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Assessing Safety Risks in Cyclist and Road User Interactions

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Abstract: *Cycling has gained popularity in Malaysia as both a mode of commuting and a recreational activity. This trend reflects growing health awareness, environmental concerns, and government initiatives to promote cycling. However, the absence of dedicated bicycle lanes in mixed-traffic environments often forces cyclists to share the road with other users, increasing crash risks and underscoring the need to examine these interactions. This study investigates the safety of interactions between cyclists and other road users, focusing on passing distances of less than 1.5 meters. Field observations were conducted at specific locations in three cities, totaling 6,063 observations at both midblock and intersection sites. Demographic and contextual factors were recorded during these observations. Binary logistic regression analysis explored the relationship between risky interactions and variables such as the gender and age of cyclists and other road users, bicycle type, group cycling, and vehicle type. The study identified several factors that significantly contribute to risky interactions between cyclists and other road users. Female cyclists were more prone to risky interactions than male cyclists. Younger cyclists were also more likely to engage in such behaviors, while those riding e-bikes faced greater risks than cyclists on traditional bicycles, such as mountain or road bicycle. Interestingly, cyclists riding in groups experienced fewer risky interactions than those riding solo. Additionally, young drivers were found to be more aware of risks and maintained safer passing distances compared to adult drivers. These results highlight the importance of targeted awareness campaigns and infrastructure improvements to enhance cyclist safety. Efforts should prioritize promoting safer interactions between cyclists and other road users to reduce crash risks and improve overall road safety.*

Keywords: cyclist, cyclist safety, road traffic crash, road user interaction, mixed traffic

1. Introduction

Cyclist safety remains an important global concern, with alarming statistics pointing to significant risks. Recent data from the World Health Organization reveals that cyclist fatalities have increased by over 20%, resulting in approximately 71,000 fatalities worldwide, which account for nearly 6% of all road traffic fatalities (WHO, 2024). In Europe, the European Road Safety Observatory recorded between 1,900 and 2,100 cyclist fatalities annually since 2010 (ERSO, 2021; ERSO, 2024). There were 426 fatalities reported in 2020 in Germany, while countries like Romania and France have experienced notable increases. In the United States, cyclist fatalities rose by 13% in 2022, reaching 1,105 fatalities (Mark, 2024). In Malaysia, 70% of bicycle-related crashes are fatal, making up 2% of total road fatalities (Roslan et al., 2021). According to the National Highway Traffic Safety Administration (NHTSA), most of these incidents involve collisions with motor vehicles, with driver negligence accounting for over

80% of fatalities (NHTSA, 2023). A detailed analysis of road traffic crashes is essential to gain a deeper understanding of incidents involving cyclists.

Several factors have been identified as contributing to the rising number of road traffic crashes involving cyclists, including poor visibility, inadequate infrastructure, and high vehicle speeds (Boufous et al., 2012). Intersections are also recognized as hazardous locations, as they are common sites for cyclist-vehicle conflicts. Inadequate passing distances, such as those less than 1.5 meters, have also been identified as increasing the risk of crashes, including sideswipes. To improve road safety for cyclists, some countries have implemented minimum passing distance laws. For example, in 2015, South Australia introduced laws mandating a minimum passing distance of 1 meter on roads with speed limits up to 60 km/h and 1.5 meters on higher-speed roads (Matt, 2023). Additionally, the behavior of other road users has contributed to these types of collisions. For instance, drivers making left turns without checking for cyclists or overtaking with insufficient clearance often led to crashes (Johnson, 2016). Dooring incidents, where vehicle doors are opened into cyclists' paths, are another significant hazard (Jänsch et al., 2015), often linked to poor parking habits and failure to check for cyclists. Other contributing factors include running red lights, improper use of bicycle lanes, and environmental factors such as poor visibility due to adverse weather or insufficient lighting (Garrard et al., 2008; Pucher & Dijkstra, 2003). However, these findings are primarily from developed countries, which have different road geometries and cyclist facilities compared to developing countries like Malaysia.

