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Evaluating Risk Factors in Motorcycle-Passenger Car Crashes through Real-World Investigation

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Abstract – *The study analyses 55 real world crashes involving motorcycles with passenger cars through on-the-spot crash investigation. Analysis was performed based on input gathered during vehicle damage assessment, crash site inspection and injury information provided by the treating hospital. Through the analysis performed, the data revealed that weekday crashes mostly occurred during morning period while weekend crashes were more prevalent at night. Crashes occurring during weekends were less likely to occur between 06:00 until 11:59 and 6.125 times more likely to occur during the night period (18:00 – 23:59). Most of the motorcycle – passenger vehicle crashes investigated involved situations whereby both the vehicles were travelling in the same direction, with one of the vehicle in turning manoeuvre. Moreover, 61.8% of the investigated crashes occurred when the passenger vehicles were at fault. The data revealed 28.7% of the involved riders suffered injuries to lower extremities, followed by head and neck injuries at 25%. In terms of injury severity of the involved riders, odds ratio value reveals that side impact, compared to other types of crash configuration were 3.750 times more likely to result in MAIS 3 and above. The result also proved that impact speed has a significant effect on the injury severity of the riders. MAIS level 2 and below injury severities were over presented for the lower range impact speeds while an adverse trend was observed for the higher range impact speeds.*

Keywords: On-the-spot crash investigation, motorcycle safety, passenger vehicle, injury severity

1.0 INTRODUCTION

Throughout the years, the motorcycle has become one of the most common type of vehicles on the road, particularly in the Southeast Asian region due to its size-convenience and affordable price. The motorcycle constitutes approximately 58% of vehicles in ASEAN countries, and over the last decade it has been the major contributor, with 52%, to road traffic fatalities in ASEAN region (WHO, 2009). According to Padmanaban and Vitaly (2009), evidence suggests that increasing congestion, availability of parking, and travel costs are encouraging the purchase of powered two wheelers (PTW) for transport, particularly the underbone-typed motorcycles. In Malaysia, a similar trend is also observed. Leong et al. (2005) reported that composition of annually registered vehicles on Malaysian road consist mainly of motorcycles, passenger cars, buses and lorries and 50% of the total registered vehicles were motorcycles. In terms of the demand for motorcycles in Malaysia, the market will continue to sustain and further grow in the future due to several factors including traffic congestion, social economic, inefficiency of public transport and parking space convenience for motorcycles compared to cars (Leong et al., 2005).

Road injuries and fatalities are a major concern in Malaysia, with more than 6000 road users killed and over 25,000 injuries recorded annually for the past 5 years (RMP, 2009). Every year in Malaysia, approximately 60% of road crash fatalities involve motorcycle crashes and motorcyclist are found to contribute almost 70% of all level injuries in road crashes. When viewed in terms of number of motorcyclist fatalities by 100,000 populations, Malaysia ranks the highest in the ASEAN region (WHO, 2009). The hazards associated with motorcycle is significant due to mixed traffic flow on roads. Huang and Preston (2004) concluded that more than half of fatal motorcycle crashes involve another vehicle as a crash partner in which the latter is most often at fault. Commonly, this involves violations of the motorcyclist's right of way. On the other hand, Wing et al. (2013) mentioned that the Malaysian in-depth crash investigation data confirmed that approximately 38% of the total fatal motorcycle crashes involved passenger vehicles (cars, SUVs & MPVs) as their crash partners and a majority of injuries involved frontal impact (40.0%). Unlike car drivers, motorcyclists are directly exposed to the environment. Compared to other types of road motor vehicles, the motorcycle is designed with low safety protection and inferior structural integrity (Walker et al., 2011).

Walker et al. (2011) also mentioned that other than lack of occupant protection, one of the reasons for motorcyclists being exposed to higher risks of crashing is the motorcycle's instability and difficulty in braking. Although numerous Intelligent Transportation System (ITS) technologies have the potential to actively prevent crashes involving motorcycles or passively lessen the severity of injuries when a motorcycle is involved in a crash, motorcycles face a particular problem when it comes to technical adaptation of certain ITS systems because their dynamics differ from those based on a four-wheel platform (Turner & Higgins, 2013). With regard to crash configurations, crash data from the Royal Malaysian Traffic Police (RMP) showed the largest group of motorcycle fatalities occurred from 'Angular or Side', followed by 'Out of Control' and Head-on' type of collisions. However, more in depth information including the role of the motorcycle in such an impact – whether as an impacting or an impacted vehicle – or the type of object being hit by the motorcycle and the kinematics of the crash is unknown in the available data. Moreover, looking closely at the type of crash partner involved, collision between a motorcycle and passenger car was the most frequent cause of fatality. A study conducted by Fitzharris et al. (2009) analysed hospital records and found that injuries to the head were the most common, followed by injuries to the upper extremity, and lower extremity.

