

Comparative Analysis of Fatal Crash Risk in Heavy Vehicle–Motorcycle and Heavy Vehicle–Passenger Car Collisions on Malaysian Expressway

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ABSTRACT – The crashes involving heavy vehicles and smaller vehicles often result in severe injuries and fatalities due to the significant differences in size, weight, and operational restrictions between these vehicles. Heavy vehicles such as trucks, lorries, and container carriers have longer stopping distances, restricted maneuverability, and larger blind spots, all of which increase collision risk with more vulnerable road users, particularly passenger cars and motorcyclists. These factors contribute to the high severity of crashes involving heavy vehicles on expressways. The purpose of this study is to identify the characteristics of heavy vehicle crashes involving other road users, particularly cars and motorcyclists, on Malaysian expressways for the year 2022. Utilizing detailed crash data analysis, the study examines crash types, temporal patterns, and roadway conditions—focusing on traffic environment, road geometry, speed zones, and illumination factors influencing crash frequency and severity. Analysis of crash data revealed that factors such as inadequate roadway lighting and the expressway speed limit of 110 km/h significantly increase the risk of fatal outcomes in both heavy vehicle–passenger car and heavy vehicle–motorcycle crashes. For heavy vehicle–passenger car crashes, additional contributing factors include cross-directional collisions and closed toll highway systems. The results provide valuable insights for highway operators, road safety authorities, and policymakers to formulate targeted interventions aimed at reducing the frequency and severity of crashes involving heavy vehicles. Strengthening such measures is essential to minimize fatalities and serious injuries on Malaysian expressways, which could help achieve the Malaysia Road Safety Plan (MRSP) 2022–2030 target of a 50% reduction in road traffic fatalities by 2030.

KEYWORDS: Fatality, heavy vehicle, likelihood, motorcycle, passenger car

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1. INTRODUCTION

Globally, the definition of heavy vehicle varies based on local regulations. In the US, the Federal Motor Carrier Safety Administration (FMCSA) and state agencies such as Iowa Motor Vehicle Enforcement establish the categories for heavy vehicles based on axle count, weight, and vehicle structure (FHWA, 2001; Kim & Coifman, 2013). According to their weight, heavy vehicles in Malaysia are classified into two primary classes by the Road Transport Department (JPJ): Category N for goods vehicles based on their weight, and Category O for trailers (JPJ, 2017). However, the Malaysia Highway Authority (MHA) classifies heavy vehicles on expressways according to the number of axles and weight, where Class 2 comprises small trucks with two axles, and Class 3 comprises heavier trucks with three or more axles. The crash data analyzed in this study are from expressways, where heavy vehicles are classified based on the Malaysia Highway Authority (MHA) standards. In this context, "heavy vehicles" includes both Class 2 (small trucks with two axles) and Class 3 (trucks with three or more axles), as defined by the MHA.

On Malaysian highways and expressways, trucks were responsible for 58.3% of heavy vehicle crashes, resulting in 4.6% fatalities, 14.7% serious injuries, 12.6% minor injuries, and 68.1% property damage, while trailers were responsible for 28.1% of crashes, with slightly higher fatality rates according to a study by Manap et al. (2021). Besides, the most frequent crash type involving heavy vehicles is a rear-end collision (43%), which is followed by a sideswipe and a loss of control (28%) (Manap et al., 2021). Rear-end collisions in Europe, heavy vehicles are usually involved in rear-end collisions with vehicles, and distraction has been found to be a significant contributing factor; the average speed drops from around 50 km/h to 30 km/h during the impact (Schindler et al., 2022). Heavy vehicles are more dangerous to other road users because of their size and longer stopping distances, which can result in more blind areas and less flexibility (Zainuddin et al., 2023). According to research from China and Korea, heavy vehicle rear-end collisions are primarily nighttime events, with China reporting 72% of these crashes at night and peak fatalities between 4:00 and 5:00 AM (Yuan et al., 2017), whereas Korea finds a higher crash risk at night due to fewer passenger vehicles but more heavy vehicles on the road. (Jo et al., 2019). Furthermore, research also indicates that smaller cars engaged in heavy vehicle incidents have a far higher death rate, underscoring the risks associated with mixed traffic networks (Hamidun et al., 2019). Because of their size and operational characteristics, heavy vehicles also have a negative influence on motorcycle riders' safety on expressways (Suzuki et al., 2019). These results show that certain safety measures are required to handle the difficulties that heavy vehicles present on Malaysian roadways.