2. Method

Data Collection

This study focused on three cities—Kuala Lumpur, Shah Alam, and Cyberjaya in Malaysia—selected for their unique urban dynamics and active cycling communities. In addition, the selection of these cities was also due to the promotion of cycling activities from local authorities. For example, Kuala Lumpur home to 1.8 million residents in 2020 (ESCAP, 2020), actively promotes cycling through workshops and informal talks aimed at encouraging eco-friendly transportation (DBKL, 2019). Shah Alam, with a population of 438,745 in 2024 (DOSM, 2024), offered valuable insights into cyclist behavior based on findings from prior safety studies. Meanwhile, Cyberjaya, located within the Sepang district and home to approximately 140,000 residents (MPS, 2024), provided a perspective on cycling trends within a rapidly evolving intelligent city (Sarimin & Yigitcanlar, 2011).

In this study, research assistants were appointed to observe risky interactions between cyclists and other road users. A passing distance of less than 1.5 meters was identified as a risky interaction in this study. Although the law mandating a minimum passing distance has not yet been implemented in Malaysia, such interactions may increase safety risks for cyclists. Additionally, demographic information such as gender, age, bicycle type, group cycling, and vehicle type of other road users was recorded. Bicycle type (road, mountain, and electric) was noted due to variations in speed, maneuverability, and riding patterns, while group cycling was observed for its potential impact on safety behaviors. The vehicle type was also recorded, with particular attention given to heavy vehicles like trucks and buses, which pose greater risks due to their size and blind spots.

Data collection took place across six types of road facilities in Kuala Lumpur, Cyberjaya, and Shah Alam: midblock, priority and signalized intersections, roundabouts, roads with exclusive bicycle lanes, and roads without bicycle lanes. Each road facility presented unique challenges, such as turning maneuvers at intersections and merging behavior at roundabouts.

Data Analysis

Binary logistic regression models were developed to analyze risky interaction passing distances of less than 1.5 meters. Research assistants manually transform data from paper-based forms into Excel spreadsheets, consolidating records from Kuala Lumpur, Cyberjaya, and Shah Alam into a master dataset. Variables were standardized by applying consistent naming conventions and uniformly coding categorical values. The data cleaning process included removing duplicates, addressing missing data through imputation or record removal, and ensuring all entries were within valid ranges. This resulted in a consistent and reliable dataset for analysis.

The model included explanatory variables related to the demographics of cyclists and other road users, such as gender, age, type of bicycle, group cycling, and vehicle type, across six road facilities. Binary logistic regression was chosen to predict the probability of binary outcomes based on these variables. This method utilizes a logistic function to generate probabilities between 0 and 1, making it suitable for classification tasks with two possible outcomes. Equation 1 demonstrates the binary logistic regression applied in this study.

$$Z = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \epsilon \qquad (1)$$

where Z is the logit (log-odds) of the probability p in binary logistic regression, and p represents the probability of performing a risky interaction, $\frac{p}{1-p}$ represents the odds of risky interaction, $\log\left(\frac{p}{1-p}\right)$ is the natural logarithm of the odds, also known as the logit, β_0 is the intercept term, β_1, β_2, β_3… are the coefficients corresponding to the predictor variables (gender, age, type of bicycle, group cycling and type of vehicle) represented by X_1,X_2,X_3, and ϵ is the error term.

