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Side Impact Crashes: Analyzing Vehicle Impact Speed Using Real-World Data

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ABSTRACT – *Side-impact crashes represent a significant portion of traffic crashes worldwide, often resulting in severe injuries and fatalities. Understanding the dynamics of these collisions, particularly the impact speed of the vehicles involved, is crucial for improving vehicle safety systems and designing effective countermeasures. Additionally, side impact testing for ASEAN NCAP was conducted at a speed of 50 km/h, which is equivalent to Euro NCAP speed testing. This research aims to analyze real-world data collected from side-impact crashes to gain insights into the range of impact speeds and their implications for injury severity. The study utilizes a comprehensive dataset (25 cases) including EDR cases comprising 85 occupants and detailed information from various side impact crash scenarios involving passenger vehicles, including vehicle weight and damage, crash configurations, injury outcomes, and, most importantly, the outcome of the analysis, which is the impact speeds and crush extent of the vehicle during the crash. By employing advanced statistical (SPSS) and data analysis techniques (AI Damage Software), the key trends and patterns in the data will be identified. These findings shed light on the distribution of impact speeds, crush extent, and their influence on injury severity. From the result, the mean estimated total weight of the striking vehicles involved in side impact crashes is 1,453.08 kg, while the average estimated impact speed of the vehicles involved is 58.96 km/h. Impact speed and occupant exposure were found to be significantly associated with occupant fatalities in side-impact crashes.*

KEYWORDS: Side-impact, passenger vehicles, impact speed, injury severity, real-world data

1. INTRODUCTION

Side impact crashes occur when the frontal section of one motor vehicle collides with the lateral aspect of another vehicle at an angle that is either perpendicular or closely approximates perpendicularity (Lau et al., 1991). The relative lack of protection offered by the sides of a vehicle, as compared to the front or rear, renders collisions involving the sides of vehicles highly dangerous. The magnitude of side-impact collisions is contingent upon various aspects, encompassing the velocity of the vehicle, its dimensions, and the presence of safety mechanisms.

Side impact crashes frequently result in severe injuries, particularly among occupants seated on the impacted side. Frequently encountered injuries encompassing chest injuries, head injuries, and fractures of the pelvic region. The severity of these injuries can be amplified in cases where the striking vehicle is substantially larger or is operating at high velocities.

The impact speed of side-impact crashes can vary widely depending on factors such as the vehicles involved, their respective speeds, the angle of impact, the size and weight of the vehicles, and the road conditions. There is no fixed impact speed for side-impact crashes, as each collision is unique and influenced by multiple variables.

However, it's important to note that even relatively low-speed side-impact collisions can result in significant damage and injuries due to the vulnerability of the side of vehicles and the proximity of occupants to the point of impact (Radzi et al., 2021). Crash tests conducted by regulatory agencies and organizations like the National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS) often evaluate side-impact scenarios at various speeds to assess vehicle safety (Lidbe et al., 2020). Additionally, side impact testing for ASEAN NCAP was conducted at a speed of 50 km/h, which is equivalent to Euro NCAP speed testing (Ariffin et al., 2014).

In real-world situations, side-impact collisions can occur at speeds ranging from a few kilometers per hour (low-speed urban intersections) to much higher speeds (highway intersections or when one vehicle fails to yield the right of way). Generally, the severity of the collision increases with higher impact speeds as the forces involved are greater, potentially leading to more serious injuries to occupants.

According to studies by Elvik (2013) and Tefft (2011), speed has an impact on the severity of crash outcomes. Specifically, fatal crashes tend to see a more significant decline in frequency with the same amount of mean speed reduction compared to all injury crashes. In simpler terms, reducing the mean speed of vehicles can lead to a decrease in the severity of crashes.

The effect of impact speeds on the severity of several crash types in Australia and New Zealand is demonstrated through the utilization of a model introduced by Wramborg in 2005, as depicted in Figure 1. This model incorporates three correlations between impact speed and the probability of fatalities, specifically in scenarios where vehicles with equal mass and speed are in conflict. According to the probability curves provided, it may be inferred that there exists a 10% possibility of a fatality occurring when vehicles collide at the following speeds:

i. 30 km/h in pedestrian/cyclist crashes
ii. 50 km/h in side-impact collisions
iii. 70 km/h in head-on collisions.

According to Jurewicz et al. (2016), the analysis of risk curves in Wramborg indicates that speeds considered to be 'safe' based on a 10% probability of death are 30 km/h for pedestrian collisions, 50 km/h for side impacts, and 70 km/h for head-on collisions. Based on the study by Doecke et al. (2020), the probability of sustaining a severe injury increases to 1% when the speed of a head-on collision hits 28 km/h, 51 km/h for side impacts, 64 km/h for front impacts and 67 km/h for rear impacts.

