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Side-Impact Collisions involving Passenger Vehicles in Real-World Crashes

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Abstract – *In Malaysia, 6,570 fatalities were recorded as a result of road deaths in 2016. From that figure, 1,197 or 18.2% were involved in side-impact collisions. An in-depth crash investigation study was conducted by utilizing data from the MIROS crash investigation database (MICARS) to better understand the mechanism and characteristics of the crash and to correlate the impact and damages profile with the injury outcome of the involved occupants related to the side-impact crash. The data obtained from MICARS for this study was selected from 2007 until 2016, during which MIROS had investigated 794 for both East and West Malaysia. Out of that number, 41 cases involving passenger vehicles were selected for analysis purposes. The results found that the risk of serious or fatal injury to nearside occupants was eight times higher compared to the far-side occupants. Besides that, the use of the restraint system does not show a significant association with the occupants' fatality. In a conclusion, car manufacturers should equip all new passenger vehicle models with passive safety features such as side and curtain airbags and should also increase the rigidity of the side structure of the said vehicles to reduce the injury severity level of the occupants. Furthermore, the government needs to review all these issues together with the vehicle manufacturers to make it become a Malaysian Standard before mandating it for all passenger vehicles in Malaysia. Thus, continuous efforts and commitment by car manufacturers and the government are essential to produce safer cars with proper and adequate active and passive safety features.*

Keywords: Side-impact, passenger vehicles, injury severity, real-world data, road safety

1.0 INTRODUCTION

Every year, approximately 1.25 million people are killed in road crashes worldwide. Half of this number are occupants of 4-wheeled motor vehicles, while the remainder drive powered two-wheelers, are cyclists, or pedestrians (WHO, 2015). In Malaysia, 7,152 people died from road crashes in 2016. From that figure, 1,197 or 18.2% were involved with side-impact collisions.

Side-impact collisions are one of the particularly severe types of vehicle crashes on the roads, especially in Malaysia. Based on the Royal Malaysia Police (RMP) Statistical Report (RMP, 2016), the number of side-impact crashes, at 29%, is the highest type of crash configuration. The percentage distribution of crashes by crash configurations is illustrated in Figure 1 below. The high occurrence of side-impact collision of passenger vehicles warrants for a detailed study to be conducted, specifically in order to understand the mechanism and characteristics of a crash, and to correlate the impact and damages profile to the injury outcome of the involved occupants. Furthermore, further analysis needs to be performed and information to be digested from the series of collected side-impact cases from the MIROS Crash Investigation Database (MICARS), specifically with regards to vehicle damages.

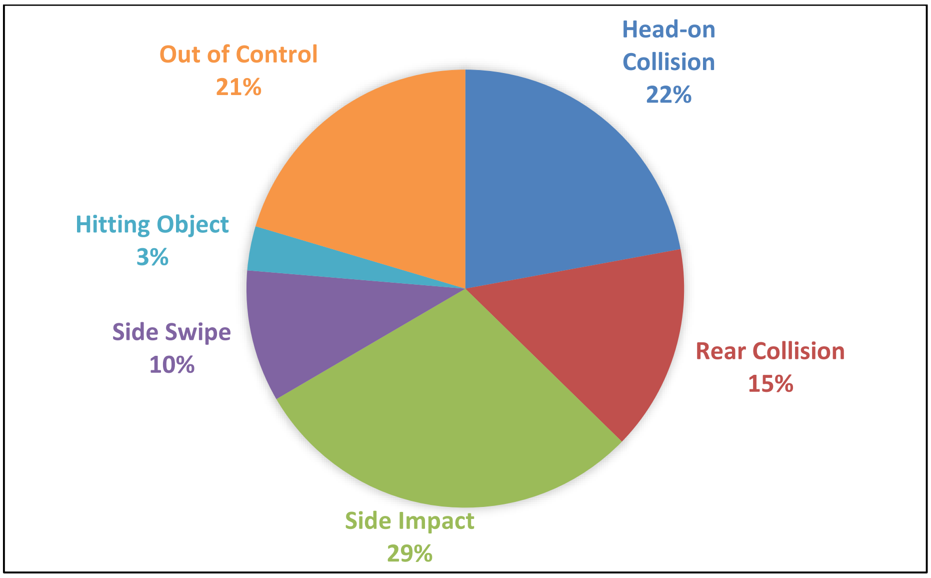

Figure 1: Percentage distribution of crashes by crash configurations (RMP, 2016)

Side-impact collision presents a difficult problem in crash protection as there is little structure between the occupant and the impacting vehicle or object. The front structure of the car can absorb two to five times as much energy as the side structure (Cesari & Bloch, 1984). Also, the occupants of the passenger vehicle struck in the side by another vehicle are more likely to sustain serious injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than when it is a car (Farmer et al., 1997).

