affecting drivers' speeding Behaviour in Lahore. *KSCE J. Civ. Eng.* **25**, 2701–2712. https://doi.org/10.1007/s12205-021-1289-x (2021).
43. Javid, M. A. et al. Analysis of driver's socioeconomic characteristics relating to speeding behavior and Crash involvement: a Case Study in Lahore. *Infrastructures* **7**, 18 (2022).
44. Tanglai, W., Chen, C. F., Rattanapan, C. & Laosee, O. The effects of personality and attitude on Risky Driving Behavior among Public Van drivers: hierarchical modeling. *Saf. Health work*. **13**, 187–191. https://doi.org/10.1016/j.shaw.2022.03.005 (2022).
45. Alizadeh, M., Davoodi, S. R. & Shaaban, K. Drivers' speeding behavior in Residential streets: a structural equation modeling Approach. *Infrastructures* **8**, 11 (2023).
46. Oxley, J. A., Fildes, B. N., Ihsen, E., Charlton, J. L. & Day, R. H. *Age Differences in Road Crossing Decisions Based on Gap Judgements*. (Annu Proc Assoc Adv Automot Med. ;43:279–300., 1999). (1999).
47. Wieschen, E. M., Makani, A., Radev, S. T., Voss, A. & Spaniol, J. Age-related differences in Decision-Making: evidence Accumulation is more gradual in older age. *Exp. Aging Res.* 1–13. https://doi.org/10.1080/0361073X.2023.2241333 (2023).
48. Kline, R. B. *Principles and Practice of Structural Equation Modeling* (Guilford, 2023).
49. Hair, J. F. & Black, W. (Prentice Hall: New Jersey, (2010).
50. Wisutwattanasak, P. et al. Examining the impact of service quality on passengers' intentions to Utilize Rail Transport in the post-pandemic era: an Integrated Approach of SERVQUAL and Health Belief Model. *Behav. Sci.* **13**, 789 (2023).
51. Wisutwattanasak, P., Jomnonkwao, S., Khampirat, B., Raungratanaamporn, I. & Ratanavaraha, V. Multilevel structural equation modeling of willingness-to-pay for fatality risk reduction: perspectives of driver and district levels. *Int. J. Injury Control Saf. Promotion*. **31**, 96–110 (2024).
52. Fornell, C. & Larcker, D. F. Evaluating Structural equation models with unobservable variables and measurement error. *J. Mark. Res.* **18**, 39–50. https://doi.org/10.1177/002224378101800104 (1981).
53. Theerathitichaipa, K. et al. Measurement model for determining the Disparity Factors of Intercity Railway Transportation. *Civil Eng. J.* **10**, 668–688 (2024).
54. Satiennam, T. et al. Wrong way driving intention and behavior of young motorcycle riders. *Transp. Res. Interdisciplinary Perspect.* **19**, 100827 (2023).
55. Tavakol, M. & DENNĠCK, R. Making sense of Cronbach's alpha. international journal of medical education, 2: 53–55. *PMCID: PMC4205511, PMID* 28029643 (2011).
56. Wisutwattanasak, P., Jomnonkwao, S., Se, C. & Ratanavaraha, V. Influence of psychological perspectives and demographics on drivers' valuation of road accidents: a combination of confirmatory factor analysis and preference heterogeneity model. *Behav. Sci.* **12**, 336 (2022).
57. Joreskog, K. & Sorbom, D. Structural equation modelling: guidelines for determining model fit. *NY: Univ. Press. Am.* (1993).
58. Deb, S. & Ahmed, M. A. Determining the service quality of the city bus service based on users' perceptions and expectations. *Travel Behav. Soc.* **12**, 1–10 (2018).
59. Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A. & King, J. Reporting structural equation modeling and confirmatory factor analysis results: a review. *J. Educational Res.* **99**, 323–338 (2006).
60. Forward, S. E. An assessment of what motivates road violations. *Transp. Res. Part. F: Traffic Psychol. Behav.* **12**, 225–234. https://doi.org/10.1016/j.trf.2008.12.003 (2009).
61. Shandhana Rashmi, B. & Marisamynathan, S. Investigating the contributory factors influencing speeding behavior among long-haul truck drivers traveling across India: insights from binary logit and machine learning techniques. *Int. J. Transp. Sci. Technol.* https://doi.org/10.1016/j.ijtst.2024.01.008 (2024).
62. Özkan, T., Lajunen, T., Doğruyol, B., Yıldırım, Z. & Çoymak, A. Motorcycle accidents, rider behaviour, and psychological models. *Accid. Anal. Prev.* **49**, 124–132 (2012).
63. Newnam, S., Watson, B. & Murray, W. Factors predicting intentions to speed in a work and personal vehicle. *Transp. Res. Part. F: Traffic Psychol. Behav.* **7**, 287–300. https://doi.org/10.1016/j.trf.2004.09.005 (2004).
64. Ajzen, I. *Attitudes, Personality and Behaviour* (McGraw-hill education (UK), 2005).
65. Deng, Y., Shi, C. & Jin, J. Exploring influences on the intention of motorcyclists to drink and ride: an investigation in a fourth-tier city of China. *Traffic Inj. Prev.* **24**, 121–125. https://doi.org/10.1080/15389588.2022.2159763 (2023).

