Injury and Damage Severity Factors in Real-World Passenger Vehicles Frontal Impacts

Z. A. Ahmad Noor Syukri, K. D. Wing, O. Mohd Rasid, S.V. Wong[1]

Abstract: Malaysian in-depth crash data between year 2007 and 2012 revealed that 90.4% of frontal impact crashes involved passenger vehicles. The study is intended to understand the characteristics and understand the contributing factors of occupants' injury outcome in passenger vehicle frontal impact crashes. Fatal crashes involving passenger vehicles' frontal impacts from the Malaysian Institute of Road Safety Research (MIROS) crash database for year 2007-2012 was utilized for the study. The analysis revealed that involvement of vehicles with Antilock Braking System (ABS) and Electronic Stability Control (ESC) active safety systems were relatively low which was 5.5% of the total vehicles involved. The data revealed that in rear impacts, driver and front passenger fatality was definite. It was also proven that in the condition of unrestraint and without frontal airbags, passenger vehicles frontal occupants are more likely to be killed in frontal impacts. The result also revealed significant difference in the mean value of Energy Equivalent Speed (EES) and Velocity Change upon Impact (Delta-V) between fatal and non-fatal drivers involved in passenger vehicle frontal impacts. The finding highlights the necessity in ensuring proper active and passive safety systems being equipped in passenger vehicles to improve protection to passenger vehicle occupants in frontal impacts.

Keywords Crash severity, Delta-V, EES, frontal impacts, injury severity

I. INTRODUCTION

Injury pattern and severity could be different in different crash impact directions. A study conducted using the Crash Injury Research and Engineer Network (CIREN) database had shown that, for drivers, lower extremity, upper extremity, thorax and abdomen injuries were the most frequent injuries found in frontal impacts. In frontal impacts, the drivers were 4 times more likely to suffer an AIS score of 3 or greater in head injury for wide impacts as compared to drivers in narrow impacts [1]. Contact-contusion of the vehicle occupants to A-pillar would cause serious injury to the brain whereas contact at steering wheel and instrument panel would cause lung and liver injury [2].

Furthermore, the safety of car occupants does not only depend on the safe design of the car they ride, but depend also on the vehicle design aggresitivity of the crash partner in which the car had involved with in a head-on-collision [3]. Aggressivity is measured in terms of the casualties to occupants of the other vehicle involved in the collision [4]. Compatibility of vehicles on vehicle-to-vehicle frontal impacts is classified as the mass, stiffness and geometry compatibility. Moreover, although impact speed is positively correlated with injury severity, other variables are also likely to have an effect on occupants' injury severity such as vehicle body types, damage intrusion and Delta V. To complement for occupant's

Z. A. Ahmad Noor Syukri and K. D. Wing are researchers at the Vehicle Safety and Biomechanics Research Center of Malaysian Institute of Road Safety Research (MIROS) (Tel : +603 8924 9200, Fax : +603 8733 2005, Email : ansyukri@miros.gov.my). O. Mohd Rasid is the Director of Vehicle Safety and Biomechanics Research Center of MIROS and S.V. Wong is the Director General of MIROS.

protection in crashes especially in frontal impacts, airbags and safety belts are important vehicle safety features.

In Malaysia, passenger vehicles comprise 40% of all total registered vehicles on the roads. From the national accident database, the most common types of crash configurations are side impact collisions (46%) and head-on collisions (19%) which both involve frontal impacts of passenger vehicles [5]. The high occurrence of passenger vehicles' frontal impacts in the country warrants for a detail study to be conducted, specifically in order to understand the mechanism and characteristics of this type of impact configuration, and to correlate vehicle safety features and damage profiles to the injury outcome of the involved occupants.

Furthermore, further analysis of the collected frontal impact cases from the in-depth crash investigation database needs to be performed, specifically with regards to vehicle damage, impact speeds and injury details. With a better understanding of the relationship between occupants' injury outcomes with other crash parameters, the level of occupants' safety in passenger vehicle frontal impacts can be improved.