Chawla et al. (2005) concurred that motorcycle crashes were far more difficult to analyse due to the multiplicity and complexity of the interactions involved, although quite a few studies tried to compare occupant kinematics in motorcycle-passenger vehicle crashes between computer simulation and full scale tests. However, much of the information necessary to understand these complex issues is found at the scene of the crash and is lost once the accident scene is cleared. This is best achieved through in-depth crash investigations, as noted by

Mackay et al. (1985). Thus, through this study, information from real world crashes was gathered in order to thoroughly understand the consequences of motorcycle crashes particularly to the crash mechanism and severity outcome. This information is crucial in providing more detailed insights of motorcyclist safety particularly with regard to crashes with passenger vehicles.

2.0 METHODOLOGY

In order to understand how and why the crash between motorcycle and passenger car occurred and how injury to the involved motorcyclists happened, prospective approach of on-the-spot crash investigation was utilized in this study. The overall process flow of the study in shown in Figure 1.

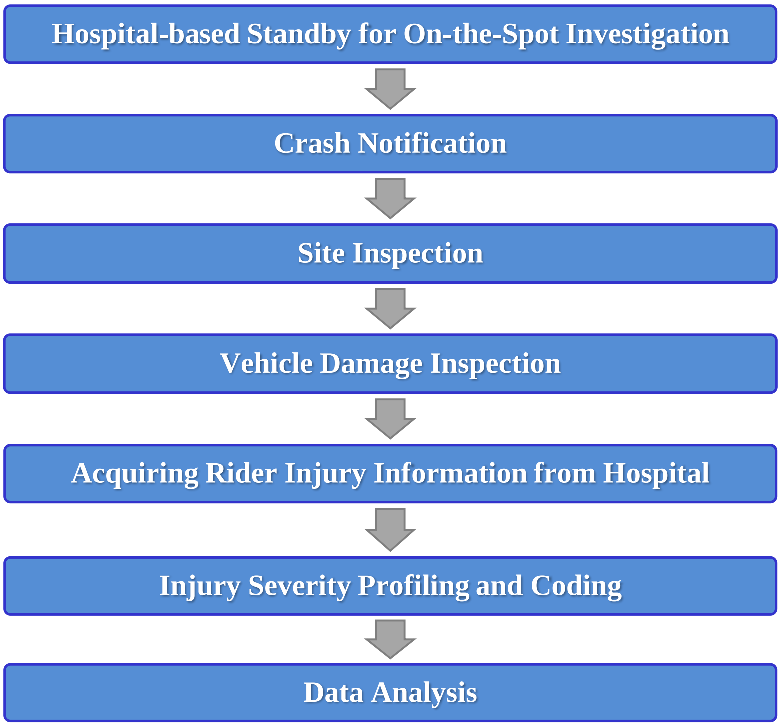

Figure 1: Flow of work involved in the study

Through this approach, the researcher was able to avoid loss of information particularly volatile evidences of the crash such as brake marks and rest positions of the vehicles and occupants. The investigation process is divided into two areas; namely the crash scene investigation and the vehicle damage inspection. Crash scene investigation involves measuring and recording of technical parameters leading to the crash occurrence and crash dynamics such as physical evidence of tire marks, distance between vehicle rest positions and the occupants, and other important parameters, upon arriving at the crash scene. Vehicle inspection mainly focuses on identifying structures and components of the vehicles (passenger car) which involves direct and indirect force impacts, availability of vehicle safety features, evidence of restraint wearing and others.

The study focuses on crashes involving motorcycles with passenger cars. Researchers were stationed at the Trauma and Emergency Department of Hospital Kajang to facilitate the crash notification by the hospital. Hospital-based investigation was utilized in order to enable on-the-spot investigations to be conducted at the crash scene. Moreover, this method was important in allowing acquisition of detailed injury information of the involved motorcyclists from the initial treating hospital. Standby period was performed in a total of three 8-hour shifts on a weekly alternate basis for a continued one-year period. This method enabled the team to collect the entire population of cases, covering the entire shift. A set of four dedicated data collection forms were utilized in the study to record important parameters such as the general information of the crash, pre- and post-crash vehicle information of both passenger car and motorcycle, and also injury aspects of the involved motorcyclists.