According to Marcus et al. (1983), lateral impact produces a large proportion of all serious and fatal injuries – as much as 27% to 30% according to Fan (1987). From a study by Digges and Dalmotas (2001), near-side occupants account for more than 70% of all side-impact injuries. Also, Jones (1977) discovered that restrained occupants were at a lower risk of sustaining moderate or serious injuries compared to unrestrained occupants, especially if the former were off-side occupants.

The three-point seat belt should not be overlooked as a countermeasure. It has a substantial protective effect for opposite side occupants; even for side-impact occupants it still has a small effect – for example, reducing the chance of the head swinging through the plane of the window and contacting the striking object (Mackay et al., 1993). Jones (1977) found that impact-side occupants had an injury risk of 77.9% if unbelted, but 74.5% if belted, while other-side occupants had an injury risk of 70.3% if unbelted and 63.6% if belted. When the severity level of the collision is increased and only fatal casualties are considered, belts reduced only head injuries significantly (from 94% to 67%) in opposite-side occupants (Lestina et al., 1993). When the initial trajectory of the occupant could be determined, if its angle with the longitudinal axis of the car was not more than 45 degrees, the three-point belt provided as much protection as in frontal crashes (Schuller et al., 1989). Augenstein et al. (2000) also reveal that belted drivers and passengers have different injury modes in far-side crashes. Head injuries are more prevalent in belted drivers than in belted passengers, representing 40% of the AIS 3+ injuries for drivers, but only 27% for passengers.

In general, higher speed would result in an increased fatality risk of the vehicle occupants in the event of a crash. When a vehicle travelling at high-speed crashes, the high kinetic energy would convert into crush energy to deform the vehicle structure and cause injury to all occupants in the vehicle. Wramborg (2005) proposed the three-impact speed – fatality probability relationships as shown in Figure 2 below including for side-impact collision.

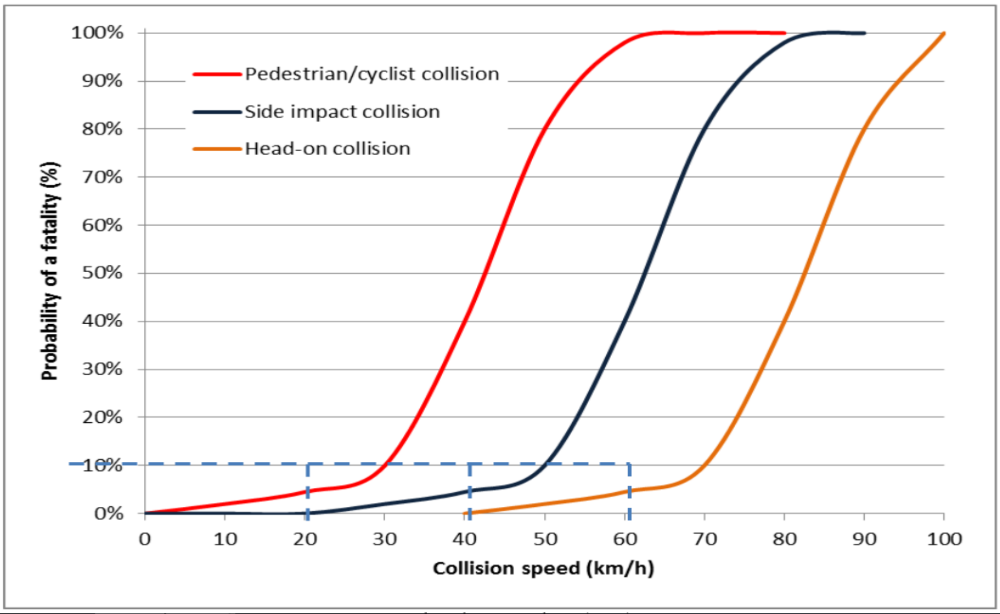

Figure 2: Probability of car driver/passenger fatality vs collision speed (Wramborg, 2005)

Considering the distributions of injury and speed in real-world crashes, Viano (1987) suggests that reductions of up to 30% in seriously injured occupants may be possible with a low stiffness energy absorbing material that is effective in low-speed (Delta-V = 4-8 m/s) crashes. Low or high stiffness padding was ineffective in high-speed crashes (Delta-V > 10 m/s).