Human factors are responsible for 50% of heavy vehicle collision causes, followed by road and environmental variables (26.5%) and vehicle factors (23.5%), according to research by Zainuddin et al. (2023). One of the main human factors causing collisions is driver fatigue, which is brought on by long hours, inadequate sleep, and heavy traffic (Shabadin et al., 2022). According to Naderi et al. (2021), a lack of sleep raises the probability of an accident by 32%, underscoring the need for controlled driving hours. Additionally, speed and speed fluctuation increase the likelihood of heavy vehicle crashes (Wang et al., 2022). Among road and environmental factors, road geometry is most studied, with crashes more likely on straight roads than curves, as proven in Korea (Lee & Jeong, 2016). Crashes mostly occur during daytime (54.8%) and clear weather (88.1%), with nearly half of fatal crashes happening in daylight and most in good weather conditions (Manap et al., 2021). Similarly, Schindler et al. (2022) showed that most heavy vehicle crashes in Europe occur in dry, clear weather, during daylight hours, on dry roads, outside of urban areas, and on non-highway routes. Despite involving only 21.3% of crashes, heavy vehicles are responsible for a disproportionate 32.5% of fatalities (Manap et al., 2021). While numerous research is carried out over the world, many accident characteristics are quite comparable to Malaysia. Although traffic compositions may differ (traffic volumes, congestion patterns, and vehicle mix), Malaysian studies also highlight the importance of distraction, fatigue, environmental conditions, and road geometry in heavy vehicle crashes, particularly on highways and expressways. As a result, this study combines worldwide results with local data to give a thorough picture of heavy vehicle collisions on Malaysian expressways.

Economic growth and the need for effective logistics have increased the demand for heavy vehicle transit on highways and expressways in Malaysia. The increasing number of heavy vehicles will affect the likelihood of crashes, especially crashes that involve smaller vehicles. Crashes that involve heavy vehicles on expressways usually result in more serious injuries, including fatalities, due to the difference in size, weight, and operational restrictions (Zainuddin, 2023; Jo, 2019; Hamidun, 2019). In China, variations in traffic flow have a major impact on expressways, with low average speeds and strong within-lane speed fluctuations raising the possibility of crashes involving large vehicles (Wang, 2022). On Malaysia's North-South Expressway (NSE), hotspot portions for heavy vehicle collisions were discovered by Manap et al. (2021). Although making up just around 9% of total traffic on the NSE, heavy vehicles are responsible for 42.9% of all collision fatalities. This trend reflects that every crash that involves heavy vehicles on a highway and expressway seems like it will be most likely to result in a fatality.

Even though heavy vehicle collisions have been studied extensively across the world, less is known about their features and contributing variables in Malaysia, particularly on highways and expressways. This study aims to examine the patterns of heavy vehicle collisions on Malaysian expressways that involve other road users, including passenger cars and motorcycles. Passenger cars and motorcycles were chosen for study in heavy vehicle incidents because their smaller size and lower mass make them particularly vulnerable in collisions, often resulting in more severe injuries and fatalities. Small vehicle

occupants confront significant safety concerns when colliding with larger, heavier vehicles, especially given Malaysia's various traffic and injury patterns. Consequently, the objective of the research is to identify the characteristics of these collisions to gain a better understanding of their contributing elements. As a result, this study examines collision trends involving passenger cars, motorcycles, and heavy vehicles and intends to guide specific safety enhancements to lower the number of deadly heavy vehicle collisions on Malaysian highways and expressways.

2. METHODOLOGY

The purpose of this study is to determine the traits and trends of heavy vehicle collisions on Malaysian expressways that involve both passenger cars and motorcyclists. To identify the elements impacting heavy vehicle collisions, desktop research that evaluated previous reports and literature was the first step in a five-step technique. The Malaysian Highway Road Accident Analysis and Database System (MHROAD) was then used to gather crash data for 2022, with an emphasis on collisions between heavy vehicle–motorcycle (HV–MC) and heavy vehicle–passenger car (HV–Car) on 31 expressways. Numerous heavy vehicle types and comprehensive collision data, including severity and contributory variables, were included in the report. Proper data cleaning techniques were utilized to guarantee that the data were consistently classified and labelled, hence improving its clarity and usefulness for analysis. The accident data was initially analyzed and simply reported using descriptive statistics to determine the crash pattern. The relationships between categorical variables were further investigated using inferential statistical studies that used Fisher's exact test and the chi-square test, which assess the independence and link between variables in contingency tables. Odds ratios were also computed to measure the direction and intensity of relationships between risk variables and outcomes.