Real world crash cases obtained from the hospital-based on-the spot investigation were analysed and reconstructed to assess important parameters during the vehicle and crash site investigation. The injury information retrieved from the hospital was then coded to rank the injuries according to level of severity using the Abbreviated Injury Scale (AIS) which was then profiled with the technical information retrieved from the crash reconstruction process. In order to indent the level of injury severity sustained by the involved riders in the investigated crashes, the Maximum Abbreviated Injury Scale (MAIS) was used. The speed calculation analysis was conducted by considering the final state of the crash, or the final rest positions of vehicles involved, and analysed backwards. For the purpose of conducting this analysis, the investigated crashes were considered in chronological phases; pre-impact, during impact and post-impact.

The crash data was then analysed collectively through descriptive and statistical analysis method utilizing the SPSS program Version 20. Non parametric test was used to study the difference between distributions of impact speeds. Cross tabulation was conducted to evaluate the odds ratio value of each identified crucial factor to identify ratio of likelihood of the riders involved being injured.

3.0 RESULTS AND DISCUSSION

The study analyses 55 real-world motorcycle-car crashes through on-the-spot investigation between June 2016 and July 2017. The primary information gathered through vehicle and site inspection was further complemented by injury information provided by the Emergency and Trauma Department of Kajang Hospital, as the treating medical institution.

3.1 Temporal Characteristics

With regard to the temporal characteristics of crashes, the study analysed the crash occurrence distribution represented by the day and time of crash. As shown in Figure 2, a different trend was observed between weekday and weekend crashes. For the purpose of analysis, weekend was considered as Saturday and Sunday which was the public holiday period in the state of Selangor. Overall, the majority of motorcycle-passenger car crashes occurred on weekdays with 44 cases (80% of the total investigated crashes). For weekday crashes, the data revealed that crashes mostly occurred during the morning period (06:00 – 11:59), with 48.8% of crash occurrence. This may be due to the high traffic volume during the specific period with more road users occupying the roads to commute to work. Meanwhile, the lowest distribution in crash occurrence pattern can be seen during the wee hours, between midnight till dawn, which had the lowest traffic volume on a normal working day. Previous studies show that motorcycles were commonly used in Malaysia to ease the journey and avoid traffic congestion particularly for work rather than recreational (Leong et al., 2005). On the other hand, weekend crashes were most dominant during the night period, between 6.00 pm until midnight (58.3%). The high number of crash occurrence during this specific period may be contributed to the rise in motorcycle volume whereby younger riders particularly teenagers would generally go out for leisure.

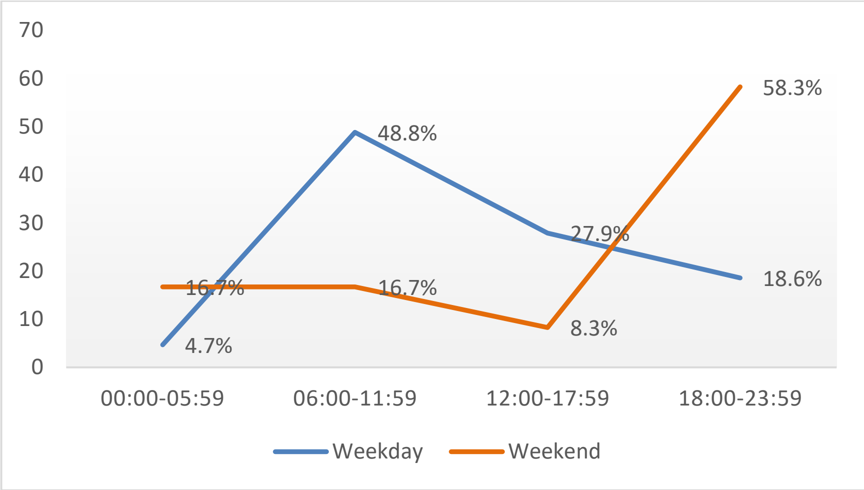

Figure 2: Distributions of crash occurrence time according to types of day

Association between the type of day and time for motorcycle-passenger car crash occurrence is shown in Table 1. Overall, two time periods were found to be associated (*p* value < 0.05) with the type of day in regard to the crash occurrence, namely the morning period (06:00 – 11:59) and night period (18:00 – 23:59). The odds ratio value indicates that a motorcycle-passenger car crash occurring during weekend was 0.210 times less likely to occur between 06:00 until 11:59 and 6.125 times more likely to occur during night period (18:00 – 23:59) when compared to other time periods.