1.1 Objectives of Study

This study will explore and analyse the characteristics of passenger vehicles involved in 41 cases of side-impact collisions in Malaysia.

The objectives of this study are:

i. To identify damage severity of passenger vehicles involved in side-impact collisions.
ii. To determine injury pattern and severity in side-impact collisions.
iii. To evaluate crash severity outcome based on the selected crash parameters.

2.0 METHODOLOGY

2.1 Scope of Study

The scope of this study is focused on passenger vehicles, namely cars, SUVs, MPVs and vans involved only in side-impact crashes. Other types of collisions were not considered, but the crash partners such as buses, lorries and motorcycles were counted as data for this study.

2.2 Method

Data from the MIROS crash investigation database (MICARS) from 2007 until 2016 was used for data collection. MIROS had investigated 794 cases during that period for both East and West Malaysia, 64 of which were involved in side-impact collisions comprising several vehicles. Upon filtering through the database, 41 cases involving passenger vehicles were selected for this study. The method of this study is illustrated in Figure 3 below:

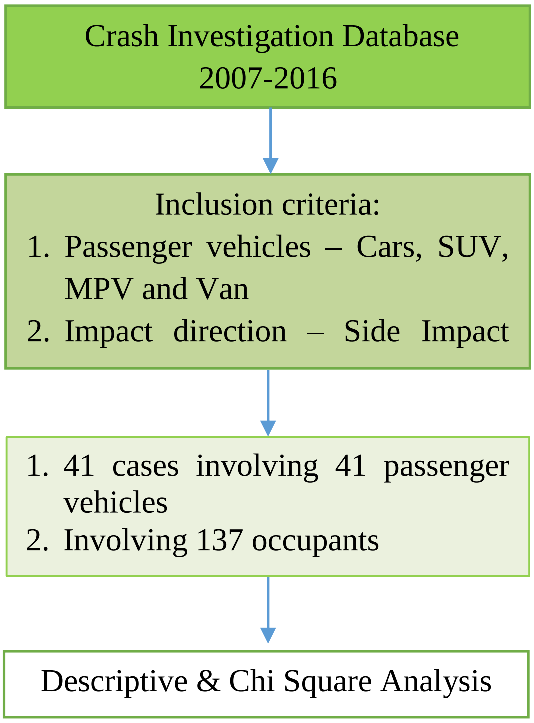

Figure 3: Method of the study

The selected crash cases were analysed to assess several parameters related to the side-impact crashes, for example, the principal direction of force (PDoF), maximum crush, restraint wearing status and the injury outcome of the occupants involved. In addition, the seating location of the occupants in each vehicle involved was also determined to investigate the injuries sustained after the crash. The data were analysed concerning the objectives of the study. Descriptive analyses were carried out to obtain the distributions and profiles of the data. Meanwhile, statistical analyses such as inferential analysis and odds ratio were performed using the Statistical Package for the Social Sciences (SPSS) software. The findings of the analyses were used to conclude this study.

3.0 RESULTS AND DISCUSSION

3.1 General Information

A descriptive analysis was conducted to describe and summarize the investigated cases of passenger vehicles involved in the side-impact collision and the results obtained are illustrated in Table 1 below. From the analysis, it was found that in terms of occupant exposure, 46.0% of the cases were nearside occupants while 54.0% were far side occupants. As for seatbelt wearing, 56.2% of the occupants were not buckled up during the crash and only one car or 2.4% has a side airbag.

For the frequency of crash partner, the car recorded the highest percentage (50.0%) crash partner for side-impact collision being studied. Meanwhile, with regards to the principal force of direction (PDoF) during the crash, direction number 2&10 (43.9%) was found to be the highest, followed by 4&8 (22.0%). As for the impacted side, the majority of the side-impact cases happened at the nearside of the vehicle (80.5%), while for the impacted area, most of the cases or 65.9% happened at the middle part or B-pillar area.