II. METHODS

Crash Investigation

The real-world crashworthiness investigation conducted by the Crash Reconstruction Unit (CRU) of the Malaysian Institute of Road Safety Research (MIROS) was used as the data source for the current study. The real-world investigations cover all types of high profile road crashes throughout Malaysia, involving all types of vehicles. The investigation covers all types of crashes with 3 fatalities and above involving all types of vehicles and also cases with at least 1 fatality involving heavy vehicles that occurs in every types of roads nationwide. Between year 2007 and 2014, more than 900 crash cases were investigated, reconstructed and analyzed.

During investigation, a primarily trained team of crash analysts were dispatched to the crash site and to the respective Police Stations to collect detailed information related to crash configurations, vehicle damage profiles, road attributes, and injury information of the involved occupants. Investigations were done retrospectively, within 1 or 2 days subsequent to the crash. Major evidences such as vehicle brake marks and gouge marks were assessed and crucial measurements related to the crash were recorded. Photographing of all physical evidence was thoroughly conducted while sketching of the crash scene and interviews with related personnel such as the traffic police were also carried out by the team. The information and evidence were then used to analyze and reconstruct the crash.

Crash Database

The investigated cases were recorded and managed in a dedicated database called the MIROS Crash Investigation and Reconstruction Database (CIRD). The database comprises of more than 1000 fields from various crash investigation data collection forms which includes information on the general parameters of the crash, vehicle details, road characteristics and occupants' injury details. Cases related to passenger vehicles involved in frontal impacts between the years 2007-2012 from CIRD was utilized in the current study.

Crash Data Analysis

The study focuses only on fatal frontal impact crashes involving 125 passenger vehicles comprising of cars (95), four wheel-drives (9), multi-purpose vehicles (19) and sport-utility vehicles (2). The proportion of crash partners involved, are segregated into different types of vehicles such as car (54), multi-purpose vehicles (8), 4 wheel-drives (9) and heavy vehicles (52). Specifically related to this paper, a frontal crash is a crash between a passenger vehicle with a crash partner which resulted with the passenger vehicle sustaining frontal impact and damage. In a head-on crash, both vehicles have frontal collisions. In a side or rear impact, the striking vehicle (passenger vehicle) has a frontal collision.

A total of 125 crashes cases which involved 125 drivers, 99 front passengers and 262 rear passengers were filtered and analyzed for the said study. Those cases includes all head on collisions (74 cases), rear end collisions (13 cases), side collisions (36 cases) and hitting objects collisions (2 cases) which resulted in frontal damage to the involved passenger vehicles. Cases which involved under ride occurrence of passenger vehicles with heavy vehicles were excluded as this will affect the analysis result with regards to structural deformation and intrusion.

The related crash cases were analyzed and reconstructed to assess crucial parameters such as the Principle Directional of Force (PDoF), maximum crush of a vehicle, restraint wearing status and injury outcome of the involved occupants. A computerized system was used to estimate the change of velocity (Delta-V) upon impact utilizing the damage profiles of the crashed vehicles and to calculate the energy involved in each impact in order to determine the impact speed of vehicles during impact. The Collision Deformation Classification (CDC) was used to analyze the maximum deformation sustained by the vehicles. Additionally, photogrammetry techniques were also utilized to verify dimensions gathered during crash investigations. The effects between the analyzed parameters to the vehicle occupants' fatality rate was then analyzed and is thoroughly discussed in the following section of the paper. Statistical analysis were also performed to analyze the correlations.

III. RESULTS

For analysis on vehicle damage profiles and crush extent, the Collision Deformation Classification (CDC) of deformation was utilized. CDC is a 7 digit alpha numeric code used to classify any and all crash impact damage in a systematic fashion [6]. It was created and is maintained by the Society of Automotive Engineers (SAE) and is globally used in the automotive safety industry. In the present study, the extent, with the maximum zone as Zone 9 was divided into 4 newly categorized zones namely 1-2, 3-5, 6-8 and 9 as shown in Figure 1. The extent was used to analyze the maximum deformation sustained by the vehicles in frontal impacts in accordance to the longitudinal axis and vertical regions. Along the longitudinal axis of the vehicle, the B-pillar is generally taken as the maximum (the beginning of Zone 9).