3. Results and Discussion

A total of 6,063 cyclists were observed during a nine-day field survey conducted at six road locations. The selected road facilities included midblocks, priority and signalized intersections, roundabouts, roads with exclusive bicycle lanes, and roads without bicycle lanes. The primary focus of this study was to ensure a safe passing distance of at least 1.5 meters during cyclist interactions with other road users. Table 1 presents the number of risky interactions where the passing distance was less than 1.5 meters across different types of road facilities. Among these, 1,467 cyclists (87%) on roads with bicycle lanes experienced risky interactions, while 486 cyclists (44.9%) on roads without bicycle lanes faced similar risks. Furthermore, 119 cyclists (14.3%) riding on restricted highways encountered risky interactions with other road users. At intersections, priority junctions accounted for 145 cyclists (14.8%) experiencing risky interactions, while signalized junctions involved 147 cyclists (15%) in such situations. At roundabouts, 255 cyclists (50.5%) were found to face risky interactions. The Cox and Snell R^2 value of 0.231 and the Nagelkerke R^2 value of 0.311 suggest that the model explains between 23.1% and 31.1% of the variation in risky interactions between cyclists and other road users. All seven explanatory variables were found to be statistically significant at a 95% confidence interval for predicting risky interactions involving passing distances of less than 1.5 meters. These significant factors included cyclist gender, cyclist age, type of bicycle, group cycling behavior, gender and age of other road users, and type of vehicle.

Table 2 shows the passing distances of less than 1.5 meters observations across the explanatory variables. Table 3 presents the results of model estimation for this risky interaction based on demographic and vehicle factors. Female cyclists exhibited higher percentage of risky interactions 57.8% compared to male cyclists 41.1%. The odds off female cyclists being involved risky interaction were about 1.61 times higher (*95% CI: 1.346–1.926*) than male cyclists. Behavioral and environmental factors contribute to this increased risk; for example, studies have shown that female cyclists are more likely to encounter dangerous conflicts at intersections. Research in Hennepin County, Minnesota, by Greg (2019) and Humphrey (2017) revealed that drivers passed female cyclists an average of three inches closer than male cyclists and that female cyclists were 3.8 times more likely to experience close passing incidents, defined as passing within three feet. This behavior may result from perceived vulnerability or differences in road positioning, as female cyclists often ride closer to the edge, reducing the available passing space. Angie (2019) also found that 73% of close-passing incidents involved female cyclists, despite their smaller representation among observed riders. However, Prati et al. (2019) suggested that female cyclists generally report greater discomfort and risk perception in mixed traffic, which could influence their behavior in maintaining safer distances from vehicles. However, Haworth et al. (2018) found no significant differences in passing distances based on gender in a study conducted in Southeast Queensland, Australia. These findings emphasize the need for improved cycling infrastructure, such as protected lanes, to address gender disparities in road safety and reduce unsafe passing incidents.

The safety of young cyclists on the road remains a significant concern, as they are often more vulnerable to risky interactions with vehicles compared to adult cyclists. Table 2 shows that 59.4% out of 190 young cyclists observed perform risky interaction. In addition, compared to adult cyclists, young cyclists were 1.912 times more likely to exhibit risky interactions (*95% CI: 1.471–2.484*). A study shows that younger cyclists are more likely to engage in risky behaviors, such as riding too close to vehicles or pedestrians, as they tend to underestimate the dangers of insufficient passing distances (Varet et al., 2024). Previous research also indicates that young cyclists were more likely to face safety concerns, particularly with passing distances of less than 1.5 meters. For example, a study in Southeast Queensland, Australia, by Debnath et al. (2018) found that younger cyclists are at greater risk during interactions with vehicles, experiencing closer passing distances and a higher incidence of unsafe passes compared to adult cyclists. Additionally, young cyclists' heightened vulnerability during overtaking maneuvers contributes to behaviors such as riding closer to the edge, increasing their risk of unsafe passing and closer vehicle interactions (Rubie et al., 2023). However, a study by the (NHTSA, 2021) suggests that while young cyclists may take more risks, the distance vehicles leave when passing them is often similar to older cyclists when factors such as traffic and route choices are considered. This finding highlights the difference level of risk compassion between cyclist age group and the need for further investigation to investigate cyclist safety across different age groups.