66. Tan, C. et al. Modeling effects of driver safety attitudes on traffic violations in China using the theory of planned behavior. *IATSS Res.* **46**, 63–72 (2022).
67. Jie-Ling, J. & Yuan-Chang, D. Analysis of drink-driving behavior: considering the subjective and objective factors of drivers. *Traffic Inj. Prev.* **22**, 183–188. https://doi.org/10.1080/15389588.2021.1873301 (2021).
68. Swaddiwudhipong, W., Boonmak, C., Nguntra, P. & Mahasakpan, P. Effect of motorcycle rider education on changes in risk behaviours and motorcycle-related injuries in rural Thailand. *Tropical Med. Int. Health*. **3**, 767–770 (1998).
69. Camden, M. C., Soccolich, S. A., Hickman, J. S. & Hanowski, R. J. Reducing risky driving: assessing the impacts of an automatically-assigned, targeted web-based instruction program. *J. Saf. Res.* **70**, 105–115. https://doi.org/10.1016/j.jsr.2019.06.006 (2019).
70. Lin, P. S., Ozkul, S., Guo, R. & Chen, C. Assessment of countermeasure effectiveness and informativeness in mitigating wrong-way entries onto limited-access facilities. *Accid. Anal. Prev.* **116**, 79–93. https://doi.org/10.1016/j.aap.2017.11.027 (2018).
71. Levym, D. T., Miller, T. E. D. & Review Risk compensation literature — the theory and evidence. *J. Crash Prev. Inj. Control*. **2**, 75–86. https://doi.org/10.1080/10286580008902554 (2000).
72. De Pauw, E., Daniels, S., Brijs, T., Hermans, E. & Wets, G. Behavioural effects of fixed speed cameras on motorways: overall improved speed compliance or kangaroo jumps? *Accid. Anal. Prev.* **73**, 132–140 (2014).
73. Perzyński, T. & Lewiński, A. in *Management Perspective for Transport Telematics: 18th International Conference on Transport System Telematics, TST* Krakow, Poland, March 20–23, 2018, Selected Papers 18. 101–114 (Springer). (2018).
74. Karimpour, A., Kluger, R., Liu, C. & Wu, Y. J. Effects of speed feedback signs and law enforcement on driver speed. *Transp. Res. Part. F: Traffic Psychol. Behav.* **77**, 55–72. https://doi.org/10.1016/j.trf.2020.11.011 (2021).
75. Yannis, G., Papadimitriou, E. & Antoniou, C. Multilevel modelling for the regional effect of enforcement on road accidents. *Accid. Anal. Prev.* **39**, 818–825 (2007).
76. Liu, Z. & Wang, C. Design of traffic emergency response system based on internet of things and data mining in emergencies. *IEEE Access*. **7**, 113950–113962 (2019).
77. Newnam, S. et al. Safety in the Grey Zone': evaluation of a training program to improve the safety of incident responders on high-speed roads. *J. Saf. Res.* **89**, 83–90. https://doi.org/10.1016/j.jsr.2024.01.011 (2024).
78. Jamil Alsayaydeh, J. A., Yusof, Mohan, M. F., Zakir Hossain, K. S. & Leoshchenko, S. A. Advancing Road Safety: Precision driver detection system with Integrated Overspeed, Alcohol Detection, and Tracking capabilities. *Int. J. Adv. Comput. Sci. Appl.* **14** (2023).
79. Graham, D. J., Naik, C., McCoy, E. J. & Li, H. Do speed cameras reduce road traffic collisions? *PLOS ONE*. **14**, e0221267. https://doi.org/10.1371/journal.pone.0221267 (2019).
80. Wu, X., Lum, C. & Koper, C. Do everyday proactive policing activities reduce vehicle crashes? Examining a commonly held law enforcement belief using a novel method. *J. Criminal Justice*. **76**, 101846. https://doi.org/10.1016/j.jcrimjus.2021.101846 (2021).