From the investigated cases, the highest proportion of crush extent on the crashed vehicles was exclusively in Zone 9 with 36.3% followed by Zone 6-8 with 29.8%, as shown in Figure 1. Zone 9, for vehicles with frontal impact configurations refer to the zone starting from the B pillar towards the rear end edge of the vehicle. Zone 6-8 on the other hand, refers to the zone starting from the vehicle's A pillar structure up to the extent of the B pillar, or the frontal cockpit of the vehicle. These severe deformations, when occurred, can cause serious or even fatal injuries to vehicle occupants due to intrusion to the passengers' compartment. Previous study has also revealed that the probability of occupants' survival without injury approaches 0% as the deformation extended to passenger compartment (beyond the 5th zone) [7]. For vertical damage profile, damage occurrence at Zone G is relatively low when compared to other zones which is due to exclusion of under ride impacts. The exclusion of under ride impact was done to ensure higher representativeness of Delta-V effects on the crashes, specifically to the damages involving stiff structures of the involved vehicles. It is noteworthy that for the investigated cases, which involved at least 1 fatality of the passenger vehicle occupants, both horizontal and vertical damage locations possessed the highest distribution of end-end damage, specifically in reference to D and A. These kinds of severe wide intrusions of the vehicle structure signifies the high amount of energy being absorb by the vehicle during impact, which is then transferred on to the human body resulting in high injury severity outcome to the occupants involved.

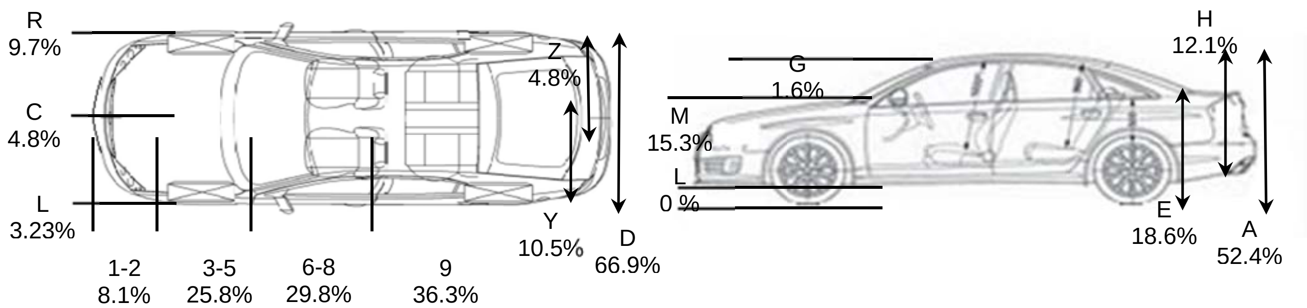

Fig. 1. Horizontal, vertical damage location and crush extent

From the 125 investigated frontal impact cases involving passenger vehicles, restraint wearing status of the drivers, frontal and rear passengers was observed, as shown in Table 1. After excluding cases with missing information on restraint wearing, the analysis was only conducted on a total of 106 drivers, 87 front passengers and 172 rear passengers. From the database, it was found that more than 70% of the involved drivers of the passenger vehicles did wear the safety belt while frontal passengers recorded a slightly lower wearing rate of 56.32%. The wearing rate for rear passengers however recorded an alarming rate of 0.58%. It is to be noted that the figures represent only the particular passenger vehicle and does not include the safety belt wearing proportions for the involved crash partners. In Malaysia, frontal (driver and passenger) safety belt wearing has been mandatory since 1978 for all types of road transport vehicles and is currently the norm for vehicle users in the country. However in contrary, rear seatbelt wearing was just made mandatory in January 2009 (6 years to date). The large difference of periodic gap between both regulations implementation may have resulted in the large discrepancies of the rates as shown in Table 1.

TABLE 1. Restraint wearing status of the involved occupants

	Restraint		Unrestraint	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Driver	77	72.64	29	27.36
Frontal	49	56.32	38	43.68
Rear	1	0.58	171	99.42

Active safety features, or sometimes being referred to as crash avoidance technologies, provides an important role in reducing the probability of vehicle crashes, by interacting with the vehicle dynamics to improve stability, traction and electronic performance. In Malaysia, Electronic Stability Control (ESC) and the Anti-Lock Braking System (ABS) are among the most common features of active safety system provided by vehicle manufacturers recently. Table 2 focuses on the active safety system availability aspect with regards to the driver and frontal passenger airbags availability and deployment for the involved passenger vehicles. As depicted in Table 2, the proportion of passenger vehicles with driver airbags was about 30.5% while the availability for frontal passenger airbags were approximately 27.9%. From the total number of involved passenger vehicles with driver airbags, 77.7% of the cases comprised airbag deployment during impacts. This was verified by the investigation teams during the vehicle post-crash inspections. Airbag deployment for frontal passenger airbags was revealed to be in a similar proportion of 78.78%.