In terms of the time of crash occurrence, the highest proportion of side-impact collisions occurred during night hours (34.1%), while weekdays recorded higher incidents of crash occurrence which is 61.0% compared to the weekend (39.0%). In terms of road type, the highest number of crashes occurred on federal roads (48.8%), while the least number of crashes occurred along expressway roads (17.1%). In terms of road geometry, curved roads had a higher number of side-impact collisions involving passenger vehicles (51.2%) compared to straight stretches. Last but not least, it was also found that vehicles older than nine years were most likely to be involved in side crashes (90.2%) compared to relatively newer vehicles, vehicles aged between five to nine years and vehicles aged less than five years on the road.

3.2 Injury Severity to Occupants

The proportions of occupants involved in passenger vehicle side-impact s by seat location and injury severity are shown in Figure 4 below which shows 39.0% of drivers were killed in the crash. Approximately 79.4% of fatalities were recorded for front passengers while the remaining 20.6% sustained severe or slight injuries. In terms of rear passengers, 62.9% were killed, while the rest were only slightly or severely injured.

3.3 Occupants Injury Severity Levels by Occupants Exposure

It is defined that in left side-impact collisions, the driver and the left rear occupant in the struck car are near-side occupants, and in right-side-impact s, the front passenger and the right rear occupant in the struck car are near-side occupants (Xu et al., 2015). Based on Table 2, the proportion of occupants' fatalities at the nearside was 43.8% higher than at the far side. Inferential analysis showed that occupant exposure did have a significant association ($p<0.001$) with the occupants' injury severity levels involved in side-impact s. The study also found that nearside occupants have a higher likelihood of fatality of more than eight times compared to far side occupants. This is because nearside occupants who are seated close to the collision position are much more likely to collide with doors, windows and the interior of the struck car directly, and thus suffer more serious injuries (Xu et al., 2015). Also, a study by Digges and

Dalmotas (2001) revealed that nearside occupants account for more than 70% of all side-impact injuries.

Table 1: Descriptive information of the crashes investigated

Risk Factor	Frequency (%)	Risk Factor	Frequency (%)
Occupant Exposure		**Impacted Area**	
Nearside	63 (46.0)	Front Part Impact	8 (19.5)
Far side	74 (54.0)	Middle Part Impact	27 (65.9)
Seatbelt Wearing		Rear Part Impact	6 (14.6)
Restraint	60 (43.8)	**Time of Accident**	
Unrestraint	77 (56.2)	00:00-05:59	5 (12.2)
Side Airbag Availability		06:00-11:59	12 (29.3)
Yes	1 (2.4)	12:00-17:59	10 (24.4)
No	40 (97.6)	18:00-23:59	14 (34.1)
Crash Partner		**Day**	
Car	22 (50.0)	Weekend	16 (39.0)
MPV/Van	1 (2.3)	Weekdays	25 (61.0)
4WD	1 (2.3)	**Type of Road**	
Heavy Vehicle	17 (38.6)	Expressway	7 (17.1)
Motorcycle	3 (6.8)	Federal	20 (48.8)
Principal Force of Direction (PDOF)		State	14 (34.1)
1&11	7 (17.1)	**Horizontal Profile**	
2&10	18 (43.9)	Straight	17 (41.5)
3&9	2 (4.9)	Curve	21 (51.2)
4&8	9 (22.0)	T Junction	1 (2.4)
5&7	5 (12.2)	Y Junction	2 (4.9)
Impacted Side		**Vehicle Age**	
Nearside	33 (80.5)	<5 Years	1 (2.4)
Offside	8 (19.5)	5-9 Years	3 (7.3)
		>9 Years	37 (90.2)