3. RESULTS AND DISCUSSION

This study examines 1,351 heavy vehicle collisions on expressways involving passenger cars and motorcycles. Among these incidents, fatalities resulting from collisions between heavy vehicles and passenger cars were relatively uncommon, constituting only 4% of cases (43 fatal crashes out of 1,074 total). In contrast, collisions involving motorcycles and heavy vehicles were substantially more severe, with fatalities occurring in 38% of such cases (104 out of 277 crashes). Non-fatal crashes accounted for 62% of motorcycle-related collisions and 96% of passenger car collisions, illustrating a markedly higher fatality risk for motorcyclists. Figure 1 presents the distribution of crash severity for both collision types. The lower number of heavy vehicle–motorcycle collisions compared to passenger car crashes represents the real crash distribution, according to MHA data. Malaysia, on the other hand, has the highest road mortality risk per 100,000 population of any ASEAN nation, with motorcycles accounting for more than half of all road crash fatalities (Abdul Manan & Várhelyi, 2012). According to research by Abdul Manan et al. (2018), many motorcycle crashes happen on primary roads rather than expressways, depending on the road hierarchy, which has distinct traffic patterns and exposure hazards for motorcycle riders. As a result of the variations in road conditions and usual collision patterns, it is expected that the number of motorcycle crashes reported on expressways will be lower than that of other vehicles.

Table 1 presents a comparison of crash severity between heavy vehicle–motorcycle (HV–MC) and heavy vehicle–passenger car (HV–Car) collisions. The percentage values are generated per row, showing that each percentage indicates the proportion of collisions within each attribute (HV–MC or HV–Car) that resulted in either non-fatal or fatal outcomes. This computational approach enables a clear comparison between the distribution of accident severity within each attribute. The findings indicate that the probability of a fatal crash in HV–MC incidents is markedly higher across all categories. Specifically, for different collision types, rear-end and side collisions are linked to significantly lower rates of fatal crashes, whereas cross-directional impacts pose the greatest risk, resulting in a fatal crash rate of 100% for HV–MC and 33.3% for HV–Car. A rear-end collision happens when one vehicle collides with another's back, whereas a side collision, sometimes known as a T-bone collision, includes contact with a vehicle's side. Skidded collisions occur when a vehicle loses control, while cross-directional crashes happen when vehicles typically cross the expressway median towards opposing traffic lanes.

TABLE 1: Crash severity for collision of heavy vehicles involving passenger cars and motorcycles

Attribute Class	Attribute	Heavy vehicle and motorcycle			Heavy vehicle and passenger car		
		Fatal	Non-fatal	Fatality risk (%)	Fatal	Non-fatal	Fatality risk (%)
First collision type	Rear-end	82	118	41.0%	28	659	4.1%
	Side collision	18	13	58.1%	6	242	2.4%
	Skidded	3	40	7.0%	7	103	6.4%
	Cross direction	1	0	100%	2	4	33.3%
Lighting condition	Bright	43	94	31.4%	15	491	3.0%
	Dark with light	25	48	34.2%	7	248	2.7%
	Dark without light	36	31	53.7%	21	292	6.7%
Expressway system	Open toll	29	66	30.5%	4	251	1.6%
	Close toll	75	107	41.2%	39	780	4.8%
Speed limit	<90 km/h – 50 km/h	16	47	25.4%	3	184	1.6%
	90 km/h	16	43	27.1%	6	198	2.9%
	110 km/h	72	83	46.5%	34	615	5.2%