The type of bicycle plays an important role in influencing risky interactions and cyclist safety in general. Cyclists using mountain or road bicycles were less likely to experience risky interactions compared to those riding electric bicycles (e-bike), with odds ratios of 0.248 lower (*95% CI: 0.199–0.308*) and 0.617 lower (*95% CI: 0.526–0.724*), respectively. Among the observed cyclists, 237 (21.5%) rode mountain bicycles, while 1,762 (44.7%) rode road bicycles perform the risky interaction. A study by People Power Movement (2024) indicates that e-bike riders face higher risks due to their speed and weight, which lead to closer vehicle passes and a greater likelihood of serious injuries, including being three times more likely to collide with pedestrians than traditional cyclists. Additionally, a study by Johnson and Rose (2015) found that e-bike riders felt less safe in traffic, particularly in complex environments, increasing the risk of unsafe interactions with vehicles. Conversely, John (2024) suggests that e-bike riders may feel more confident in traffic as their higher speeds enable them to match the flow of motor

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vehicles, potentially reducing close passes in certain situations. However, the general agreement is that traditional cyclists tend to face fewer risky interactions compared to e-bike riders, emphasizing the need for specific safety measures to protect e-bike users (Scripps, 2024). This finding underscores the importance of tailoring safety strategies to address the unique risks faced by different bicycle types.

The impact of group cycling on safety and interactions with motor vehicles is a topic of ongoing research and debate. Although a higher percentage of group cyclists (49.9%) were involved in risky interactions compared to solo cyclists (40.0%), the odds ratio indicates that cycling in a group was associated with a lower likelihood of risky interactions, with an odds ratio of 0.481 (*95% CI: 0.422–0.549*). Group cyclists are generally less likely to experience risky interactions related to passing distances compared to individual cyclists. Previous research suggests that when cyclists ride in groups, they create a larger visual presence on the road, which can encourage safer overtaking behavior from drivers. For instance, Pérez-Zuriaga et al. (2021) found that drivers give more space when passing groups of cyclists due to increased caution and awareness. However, Albers et al. (2018) conducted a study in Victoria, Australia, revealing that group cyclists experienced more close passing events, with 6% of vehicle interactions occurring at distances of less than one meter. Heeremans et al. (2022) found that group cyclists often ride closer together, which can reduce awareness of surrounding traffic and increase the likelihood of crashes. Nevertheless, guidelines suggest that group riding, when done properly, can enhance safety by allowing cyclists to maintain a tighter formation, reducing the likelihood of close passes from vehicles (CyclingUK, 2024). This finding emphasizes the importance of proper group cycling practices to maximize safety benefits and minimize risks during road interactions.

In terms of other road users' gender, females were less likely to engage in risky interactions with cyclists, with 464 (33.9%). The odds ratio shows that female road users have lower odds involved in risky interaction as much as 0.642 lower (*OR = 0.642*, *95% CI: 0.555–0.743*) compared to male road users. A previous studies show that female drivers often report higher levels of perceived risk when interacting with cyclists, which may lead them to adopt safer driving practices (Rubie et al., 2023). A study by Paschalidis et al. (2023) also indicates that female drivers exhibit less aggressive driving behavior, which may correlate with safer passing practices. However, some research suggests that while female drivers may generally provide more space, their behavior can also be influenced by factors such as traffic conditions and personal attitudes towards cyclists. For example, a study by Goddard et al. (2020) found that negative attitudes towards cyclists could result in closer passing distances, regardless of the driver's gender. Overall, while female drivers may exhibit safer behaviors on average, the complexity of driver attitudes and environmental factors can still influence their interactions with cyclists.