Table 1: Unadjusted odds ratio between time of crash occurrence and type of day

Time	Type of Day		Sig.	Odds Ratio	95% Confidence Interval	
	Weekend	Weekday			Lower Bound	Upper Bound
00:00 – 05:59	2	2	0.20	4.100	0.513	32.762
06:00 – 11:59	2	21	0.04	0.210	0.041	1.071
12:00 – 17:59	1	12	0.15	0.235	0.027	2.022
18:00 – 23:59	7	8	0.01	6.125	1.539	24.369
Total	12	43				

3.2 Demographic Trends

In terms of riders' involvement by age distribution, the data reveal that riders aged up to 25 years old were heavily involved in motorcycle-passenger car crashes (63.6%), as shown in Figure 3. Socio-economic factors in Malaysia could be the largest contributor to the trend. This age segment comprises the group of novice riders or people who recently obtained valid driving license in Malaysia, i.e. 16 years old for motorcycle and 17 years old for cars. The same segment also comprises road users between the ages of 22 to 25 years old are which is the common age range for most tertiary level fresh graduates to land their first job in Malaysia. Due to the economic factor and relatively lower price of motorcycles as compared to other types of vehicles such as cars, the percentage of motorcycle usage by riders within this age group was significantly high. Furthermore, this age group recorded also the highest fatality on Malaysian roads in recent years (Wing et al., 2013). Previous studies also related the overrepresentation of young riders in motorcycle injuries to inexperience in handling and higher exposure to riding (NHTSA, 2006). It is worth to note that the data also highlighted 5.5% of crashes involving unlicensed riders aged 13 and 15 years old.

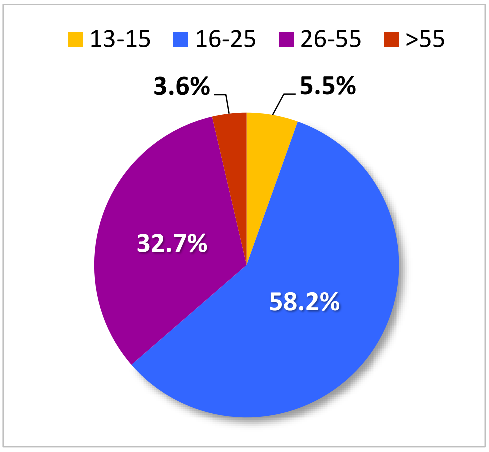

Figure 3: Riders' and drivers age information

3.3 Vehicle Involvements

With regards to types of passenger vehicle involvement as crash partners in motorcycle crashes, investigation data revealed that nearly 90% involved cars while Multipurpose Vehicles (MPVs) and Sport Utility Vehicles (SUVs) only recorded approximately 10% when combined, as shown in Figure 4. On the other hand, the national road accident records from the Royal Malaysian Traffic Police (RMP) also denotes that passenger cars recorded the highest involvement in road traffic crash compared to other vehicle types (69.7% from total accidents). The high numbers of registered passenger cars (44.6% from total number of registered vehicles) may have contributed to the high involvement of such vehicle in the overall crash statistics [RMP, 2014]. A study conducted in the USA by the National Highway Traffic Safety Administration (NHTSA) also found that passenger cars were highly involved in crashes with motorcycles, which was similar to the Malaysian scenario.

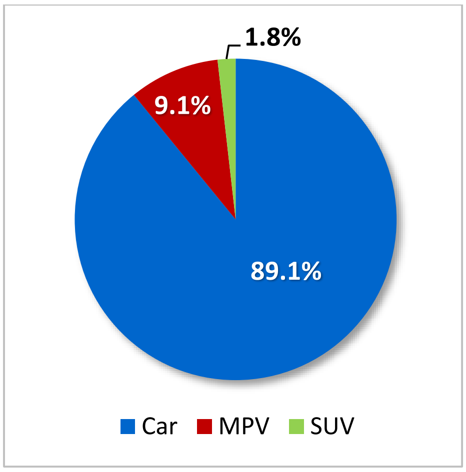

Figure 4: Percentage of types of crash partners' involvements

Meanwhile, the in-depth data revealed 61.8% of the investigated crashes occurred when the passenger vehicles were at fault (Figure 5). The data collection protocols define "the at-fault situations" as factors contributing to crash occurrence due to noncompliance to local traffic rules such as driving above speed limits, right of way issue and red light running or driving negligence including turning without proper signalling, dangerous lane change and others.

Due to their relatively small build up, this may have greatly contributed to inconspicuity of motorcycles. In terms of at fault status, Weissenfeld et al. (2011) noted that motorcyclists were more likely to be victims than perpetrators in multi-vehicle crashes. On top of that, a study by Haque et al. (2009) mentions that the likelihood of crashes where motorcycle was not-at-fault was found to occur largely at intersections and expressways.