From the total investigated cases for frontal impacts, 34.3% of the passenger vehicles were installed with ABS, which is significantly over representative as compared to ESC availability of 5.5%. Availability of both active safety systems were found at 5.5% of the total number of vehicles involved in the crash. Passenger vehicles equipped with both driver and frontal passenger airbag tended to have higher percentage of ABS availability which was 77.1% as compared to 75% for vehicles with driver airbags only. The data also showed that all vehicles equipped with ESC will also have ABS installed on the vehicles.

For the current study, the crashes are segregated into several types of crash configurations namely head on collisions, rear impact collisions, side impacts and hitting objects. Previous studies have revealed that different configurations possessed different levels of injury severity to the involved occupants. Injury outcomes in vehicle-object crashes are typically worse than in car-to-car crashes because in vehicle-object crashes, the vehicle has to absorb all the impact energy which is applied to a relatively small area of the vehicle while in a car-to-car crash, both vehicles in the crash absorb the crash energy and the impact energy is typically distributed over a wider area [8]. Meanwhile head-on and rear end collisions were often been related to high speed driving which results in the vehicle losing control and with limited space of stopping distance.

TABLE 2. Types of active safety systems of the involved passenger vehicles

	ESC		ABS		ESC & ABS	
	No	Yes	No	Yes	No	Yes
Driver Airbag			Count (% by column, % by row)			
No	80 (72.1, 32.5)	2 (28.6,0.8)	71 (92.2, 28.9)	11 (26.8, 4.5)	80 (72.1, 32.5)	2 (28.6, 0.8)
Yes, deployed	23 (20.7, 27.4)	5 (71.4, 6)	3 (3.9, 3.6)	25 (61, 29.8)	23 (20.7, 27.4)	5 (71.4, 6)
Yes, not deployed	8 (7.2, 33.3)	0	3 (3.9, 3.6)	5 (12.2, 20.8)	8 (7.2, 33.3)	0
Total	111	7	77	41	111	7
Front Passenger Airbag			Count (% by column, % by row)			
No	83 (74.1, 32.5)	2 (33.3, 0.8)	72 (92.3, 28.2)	13 (32.5, 5.1)	83 (74.1, 32.6)	2 (33.3, 0.8)
Yes, deployed	22 ((19.6, 28.2)	4 (66.7, 5.1)	3 (3.9, 3.9)	23 (57.5, 29.49)	22 (19.6, 28.2)	4 (66.7, 5.1)
Yes, not deployed	7 (6.3, 33.3)	0	3 (3.9, 14.2)	4 (10, 19.1)	7 (6.3, 33.3)	0
Total	112	6	78	40	112	6

In analyzing the fatality fate, for the purpose of consistency and to reduce indefinite variables, the analysis was separated by types of occupancies; single occupancy for passenger vehicles with driver only, and multiple occupancies, for passenger vehicles carrying frontal passengers and involving passenger vehicles carrying rear occupants. From the 125 frontal impact cases involving passenger vehicles, 21 crashes involved single occupancy (driver only) and more than half (57.1%) of those cases involved drivers being fatal as shown in Figure 2. For those single occupancy crashes, it was found that driver fatality was definite for rear impact cases (n=3). For head on crashes, the probability of driver fatality was found to be approximately 61% in which 8 out of 13 single occupancy crashes resulted in the passenger vehicle driver being fatal, as depicted in Figure 2. Meanwhile for side impacts, 1 out of the total 5 cases (20%) has resulted in the driver being fatal. It is to be noted that the figures represents drivers in the 'Impacting vehicles' rather than being the impacted party, in order to represent vehicles sustaining frontal impacts in the said crash configurations.