81. Simpson, R., McCutcheon, M. & Lal, D. Reducing speeding via inanimate police presence. *Criminol. Public. Policy*. **19**, 997–1018. https://doi.org/10.1111/1745-9133.12513 (2020).
82. Desjardins, F. & Lavallière, M. Evaluation of a Road Safety Awareness Campaign deployed along the Roadside in Saguenay (Québec, Canada). *Int. J. Environ. Res. Public Health*. **20**, 6012 (2023).
83. Balakrishnan, S. & Karuppanagounder, K. Estimating the cost of two-wheeler road accident injuries in India using the willingness to pay method. *Australian J. Civil Eng.* **18**, 65–72. https://doi.org/10.1080/14488353.2020.1721951 (2020).
84. Iamtrakul, P., Chayphong, S., Makó, E. & Phetoudom, S. Analysis of Road users' risk behaviors in different travel modes: the Bangkok Metropolitan Region, Thailand. *Infrastructures* **8**, 79 (2023).
85. Okodudu, E. E., SOCIO DEMOGRAPHIC CHARACTERISTICS OF PUBLIC VEHICLE DRIVERS & AND ROAD RAGE IN ASABA. *GPH-International J. Social Sci. Humanit. Res.* **7**, 32–48 (2024).
86. O'Brien, F., Bible, J., Liu, D. & Simons-Morton, B. G. Do Young drivers become Safer after being involved in a collision? *Psychol. Sci.* **28**, 407–413. https://doi.org/10.1177/0956797616688118 (2017).
87. Lawpoolsri, S., Li, J. & Braver, E. Do speeding tickets reduce the likelihood of receiving subsequent speeding tickets? A longitudinal study of speeding violators in Maryland. *Traffic Inj. Prev.* **8**, 26–34. https://doi.org/10.1080/15389580601009764 (2007).
88. Damaševičius, R., Bacanin, N. & Misra, S. From sensors to Safety: internet of Emergency Services (IoES) for emergency response and Disaster Management. *J. Sens. Actuator Networks*. **12**, 41 (2023).

Acknowledgements

The authors express their gratitude to the Suranaree University of Technology (SUT), Thailand Science Research and Innovation (TSRI), and National Science, Research and Innovation Fund for their support in doing this research.

Author contributions

M.S.: Conceptualization, methodology, software, formal analysis, writing—original draft preparation and writing—review and editing. P.W.: software and validation. C.S.: validation and writing—review and editing. K.T.: resources and data curation. S.J.: methodology, writing—review and editing, supervision, project administration, funding acquisition. T.C.: validation and writing—review and editing. V.R.: writing—review and editing, supervision, project administration and funding acquisition. R.K.: Conceptualization, formal analysis, writing—original draft preparation, writing—review and editing, supervision, project administration and funding acquisition.

Funding

This work was supported by (i) Suranaree University of Technology (SUT) (ii) Thailand Science Research and Innovation (TSRI), and (iii) National Science, Research and Innovation Fund (NRSF) [Project code: 195628].

Competing interests

The authors declare no competing interests.

Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Suranaree University of Technology (COE No.5/2567, 30 January 2024).

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-024-81793-1.

Correspondence and requests for materials should be addressed to R.K.