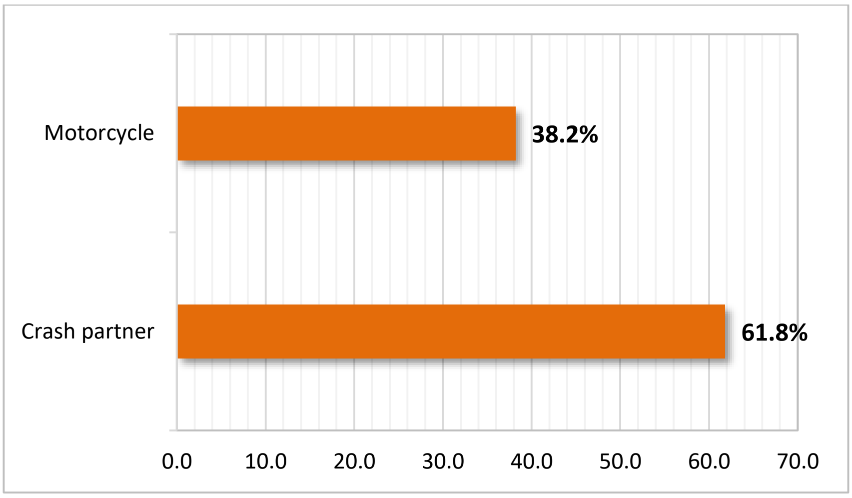

Figure 5: Percentage of at-fault status

3.4 Configurations and Classifications of Crash

In terms of crash configurations, a majority of the investigated cases were side impacts with 40% followed by rear impact collisions (36.4%), as presented in Figure 6. However, side impact collisions can be subdivided into several side impact configurations including perpendicular (90 degree) side impacts, large angle angular side impacts and side swept impacts. Due to generally higher level of damage intrusion suffered by the involved vehicle structures, perpendicular and angular side impacts generally result in higher severity outcome to the involved occupants.

Since the nature of the crash population collected in the study generally involved non-fatal crashes, small angle angular side impacts and sideswipes were found as dominant side impact configurations. With regards to national accident database, the police data showed a similar pattern with the largest group of motorcycle fatalities resulting from 'Angular or Side', followed by 'Out of Control' and Head-on' type of collisions (Abdul Manan & Várhelyi, 2012).

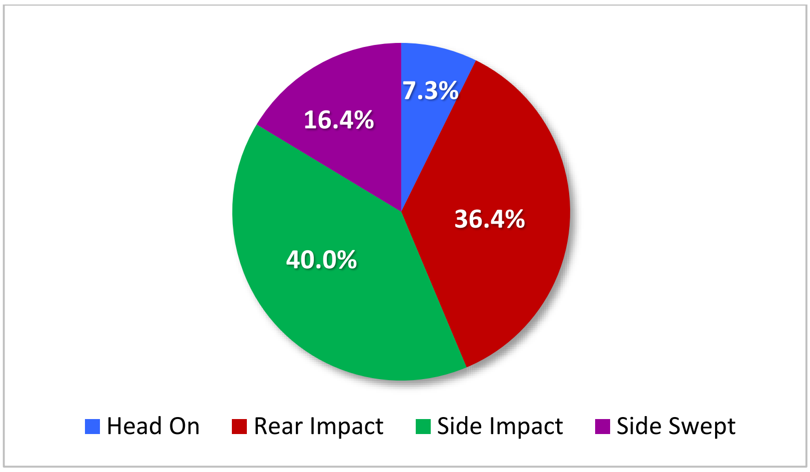

Figure 6: Motorcycle – passenger vehicle crashes by crash configurations

Still on crash configurations, the study also looked into the pre-impact movement of the involved vehicle, namely impact classification. With regards to crash classification, indented as CC, the investigated crashes were divided into seven types of classification depending on the direction of travel and manoeuvring status of the vehicles. The classifications are as follows:

CC1: Intersecting Direction of Travel;
CC2: Intersecting Direction of Travel (At Least One Vehicle Turning);
CC3: Opposing Direction of Travel (At Least One Vehicle Turning);
CC4: Opposing Direction of Travel (Head on Collision);
CC5: Running Off the Road;
CC6: Same Direction of Travel (At Least One Vehicle Turning); and
CC7: Same Direction of Travel (None of Vehicle Turning).

Most of the motorcycle-passenger vehicle crashes investigated involved situations whereby both the vehicles were travelling in the same direction, with one of the vehicle performing a turning manoeuvre (denoted 6 in Figure 7 with 54.5%). In terms of vehicle pre-impact direction, this type of crash classification consists of angular side impacts, side swept, and angular rear impact collisions.