Understanding the behavior of young road users in relation to cyclists is crucial for improving road safety. Young road users are generally less likely to engage in risky interactions with cyclists regarding passing distances of less than 1.5 meters, with the corresponding odds about 0.303 lower (*95% CI: 0.231–0.398*) compared to adults. This lower likelihood may be due to increased awareness and road safety education among younger drivers, who are likely influenced by recent campaigns promoting safe passing distances when overtaking cyclists. For example, campaigns such as the "Share the Road, Ride Wisely" initiative, organized by Suzuki Malaysia and the Malaysian Motorcycle and Scooter Dealers Association, emphasize the importance of maintaining safe distances from vulnerable road users, including cyclists (Wahid Ooi, 2025). Internationally, a study by the Department for Transport & Baroness Vere of Norbiton (2022) highlights those international campaigns like "Travel Like You Know Them" encourage drivers, especially young ones, to empathize with cyclists and maintain a safe passing distance. Additionally, younger drivers often show more cautious behavior, possibly due to their familiarity with cycling culture and a stronger tendency to empathize with vulnerable road users like cyclists (RSA, 2018). Furthermore, the presence of minimum passing distance laws in various areas has been shown to positively influence young drivers' behaviors, encouraging them to follow safer passing practices (Fruhen et al., 2021). However, Mehrotra and Roberts (2022) indicate that young drivers also tend not to comply with minimum passing distance (MPD) rules, especially in high-speed zones. This suggests that while young drivers may be aware of the risks associated with passing cyclists, their inexperience and tendency to take more risks could result in dangerous behavior, particularly in high-speed environments. Overall, this finding emphasizes the need for targeted interventions and education to improve young drivers' adherence to safe passing practices.

Vehicle type significantly influenced the likelihood of engaging in risky interactions with cyclists, particularly regarding passing distances of less than 1.5 meters. Pedestrians were identified as having the highest percentage of interactions, with a corresponding percentage of 75.3%. This was followed by motorcycles and bicycles, with corresponding percentages of 45.9% and 40.3%, respectively. About 26.5% of risky interactions occurred between passenger cars and cyclists. Heavy vehicles had the lowest interaction rate, with only 17.1%. Based on modeling results, the odds of pedestrians being involved in a risky interaction were 8.9 times higher (*95% CI: 7.687–10.468*) compared to passenger cars. The odds ratio for bicycles was about 2.174 times higher (*95% CI: 1.552–3.045*). The same observation was found for motorcycles, where the corresponding odds were about 1.924 times higher (*95% CI: 1.631–2.269*). In contrast, heavy vehicles were less likely to engage in risky interactions, with an odds ratio of 0.470 lower (*95% CI: 0.289–0.763*) compared to passenger cars. This study defined passenger cars as the reference category for the other vehicle types due to their higher traffic composition in Malaysia. The data revealed that pedestrian-cyclist interactions were more frequent, highlighting the unique challenges posed by pedestrian-cyclist conflicts in crowded environments (Haworth et al., 2014). On the other hand, bicycles also contributed to close passing incidents, primarily due to their maneuverability and high presence on the roads (Mackenzie et al., 2019). Motorcycles, due to their speed and size, may also contribute to dangerous overtaking behavior (Humphrey, 2017). A study in Michigan, United States, by Houten et al. (2018) reveals that the size of heavy vehicles and drivers' greater awareness of the need for safe overtaking distances contribute to safer interactions with cyclists. These results suggest that larger vehicles, such as buses and lorries, are less likely to come too close to cyclists compared to cars and motorcycles. However, contrary to our findings, Llorca et al. (2017) found that heavy vehicles, such as buses and trucks, tend to pass cyclists at closer distances compared to passenger vehicles, particularly in rural areas where opposing traffic further reduces passing space. In Malaysia, which does not have a legally mandated minimum passing distance for overtaking cyclists, the Ministry of Transport advises cyclists to maintain a safe distance from vehicles to avoid hazards, as outlined in the Safe Cycling Guideline (MOT, 2022). These findings underscore the importance of considering vehicle type in discussions about cyclist safety and highlight the need for targeted interventions based on vehicle characteristics.