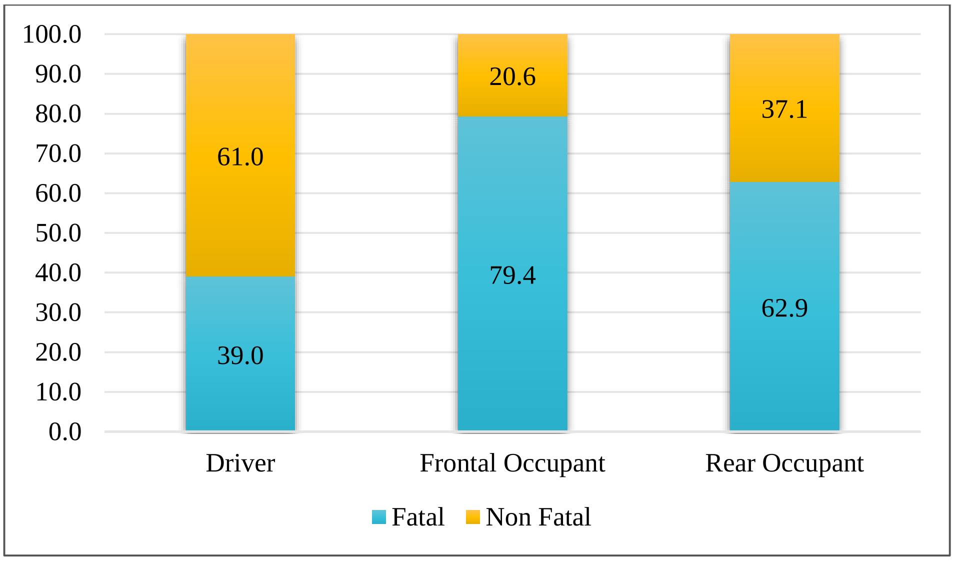

Figure 4: Occupants' seat location and injury severity

Table 2: Occupant's injury severity levels by occupants' exposure

Occupant Exposure	Injury Severity (%)		p-value	Odds Ratio
	Fatal	Non-Fatal		
Nearside (NS)	54 (85.7)	9 (14.3)	<0.001	8.32 (NS : FS)
Far side (FS)	31 (41.9)	43 (58.1)		

3.4 Occupant Injury Severity Levels by Seatbelt Wearing

Figure 5 below shows the percentage of seatbelt wearing among the occupants. Rear occupants were recorded to have the lowest percentage of seatbelt wearing (1.6%) compared to the drivers and front passengers. Besides, based on Table 3, the injury and death rates of the belted occupants and the unbelted occupants were almost similar. Results of the SPSS analysis showed that seatbelt wearing was not significantly associated (p=0.858) with the occupants' injury severity level during side-impact crashes. Gabler et al. (2005) observed that head and thorax injuries accounted for over half the serious injuries sustained in far-side crashes. Furthermore, the seat belt was recorded as the injury source in 86% of AIS2+ abdominal injuries sustained in far-side crashes.

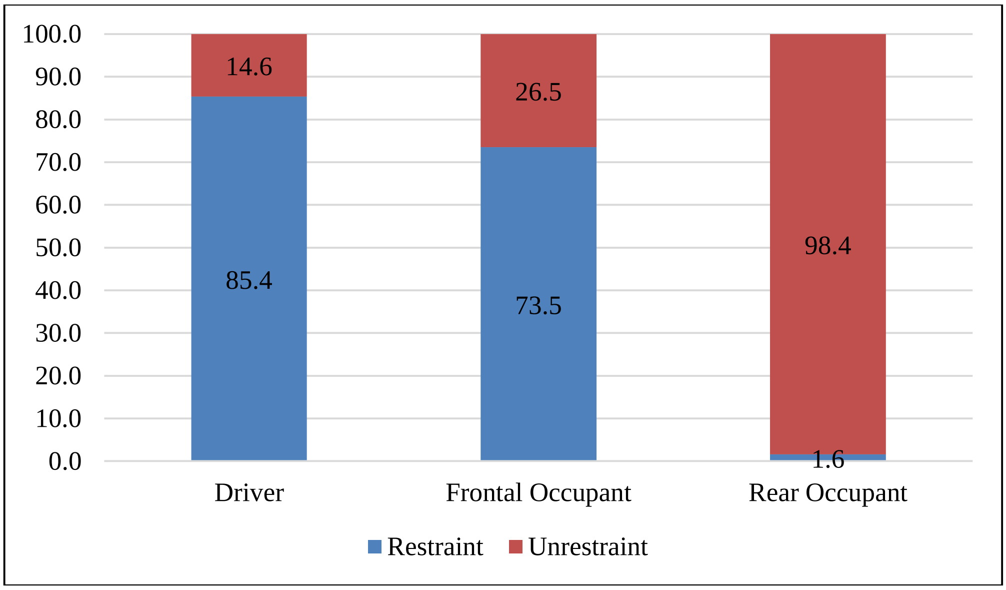

Figure 5: Restraint wearing of the occupants

Table 3: Occupants injury severity levels by seatbelt wearing

Seatbelt Wearing (All)	Injury Severity (%)		p-value
	Fatal	Non-Fatal	
Restraint (R)	36 (59.0)	25 (41.0)	0.858
Unrestraint (U)	46 (60.5)	30 (39.5)	

3.5 Vehicle Damage Profiles and Crash Extent

The Collision Deformation Classification (CDC) was used for the analysis of vehicle damage profiles and crush extent. In this study, the crush extent was divided into nine zones, namely, zones 1 until 9 as shown in Figure 6. As can be seen, zone 4 recorded the highest percentage of cases for crash extent, at 31.7%.