Meanwhile, crashes involving opposing direction of travel with one vehicle turning ranked second with 14.5% while crashes involving intersecting direction of travel with turning vehicle recorded the third highest with 12.7%. García et al. (2009) revealed that that three of the top rank crash configurations involved crashes at intersections. Intersection crashes were often linked to crash partner vehicles' driver misjudgement of oncoming motorcycle and conspicuity issue mainly to the small motorcycle size. No rear impact crashes were found in the investigations.

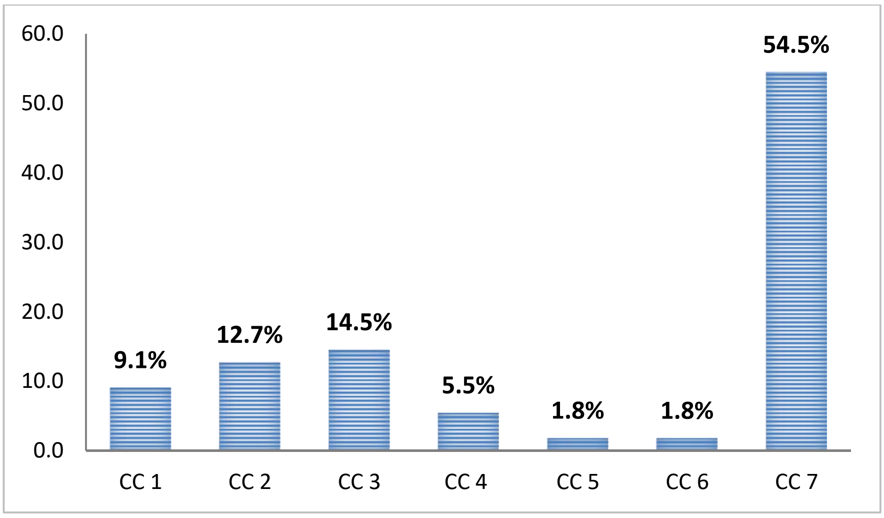

Figure 7: Crash distribution by classification of crash type

3.5 Impact Severity and Injury Outcome

The Maximum Abbreviated Injury Scale (MAIS) was used to measure the level of injury severity sustained by the riders in the investigated crashes. MAIS refers to the maximum level considering the overall AIS value denoted from each body region. Based on the result shown in Table 2, with regards to crash configurations, side impact collisions were found to be significantly associated to MAIS value of the rider. Odds ratio value of 3.750 revealed that side impact, compared to other crash configurations was 3.750 times more likely to result in MAIS 3 and above. Other crash configurations which included head-on, rear impacts and side swept were not associated to the MAIS result since the *p*-value was less than α = 0.05.

Table 2: Unadjusted odds ratio between crash configuration and MAIS

Crash Configuration	MAIS		Sig.	Odds Ratio	95% Confidence Interval	
	Above 3	Less Than 2			Lower Bound	Upper Bound
Head on	1	3	0.67	0.800	0.077	8.321
Side Impact	10	12	0.03	3.750	1.108	12.694
Rear Impact	3	17	0.07	0.299	0.073	1.218
Side Swept	2	7	0.48	0.653	0.120	3.547
Total	16	39				

With regards to injuries, the highest distributions of injured body region were recorded for lower extremities. The data revealed 28.7% of the involved riders suffered injuries to lower extremities, followed by head and neck with 25%. Injuries to lower limbs are common in motorcycle crashes due to the fact that the specific body regions were often the most exposed to contact with vehicle structures in an event of a crash. Entrapment of the rider by the other vehicle could prevent injury-producing ejection from the motorcycle, but may cause lower extremity injury through an impact between the lower extremity and a car bumper. Meanwhile, Peek et al. mentioned that lower-extremity injuries were most common in non-fatal motorcycle crashes, affecting about 30-70% of injured riders. As shown in Figure 8, all of the injured body region of the involved riders had Maximum AIS value (MAIS) of 1 while MAIS 2 level was the highest for thorax injuries. On the other hand, MAIS 3 was recorded for all body regions and was the highest for upper extremities injury, with 29%. MAIS 4 occurrence was found for the head and neck body regions, specifically referring to cases involving the red triage rider.