Crash Severity of Heavy Vehicle Crashes Involving Passenger Car and Motorcycle

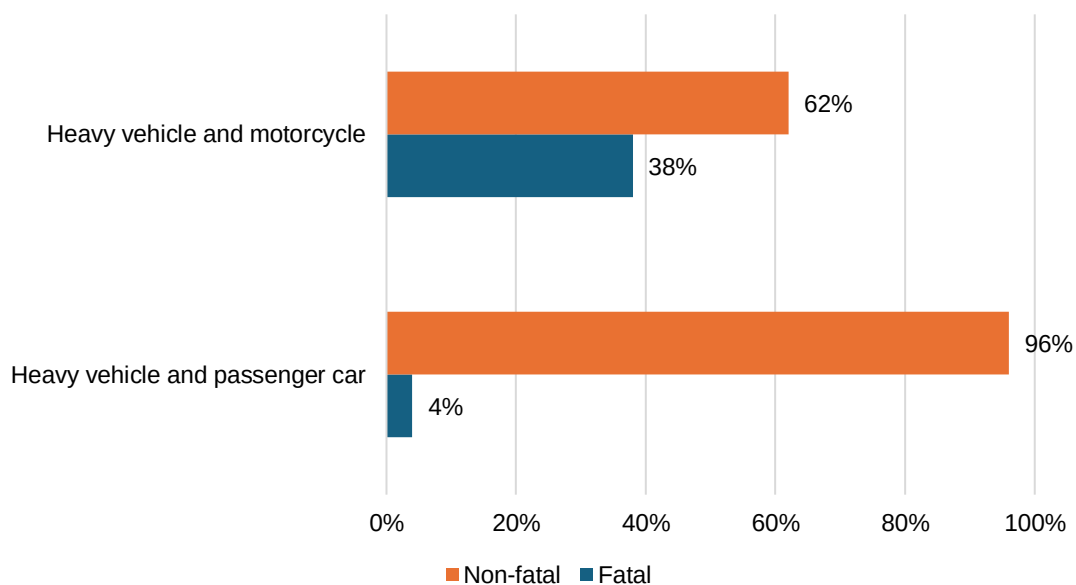


FIGURE 1: Crash severity of heavy vehicle crashes involving passenger cars and motorcycles

Regarding lighting conditions, the risk of a fatal crash for HV–Car remains relatively modest across all scenarios, but HV–MC crashes are most deadly in dark conditions without illumination, where the fatal crash rate approaches 53%. The fatal crash rates for HV–MC are also significantly higher than those for HV–Car on both open toll systems (open-access system where vehicles pay a fixed amount at designated toll plazas) and closed toll systems (controlled-access system where vehicles tap a card upon entering and pay toll fees based on the distance travelled when exiting the highway), highlighting the greater vulnerability of motorcyclists in these environments. Furthermore, the probability of a fatal crash for HV–MC rises with increasing speed limits, reaching 46.5% at 110 km/h, while the rate for HV–Car remains consistently low, peaking at just 5.2%. Overall, these results clearly demonstrate that HV–

MC collisions are associated with a much higher fatal crash likelihood than HV–Car collisions under all studied conditions.

These results are consistent with previous studies demonstrating that collisions involving heavy vehicles and motorcycles (HV–MC) are markedly more likely to result in fatal outcomes compared to those involving heavy vehicles and passenger cars (HV–Car), largely due to the stark size and protection disparities between vehicle types (Mansoor et al., 2023; NHTSA, 2024). Specifically, the heightened fatal crash rates for motorcycles under poor lighting and higher speed limits are supported by evidence that motorcyclists are far more vulnerable to severe injury or death, especially when visibility is compromised or impact forces are greater (Savolainen & Mannering, 2007; Robbins & Fotios, 2020).

According to the analysis of factors influencing heavy vehicle–motorcycle (HV–MC) crashes, both speed limits and lighting conditions significantly affect the likelihood of such collisions (Table 2). Specifically, the probability of an HV–MC crash occurring in dark conditions with light and dark conditions without light is more than twice as high, highlighting the pronounced risk posed by poor visibility. Furthermore, HV–MC collisions on road segments with speed limits above 110 km/h exhibit a risk more than double that of segments where the speed limit is below 90 km/h, underscoring the exacerbating effect of higher travel speeds. In contrast, the analysis found that neither the first collision type nor the expressway system had a statistically significant impact on HV–MC crash probability. Cross-direction collisions of HV–MC could not be analyzed using chi-square or Fisher's exact tests because there was no data for the non-fatal category. For these tests to be valid, each category of both variables must contain values; missing data in any category causes the test to fail. These results collectively emphasize that stricter regulation of speed limits and enhanced expressway illumination are crucial interventions for reducing the risk of HV–MC crashes. Emphasizing these external elements helps to focus interventions on improving road conditions to improve expressway safety. Although vehicle illumination is also important, it mainly concerns the vehicle and driver visibility, not the road or traffic factors analyzed in this study.

In contrast, analysis of passenger car–heavy vehicle (HV–Car) collisions identified two factors with statistically significant associations ($p < 0.05$) (Table 3). Cross-direction collisions exhibited a dramatically higher risk, with an odds ratio of 20.17, indicating that HV–Car crashes involving vehicles traveling at cross angles are over 20 times more likely to result in a fatal crash than rear-end collisions. Lighting conditions also played a major role; in dark without light condition the probability of a fatal HV–Car crash was 2.55 times greater than in dark with light area. For expressway system type, crashes occurring on closed toll systems were associated with a 3.14-fold increased risk of fatality compared to open toll systems. Additionally, sections of expressway with 110 km/h speed limits showed more than double the fatal crash risk (odds ratio: 2.55) relative to segments limited to under 90 km/h. These findings highlight that higher speed limits, closed toll systems, insufficient illumination, and cross-directional impacts all substantially elevate the risk of fatal HV–Car crashes.