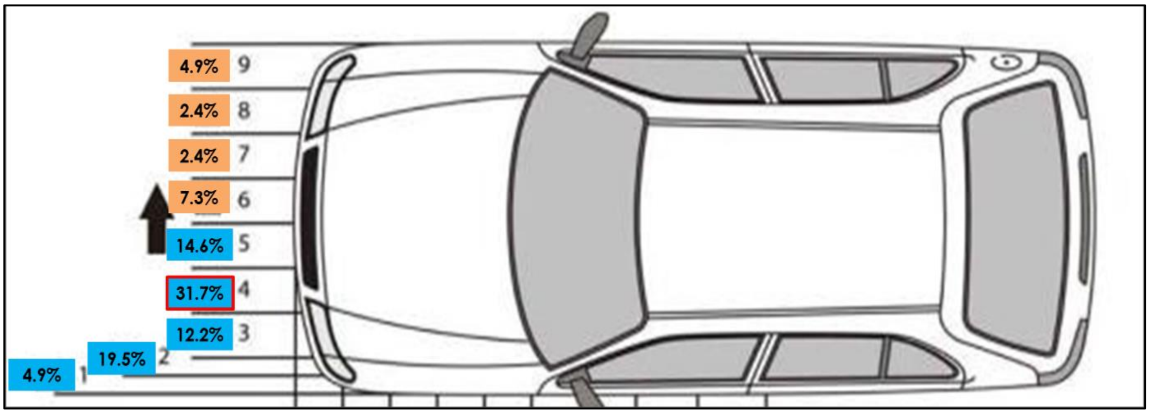

Figure 6: Vehicle crash extents

3.6 Injury Severity of Occupants by Vehicle Crush Extent

Table 4 shows the injury severity of occupants towards the vehicle crush extent. The proportion of occupants' fatalities for zones 3-9 was 35.2% higher than that for zones 1-2. This indicated that occupants had minimal probabilities of survival when severe intrusions occurred on the side structure of the vehicle. Fildes et al. (1994) found that in real-world side-impact crashes, the risk of injury was two times higher with Passenger Compartment Damage (PCD) than without. Inferential analysis showed that the crush extent did have a significant association (p=0.04) with the occupants' injury severity levels involved in side-impact. The study also revealed that when the intrusion exceeded zones 3-9, the likelihood of fatality was more than four times compared to zones 1-2.

Table 4: Injury severity of occupants by vehicle crush extent

Crush Extent	Injury Severity (%)		p-value	Odds Ratio
	Fatal	Non-Fatal		
ZONE 3-9	83 (63.8)	47 (36.2)	0.04	4.42 (3-9 : 1-2)
ZONE 1-2	2 (28.6)	5 (71.4)		

4.0 CONCLUSION

The proportion of occupants' fatalities at nearside was 43.8% higher than at the far side. This is because nearside occupants are seated close to the collision position and are much more likely to collide with the door, window and interior of the struck car directly and hence will suffer more serious injuries. Inferential analysis showed that occupant exposure had a significant association ($p<0.001$) with the occupants' injury severity levels involved in side-impact collisions. Furthermore, the study also confirmed that nearside occupants had a higher likelihood of fatality compared to far side occupants (OR=8.32). Besides that, the use of a restraint system does not show a significant association ($p=0.858$) towards the occupants' fatality during side-impact crashes. Occupants on the struck side are injured more often and more severely than occupants seated at the opposite side even using seatbelts. Regarding head injuries, seatbelts may benefit the far side occupants but do not significantly benefit the near side occupants. The analysis of the PDOF found that a large proportion (43.9%) of the side-impact crashes occurred obliquely, at approximately 2 and 10 o'clock. Besides that, 65.9% of the cases were impacted in the middle area and almost 62.4% of the fatalities also occurred in the middle area. 39.0% of the side-impact crashes were struck by heavy vehicles and with the increase of striking vehicle's height, width and weight, the maximum deformation of struck vehicles rose rapidly. Hence, these crashes usually brought about serious crash consequences. Furthermore, the study also revealed that when the intrusion exceeded zones 3-9, the likelihood of fatality was much higher compared to zones 1-2.

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