Table 1: Risky interactions passing distance less than 1.5m on different types of road facilities

Type of road	Risky Interaction		Total
	Yes, N (%)	No, N (%)	
Road with bicycle lane – delineated by road markings	1,467 (87)	220 (13)	1,687
Road without bicycle lane / use a carriageway	486 (44.9)	597 (55.1)	1,083
Road with restricted to bicycle / restricted highway	119 (14.3)	712 (85.7)	831
Priority junction (T-junction)	145 (14.8)	834 (85.2)	979
Signalized junction (T and cross junction)	147 (15)	831 (85)	978
Roundabout	255 (50.5)	250 (49.5)	505

Table 2: Passing distance less than 1.5m based on demographic information and vehicle factors

`	Risky Interaction	
	Yes, N (%)	No, N (%)
Cyclist		
Gender		
Female	444 (57.8)	324(42.2)
Male	2,172(41.1)	3,120 (58.9)
Age		
Young	190 (59.4)	130 (40.6)
Adult	2,429 (42.3)	3,314 (57.7)
Type of bicycle		
Electric	620 (60.9)	398 (39.1)
Mountain	237 (21.5)	864 (78.5)
Road	1,762 (44.7)	2,182 (55.3)
Cycling in group		
No	1,604 (40.0)	2,405 (60.0)
Yes	1,015 (49.4)	1,039 (50.6)
Other road user		
Gender		
Female	464 (33.9)	906 (66.1)
Male	2,155 (45.9)	2,538 (54.1)
Age		
Young	142 (48.6)	150 (51.4)
Adult	2,477 (42.9)	3,294 (57.1)
Type of vehicle		
Pedestrian	1,294 (75.3)	424 (24.7)
Bicycle	64 (40.3)	95 (59.7)
Motorcycle	387 (45.9)	457 (54.1)
Car	853 (26.5)	2,366 (73.5)
Heavy Vehicle	21 (17.1)	102 (82.9)

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Table 3: Model estimation for risky interaction passing distance less than 1.5m

Variable	Reference	Odds Ratio	Confidence Interval (95%)	p-value
Cyclist gender				
Female	Male	1.610	1.346-1.926	0.001***
Cyclist age				
Young	Adult	1.912	1.471-2.484	0.001***
Type of bicycle				
Mountain	Electric	0.248	0.199-0.308	0.001***
Road		0.617	0.526-0.724	0.001***
Group cycling				
Yes	No	0.481	0.422-0.549	0.001***
Other road user				
Gender				
Female	Male	0.642	0.555-0.743	0.001***
Age				
Young	Adult	0.303	0.231-0.398	0.001***
Type of vehicle				
Bicycle	Car	2.174	1.552-3.045	0.001***
Motorcycle		1.924	1.631-2.269	0.001***
Pedestrian		8.970	7.687-10.468	0.001***
Heavy Vehicle		0.470	0.289-0.763	0.001***
Log likelihood		6,696.527		
Cox & Snell R^2		0.231		
Nagelkerke R^2		0.311		

*significant at 0.05 level,
**significant at 0.01 level,
***significant at 0.001 level

4. Conclusion

This study aims to investigate risky interactions between cyclists and other road users, focusing on demographic and contextual factors. Field observations were conducted in three cities which is Kuala Lumpur, Cyberjaya, and Shah Alam in Malaysia, covering 6,063 observations at midblock and intersection locations. Binary logistic regression was used to analyze risky interactions between cyclists and other road users, with seven explanatory variables examined: cyclist gender and age, type of bicycle, group cycling, other road user gender and age, and type of vehicle. The study found that several factors significantly influence risky interactions between cyclists and other road users. Female cyclists were more likely to experience risky interactions compared to male cyclists. Additionally, younger cyclists were more prone to engaging in risky interactions, while those on e-bikes faced greater risks than cyclists on other type of bicycles (mountain or road bicycles). Interestingly, group cycling was associated with fewer risky interactions compared to solo cycling. In terms of other road users' gender, young drivers showed greater awareness of risks and tended to maintain safer passing distances compared to adults. Finally, pedestrians, motorcycles, and bicycles were more often involved in close passing incidents, while heavy vehicles were less likely to engage in risky interactions. These findings highlight the critical need for targeted awareness campaigns and improvements in infrastructure to enhance cyclist safety. Specifically, efforts should focus on promoting safer interactions between cyclists and other road users, particularly in addressing high-risk behaviors and improving passing distances. By prioritizing these areas, we can reduce crash risks and significantly improve overall road safety for cyclists.

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