The elevated risk of fatal HV–MC crashes under dark conditions and at higher speed limits found in this study is supported by Xiong et al. (2016), who reported that poor visibility and nighttime hours significantly increase the severity of motorcycle injuries, particularly in collisions involving larger vehicles. Similarly, previous research by Mansoor et al. (2023) confirms that lighting defects and excessive speed are among the most consistent risk factors for severe outcomes in motorcycle collisions (Mansoor et al., 2023). For HV–Car crashes, cross-direction collisions, closed toll systems, insufficient lighting, and higher speed limits are linked to higher fatal crash risk. These findings agree with Robbins & Fotios (2020), who found that intersections and low-light environments increase fatal outcomes in passenger vehicle and truck crashes. However, other studies, such as Mansoor et al. (2023), did not find a statistically significant association between road system variables and collision severity, suggesting the need for further research on the unique characteristics of Malaysian expressways (Mansoor et al., 2023).

TABLE 2: Chi-square test, Fisher's Exact test and odds ratio for heavy vehicle crashes involving motorcycles

Attribute Class	Attribute	Chi-square (P-value)	Fisher's exact (P-value)	Odds ratio	95% CI
First collision type	Skidded	-	0.121	Ref	-
	Side collision			1.95	0.50 - 7.70
	Rear-end			3.01	0.84 - 10.90
Lighting condition	Dark with light	0.007	-	Ref	-
	Bright			0.88	0.49 - 1.61
	Dark without light			2.23	1.13 - 4.41
Expressway system	Open toll	0.081	-	Ref	-
	Close toll			1.59	0.94 - 2.70
Speed limit	<90 km/h – 50 km/h	0.003	-	Ref	-
	90 km/h			1.09	0.49 - 2.45
	110 km/h			2.55	1.34 - 5.88

TABLE 3: Chi-square test, Fisher's Exact test and odds ratio for heavy vehicle crashes involving passenger cars

Attribute Class	Attribute	Chi-square (P-value)	Fisher's exact (P-value)	Odds ratio	95% CI
First collision type	Rear-end collision	-	0.013	Ref	-
	Side collision			1.71	0.71 - 4.16
	Skidded			2.74	0.90 - 8.36
	Cross direction			20.17	3.08 - 132.29
Lighting condition	Dark with light	0.015	-	Ref	-
	Bright			1.08	0.44 - 2.69
	Dark without light			2.55	1.07 - 6.10
Expressway system	Open toll	-	0.026	Ref	-
	Close toll			3.14	1.12 - 8.88
Speed limit	<90 km/h – 50 km/h	0.003	-	Ref	-
	90 km/h			1.09	0.49 - 2.45
	110 km/h			2.55	1.34 - 5.88

Overall, the study found that higher speed limits and poor lighting significantly increase the risk of HV-MC collisions. For HV-car crashes, four key factors – higher speeds, closed toll systems, cross-direction collision types, and poor lighting – significantly raise the likelihood of crashes. Notably, the findings highlight that speed limits and roadway illumination significantly influence the severity of heavy vehicle collisions involving both motorcycles and passenger cars. These results reinforce the urgent need for enhanced safety measures and stricter enforcement, such as greater speed management, improved roadway lighting, and targeted infrastructure improvements to effectively mitigate the risk and consequences of heavy vehicle crashes.

4. CONCLUSION

This study analyzed 1,074 heavy vehicle–passenger car (HV–Car) collisions and 277 heavy vehicle–motorcycle (HV–MC) collisions on Malaysian expressways. The findings reveal a markedly higher fatal crash rate for HV–MC collisions (37.5%) compared to HV–Car collisions (4%). Statistical analysis identified speed limits and roadway illumination as the primary factors driving fatal outcomes for both HV–MC and HV–Car crashes. For HV–Car crashes, cross-direction collisions and closed toll systems further elevate risk. These findings underscore the urgent need for strengthened speed limit

enforcement and investment in lighting across expressways to mitigate crash severity. To address expressway crash risks, focused interventions such as infrastructure upgrades, targeted enforcement, and road design improvements should be prioritized, especially in high-risk segments. Future research should explore the detailed interaction between road design features and heavy vehicle crash severity, leveraging predictive analytics and pilot intervention studies in identified hotspots. Ultimately, the results reinforce established knowledge about the severe risks posed by heavy vehicles on Malaysian highways, particularly in relation to speed, impact type, illumination, and system design, and provide actionable insights for achieving the national goal of fatality reduction.

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