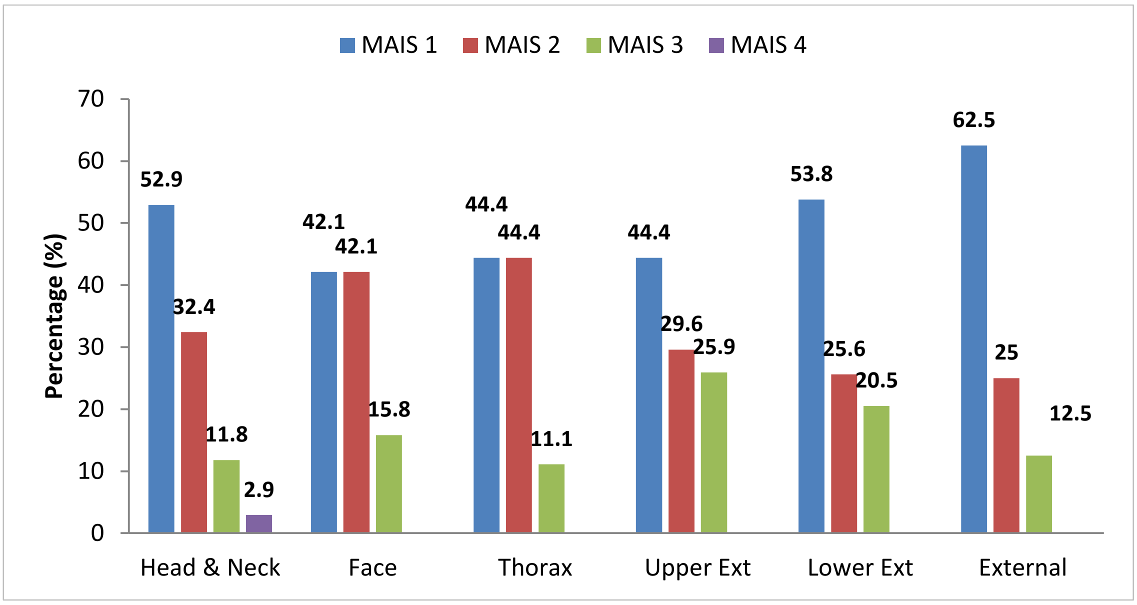

Figure 8: Maximum AIS according to specific body region

Calculation of impact speeds for the involved motorcycles enables quantifying the severity of the crash. By focusing on the motorcycle as the crash subject, the pre-impact motion of the motorcycle was characterized and the impact speed of the motorcycle was calculated. By considering the kinematics and energy dissipation during each crash phase, the calculated speeds were considered as the most probable speed of the involved vehicles. Result of the analysis reveals that the calculated impact speeds from the investigated crashes ranged from a minimum of 7 km/h to the highest of 51 km/h (1 case) in which the latter involved a rhesus coded hospital admission for the said rider. Overall, crashes with impact speed ranging between 7 to 21 km/h showed the highest distributions with 76% as compared to higher impact speeds of up to 36 km/h (22%). In regard to injury severity outcome, as presented in Figure 9, MAIS 2 and below injury severity were over presented for the lower range impact speeds while an adverse trend was observed for the higher range impact speed (MAIS $\geq$ 3 with 22%).

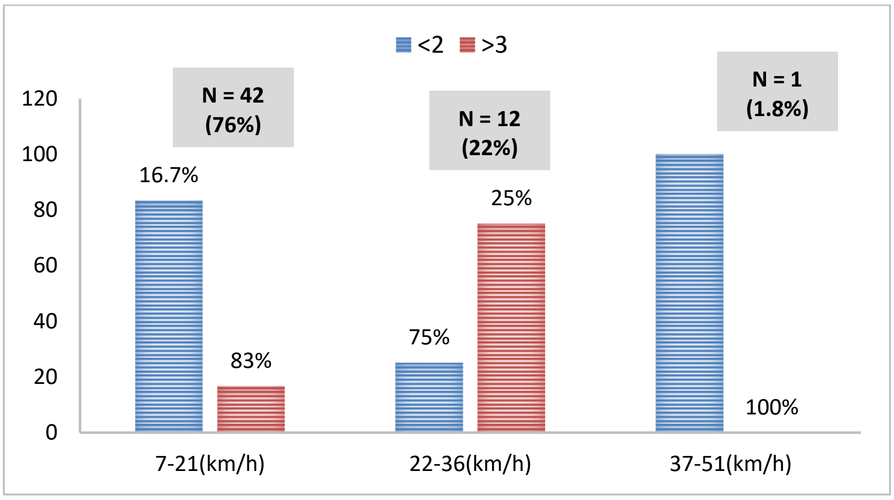

Figure 9: Crash distributions according to impact speed

Next, the author explored the difference between the distributions of impact speeds between the sub-divisions of passenger cars in a crash event with a motorcycle. Since the data was in continuous form and served to compare between two independent, categorical groups, non-parametric approach of Mann-Whitney U Test was applied. Based on the result shown in Table 3, the test reveals that the Asymptotic Significance, also known as *p*-value had value of less than 0.05. This indicates no significant difference between the types of crash partner (M= 28.65, 22.67) and that the pattern and distributions of impact speed between Car Group and MPV/SUV Group had similar pattern of distributions. Similar pattern of impact speeds may result in similar impact severity towards the involved motorcyclist in terms of injury outcomes.