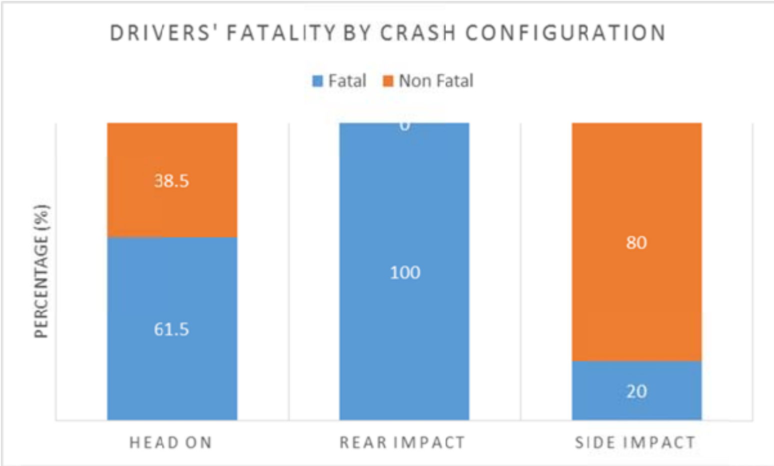

Fig. 2. Driver fatality by frontal impacts crash configuration

Further analysis of passenger vehicles carrying frontal and rear occupants utilizes the rate of fatality, in other words the proportion of fatal occupants over the total number of occupants on board for a passenger vehicle which sustained frontal impacts. This method was used to analyze the level of injury severity outcome of the investigated frontal impact crashes. In the current study, FO 0 refers to none fatalities, FO 0.5 refer to single fatality while FO 1 means both driver and frontal passenger of the passenger vehicles were fatally injured in the said crash. The distribution of fatality rate for different types of crash configuration is illustrated in Figure 3. For crashes involving passenger vehicles frontal impacts with two frontal occupants, rear end collision again was the highest in fatality rate. In rear end collisions, all cases involving dual occupancies for passenger vehicles resulted in dual fatalities. Meanwhile, side impact configurations recorded the second highest in which for 10 side impact cases involving dual occupancy passenger vehicles, 3 of those cases will end up with definite fatalities of the involved occupants.

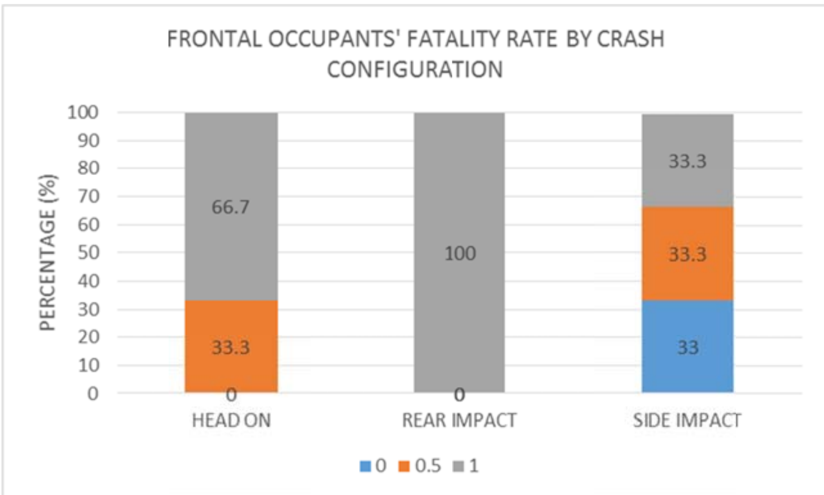

Fig. 3. Frontal passengers' fatality fate by crash configuration

The scatter plot represented in Figure 4 depicts the distribution of fatality rate for passenger vehicles carrying rear occupants on board, for each different crash configurations. The Y-axis represents each crash configuration with 1 representing head-on, 2 for rear end collisions, 3 as side impact crashes and 4 representing single-vehicle hitting object crashes. The analysis revealed that although the highest distributions of crash frequencies was recorded for head on collisions, the most common fatality rate for passenger vehicles with rear occupants was 0.5, or in other words half of the total occupancies in the involved passenger vehicles end up fatal.