Table 3: Result of Mann-Whitney U test on types of crash partners

Type of Crash Partner	Mean
Car	28.65
MPV/SUV	22.67
	Impact Speed
Mann-Whitney U Test	115.000
Wlicoxon W	136.000
Z	-0.864
Asymp. Sig. (2-tailed)	0.388

Looking further into the association between the impact speed and MAIS, the result presented in Table 4 show a strong association between both parameters with the likelihood of getting MAIS 3 and above more likely for impact speeds of 15km/h and above. The result proved that impact speeds plays an important effect towards the injury severity outcome of riders particularly towards human tolerance to velocity change during impacts. The odds ratio value implied that impact speed less than 15 is 0.080 times less likely to result in MAIS 3 and above as compared to impact speed of 15 km/h and above.

Table 4: Unadjusted odds ratio between impact speed and MAIS

Impact Speed (km/h)	MAIS		Sig.	Odds Ratio	95% Confidence Interval	
	≥3	≤2			Lower Bound	Upper Bound
< 15	3	29	0.00	0.080	0.019	0.338
More Than 15	13	10				
Total	16	39				

4.0 CONCLUSION & RECOMMENDATIONS

To evaluate the risk factors involved in motorcycle-passenger car crashes, this paper uses real world investigation data as much of the information needed to understand the issue is found at the crash scene and gets lost once the accident scene is cleared. Furthermore, due to unavailability of injury details from the Royal Malaysian Traffic Police (RMP) national accident database, injury information of the riders involved was obtained from the treating medical institution. Such information is crucial in providing thorough understanding of motorcyclist safety particularly in crashes with passenger vehicles.

As the majority of crashes involved situations whereby the crash partner was at fault, this finding highlights the issue of mixed traffic flow on the road. Due to the motorcycle's inferior design structure, the riders were directly exposed to the environment thus exposed to higher risk of injury even in low impact crashes. As efforts to completely segregate these vulnerable road users from sharing the road with other mode of vehicles with more superior structural built up tend to be too costly for road authorities and highway concessionaires, other alternative efforts are needed. Providing additional paved shoulder width along the road to enable non-exclusive motorcycle path could be an effective solution. Although this does not provide total isolation of the motorcycles from the main road, it could help minimize the hazards to motorcyclists caused by mixed traffic.

The study has also highlighted several findings related to human factors such as traffic rule violation of the involved crash partners and also the high involvement of young motorcyclists. Although efforts in terms of road traffic enforcement is already carried out by the authority, these issues appear unsolved and keep recurring. Thus, more strategic and focus enforcement activities must be planned and implemented by the relevant authorities. Resources may need to be strategized with a focus on specific areas such as near intersections where the risk of crashes involving turning vehicle is high, signalized junctions where road users running the red light may occur and during weekend night period where a majority of young motorcyclists are out on the road. Enforcement activities focusing on specific group of road users at targeted locations and during specific time period may bring more effective results and reduce unnecessary overheads in terms of enforcement personnel.

Furthermore, the study has highlighted that most of the involved riders in motorcycle-car crashes sustained injuries to the lower limb. These findings could be a useful reference and indicator for further vehicle design improvement focusing on reducing injury risks to motorcyclists. As more efforts on safety design improvement for motorcycles may seem limited due to the cost benefit factor, further automotive design research to improve design of passenger cars to be more motorcycle-forgiving could be the way forward in automotive safety. This effort, similar to the pedestrian-safety vehicle design approach may help reduce the injury sustained by motorcyclists in the event of motorcycle-car crashes.

Lastly, one of the conclusions deduced from the study is the need to fill the knowledge gap on motorcycle safety in Malaysia by establishing more collaboration works linking technical and medical data pertaining to motorcycle crashes. To the authors knowledge, at the time of this study, information on motorcyclists' injury severity, particularly in crashes with passenger vehicles was still lacking. By establishing the detailed kinematics of crash and injuries, the injury outcome of involved motorcyclists can be thoroughly assessed. This valuable information can be obtained through in-depth investigation studies and collaboration works with the treating institutions or hospitals. In this particular study, several limitations arise such as the low frequency of fatal crashes. Nevertheless, this information is important for an analysis to be conducted on the extreme group of crashes and to understand its detailed characteristics. Moreover, by establishing this knowledge, comparison between fatal and non-fatal crashes can be performed and assessment between different types of risk factors between both level of crashes can be conducted.

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