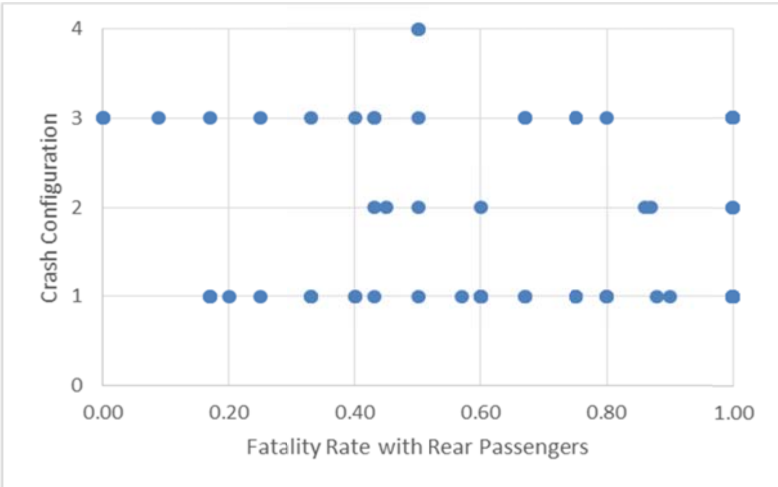

Fig. 4. Fatality rate distributions by crash configurations for passenger vehicles with rear passengers

In order to assess the association between the studied factors and occupant injury severity, since both are categorical data, chi-square test was utilized. From the chi-square test, the authors were able to determine whether the factor is or is not associated with occupant injury severity, through the significance level of the p-value. The association is significant when the p-value is <0.05 which means that a particular factor has affected the level of injury severity for the involved occupants. Cross tabulation analysis was done to look into the detailed distributions of the number of cases and percentage for each variable in each factor, and to measure the odds ratio value and p-value for each factor. In this study, the odds ratio value was needed to identify the ratio of fatality likelihood for passenger vehicle occupants' with the availability of relevant airbag systems and restraint wearing status. By using the odds ratio, the more severe variable in the analysis can be identified through 95% confidence level.

Table 3 illustrates the proportion of driver severity, categorized by fatal and non-fatal levels with the airbag availability of the vehicle. Unlike the analysis utilizing fatality rate which only considered single occupancy cases as previously discussed, the followings analysis of driver fatalities considers all of the cases which involved drivers being fatal or non-fatal. After excluding missing information cases in terms of driver airbag availability, the total number of analyzed crashes was 118. As shown in the table, the proportion of driver fatalities for passenger vehicles without driver airbag was found to be slightly higher as compared to drivers of vehicles with airbags with approximate 3% difference. Moreover, inferential analysis signified that airbag availability does have significant association (p=0.009) towards drivers' injury severity level in passenger vehicle frontal impacts. Thus, this supports the null hypothesis of adverse relationship between airbag availability and driver severity. Furthermore, the analysis also confirms that drivers of vehicles without driver airbags have a slightly higher likelihood of fatality as compared to vehicles with airbags (OR = 1.076).

TABLE 3: Drivers' injury severity by driver airbag availability

Driver Airbag Availability	**Driver Severity**		**p-value**	**Odds Ratio**
	Fatal	**Non-Fatal**		
With Airbag (WA)	10 27.8%	26 72.2%	0.009	1.076 (WOA:WA)
Without Airbag (WOA)	**24** **29.3%**	**58** **70.7%**		

Table 4 depicts the proportion, association and likelihood of frontal passengers' fatality with regards to frontal passenger airbag availability. After excluding missing information cases in terms of frontal passenger airbag information, the total number of analyzed crashes was 118. Contrary to driver fatality, a similar pattern of fatality proportion was observed for different conditions of airbag availability. The data showed that 15% of the frontal passenger involved in passenger vehicle frontal impacts suffered fatal injuries as compared to the remaining 84% of the survived ones. The analysis has also proven that frontal airbag deployment does provide significant effects in reducing the likelihood of frontal passengers being fatal in frontal impacts as compared to without airbag protection (OR: 1.011).

TABLE 4. Frontal passengers' injury severity by frontal occupant airbag availability

Frontal Passenger Airbag Availability	**Front Passenger Severity**		**p-value**	**Odds Ratio**
	Fatal	**Non-Fatal**		
With Airbag (WA)	5 15.2%	28 84.8%	0.007	1.01 (WOA: WA)
Without Airbag (WOA)	**13** **15.3%**	**72** **84.7%**		

Table 5 depicts the proportion of drivers' severity, with regards to restraint wearing status. Inferential analysis signified that restraint wearing does significantly associated (p = 0.017) with the distribution of drivers' fatality in passenger vehicle frontal impacts although the proportion of driver fatalities for both restraint and unrestraint was found to be approximately 70%. The p value has supported the null hypothesis of higher risk of fatalities for unrestraint passenger vehicle drivers in frontal impact conditions. The analysis also confirms those unrestraint drivers are 1.065 times more likely to be fatal as compared to restrained drivers in similar impact conditions.

TABLE 5. Drivers' injury severity by restraint wearing

Driver Seatbelt Wearing	Driver Severity: Fatal	Driver Severity: Non-Fatal	p-value	Odds Ratio
Restraint (R)	54	23		1.065
	70.1%	29.9%	0.017	(U:R)
Unrestraint (U)	20	8		
	71.4%	28.6%		

As illustrated in Table 6, the injury severity outcome of the frontal passengers with regards to their restraint wearing status was also analyzed. The data revealed higher distributions of fatalities to frontal passengers not wearing seatbelts as compared to those wearing (82.1% compared to 77.6%, respectively) with a higher likelihood of fatality for the unrestrained passengers (OR: 1.323). However, frontal passenger seatbelt wearing was proven to be statistically not significant to the injury severity level from the inferential analysis being performed.

TABLE 6. Frontal passengers' injury severity by restraint wearing

Frontal Passenger Seatbelt Wearing	Frontal Passenger Severity: Fatal	Frontal Passenger Severity: Non-Fatal	p-value	Odds Ratio
Restraint (R)	38	11		
	77.6%	22.4%	0.270	1.323
Unrestraint (U)	32	7		(U:R)
	82.1%	17.9%		

For the purpose of the next analysis, the vehicle damage extent was segregated into 2 groups, namely represented by Zone 1-5, referring to the crumple zones before the A-pillar and Zone 6-9, referring to the frontal passenger compartment (Zones exceeding the A pillar structure) of the vehicle. The result in Table 7 revealed that driver fatality was 20.9% higher in proportion for Zone 6-9. This was a clear evidence of a minimal survival probability for drivers when severe intrusion occurs to the passenger compartment. From the odds ratio value, it was also found that drivers are more than 2 times more likely to survive, when the intrusion did not exceed the A-pillar structure. The analysis also confirms that crush extent factor does associate to driver fatality, however that is not the case for frontal and rear occupants.

TABLE 7. Drivers' injury severity by vehicle horizontal damage profile

Crush Extent	Driver Severity		p-value	Odds Ratio
	Fatal	Non-Fatal		
Zone 1-5	24	18		
	57.1%	42.9%	0.033	2.67
Zone 6-9	64	18		(6-9:1-5)
	78.0%	22.0%		

Next, inferential analysis utilizing the ANOVA test was utilized. The ANOVA test is used to determine the impact independent variables have on the dependent variable in a regression analysis, in this case the relationship between crash parameters namely the Delta V and EES as presented in Table 8. The velocity change upon impact (Delta-V) is the difference between a vehicle's immediate pre-impact velocity and post-impact velocity at the moment of separation [8] and in this particular study, Delta-V was estimated using the computer software of AI Damage. On the other hand, the Energy Equivalent Speed (EES) is a speed measure which is transformed into deformation energy during collision [9]. Unlike Delta-V, EES is a scalar quantity, and defined as the measure of the energy dissipated by a crash.

In the current study, driver injury severity refers to whether the driver was fatal or non-fatal as an outcome of the crash. From the analysis in Table 8, it was found that for driver fatality in passenger vehicle frontal impacts, both Delta-V and EES resulted in p-value < 0.05. The result proved that in frontal impacts, Delta-V and EES provide significant difference between driver injury outcomes in terms of fatal and non-fatal. The injuries sustained by vehicle occupants largely depend on both parameters involving velocity change and energy speed during the impact phase which is related to the forces acting on their body and their tolerance to those injuries. EES and Delta-V are both highly significant predictors of the coded total injury severity according to the Abbreviated Injury Scale (AIS) [10]. Previous literatures have also highlighted the importance of using EDR Delta-V as predictor in generating risk curves for overall occupant injury and chest injuries [7].

TABLE 8. Relationship between drivers' injury severity and mean value of EES and Delta-v

	Sources	Mean Square	F	p-value
EES (km/h)	Between Groups	12780.123	5.580	0.02
	Within Groups	2290.206		
Delta-V (km/h)	Between Groups	25014.237	5.737	0.018
	Within Groups	4359.873		

IV. DISCUSSION

From the investigated cases, the highest proportion of crush extent on the crashed vehicles was exclusively in the Zone 9 with 36.3% and driver fatality was 20.9% higher in proportion for Zone 6-9. Vehicle acceleration and passenger compartment intrusion influence car occupant injury through interior contact and restraining loads [11]. Mass incompatibility causes high acceleration of the lighter car in a collision. Stiffness incompatibility allows large deformation for the less stiff vehicle, which results in the risk of compartment intrusion. From the analysis conducted, the results proved clear evidence of a minimal survival probability for drivers when severe intrusion occurs on the occupants' compartment.

The results showed an average wearing rate of 70% for driver safety belts and 56.32% for frontal passengers. However, rear seatbelt wearing showed an alarming 0.58% wearing rate. The usage of seat belts are considered as the best protection especially against ejection in a crash [2]. Previous studies on comparison between belted and unbelted drivers and passengers have shown that the rate of injury was reduced by 48% at higher speeds for belted occupants. Furthermore, the analysis also confirms that drivers of vehicles without driver airbags have a higher likelihood of fatality compared to drivers of vehicles with airbags. It also proved that frontal occupants (frontal passenger and driver) airbags availability do provide significant effects in reducing the likelihood to be fatal as compared to conditions without airbags protection. Previous study of the Fatality Analysis Reporting System (FARS) has also revealed that for head on passenger vehicles collisions, air bag deployment was found to reduce fatality 63% while lap-shoulder safety belt reduced fatality rate by 72%.

The current study also found that driver fatality was definite for rear end collision cases and 61.5% of head on crashes resulted in driver fatal. For crashes involving dual occupancies passenger vehicles sustaining frontal impacts, rear end collision again was found to be the highest in fatality rate with all cases resulted in dual fatalities. The data showed that all of the investigated rear end collisions involved heavy vehicles as the crash partners. In terms of mass, size and height, heavy vehicles are heavier, are more rugged in term of construction, and possess higher ground clearance than passenger cars. These differences in design features may end up causing incompatibility issue between the heavy vehicles and the passenger vehicles in crashes, and in some cases resulting higher injury severity to the occupants of the passenger vehicles [4]. Previous works have also proved that rear-end impacts pose the highest risk of whiplash injuries [12].

Significant difference of EES and Delta-V mean values contributed to different driver injury severity level in terms of fatal and non-fatal. Previous study on frontal impacts has also shown the probability of fatal injury rapidly increased as the impact speed increased from 60 km/h to 100 km/h [13]. However it is to be noted that severity of a crash does not only depends on the impact speed, but also on other contributing factors as well. Other factors that may affect injury severity for frontal impacts includes the vehicle body type, intrusion, vehicle curb weight, age of occupants, proper safety belt wearing and also the vehicle structural aggresivity of the crash partner.

The study also revealed that the involvement of vehicles with both active safety systems (ABS and ESC) were found at a low percentage of 5.5% of the total number of vehicles involved in the crash. This may have provided highlights on the significance of ABSs and ESCs as crash avoidance interventions in automotive safety. ESCs in previous studies were found to reduce vehicle involvement in crashes, particularly single vehicle crashes by 40% – 70% [12].

V. CONCLUSIONS

The limit of tolerance of occupants' injury is important in relation to provisions of crash protection in passenger vehicles. Improving performance of key structural components of a passenger vehicle which absorb significant amount of crash energy will therefore improve the crash safety performance of the vehicle in the event of a crash. With proven evidence-based information on the effectiveness of seatbelt wearing in minimizing occupant injury severity in crashes, stringent enforcement of frontal and rear seatbelt wearing needs to be implemented in Malaysia. Furthermore, since manufacturers in Europe has begun equipping vehicles with ESCs as early as the mid-1990s, continuous efforts and commitment by vehicle manufacturers in producing safer cars with proper and adequate active and passive safety features, i.e. airbags, ABSs and ESCs, are essential in developing countries including Malaysia. Incompatibility issues may continue and self-protection improvements for all vehicle types in all crash modes should continue to be a high priority.

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