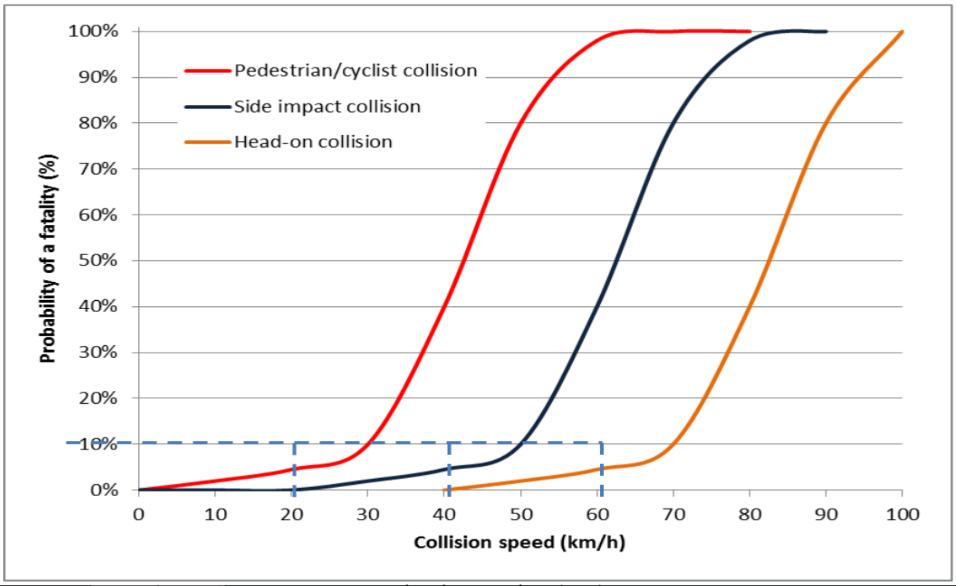

FIGURE 1: Probability of car driver/passenger fatality vs collision speed (Wramborg, 2005)

This study will indicate a comprehensive approach to studying side-impact crashes, covering damage severity, total vehicle weight, and impact speed, which are essential factors in understanding and addressing the safety concerns associated with such crashes.

The objectives of this study are: (i) to identify the severity of damage to passenger vehicles involved in side-impact crashes; and (ii) to evaluate the impact speed of the passenger vehicles involved in crashes.

2. METHODOLOGY

2.1 Scope of Study

The study is limited to side-impact crashes, and it does not encompass other types of collisions, such as head-on collisions or rear-end collisions. The primary concern is to investigate the specific circumstances and consequences of side-impact crashes involving passenger vehicles.

Also, it will focus exclusively on passenger vehicles, which include cars, SUVs (Sport Utility Vehicles), MPVs (Multi-purpose Vehicles), and vans. It does not consider other types of vehicles, such as buses, trucks, or motorcycles.

2.2 Method

The study utilized data from the MIROS Crash Investigation and Reconstruction Database (MiCERD), spanning from 2007 to 2021 (Jamaludin et al., 2021). During this period, MIROS conducted investigations into cases of road crashes in both East and West Malaysia, including the cases with the Event Data Recorder (EDR) (Ahmad et al., 2022). After a thorough review and filtering process of the database, 25 cases were selected for inclusion in this study. These 25 cases were specifically chosen because they involved passenger vehicles, aligning with the study's focus on this particular category of vehicles and side-impact collisions.

This dataset selection is crucial for ensuring that the study's analysis and findings are relevant and directly applicable to the specific scope and objectives outlined, which is the study of side-impact collisions involving passenger vehicles. The selected crash cases were subject to a comprehensive analysis to evaluate various parameters associated with side-impact collisions. The study assessed several key factors, including:

i. <u>Principal Direction of Force (PDoF)</u>: The analysis considered the primary direction from which the force impacted the vehicles involved in the side-impact crashes. This parameter provides critical information about the nature of the collision.

ii. <u>Seating Location of Occupants</u>: The study determined where each occupant was seated within their respective vehicles at the time of the collision. This information is essential for investigating the relationship between seating position and injury outcomes.

iii. <u>Restraint Wearing Status</u>: The study examined whether the occupants involved in the crashes were wearing safety restraints (e.g., seat belts). This information is vital for understanding the role of restraint use in mitigating injuries.

iv. <u>Maximum Crush</u>: The extent of structural deformation or crush damage sustained by the vehicles was evaluated. This measurement can help assess the severity of the collision.

v. <u>Injury Outcomes of Occupants</u>: The analysis included an assessment of the injuries sustained by the occupants involved in the side-impact crashes. This parameter is fundamental for understanding the impact of collisions on human safety.

The collected data was then subjected to a series of analytical techniques to meet the study's objectives. The AI Damage software has been used to calculate delta-V values for assessing the impact severity in vehicle collisions. By incorporating damage profiles, energy data, and speed measurements during the impact, this method can provide a more detailed and data-driven analysis of the collision dynamics.

AI damage, as described, seems to offer a comprehensive way to quantify and understand the effects of vehicle impacts. It may lead to more accurate estimations of delta-V, which can be crucial for assessing crash severity and its implications for injury outcomes.

After determining the delta-V, the impact speed was calculated using a common practice in physics and crash reconstruction, particularly in the context of vehicle collisions. The equation used to relate these two parameters is derived from the principles of linear motion. The equation is as follows:

$$V_f = \sqrt{V_i^2 + 2as}$$

Where:

Vf is the final impact speed.
Vi is the initial velocity (often assumed to be the vehicle's initial speed).
a is the acceleration during the collision.
s is the stopping distance of the vehicle before the final rest position

For this calculation, constant acceleration was assumed, which may not always be the case in real-world collisions. The actual collision dynamics can be quite complex, and this simplified equation is a representation that is used for estimation and reconstruction purposes. Additionally, the accuracy of this calculation depends on several factors, including the accuracy of the delta-V measurement, the choice of acceleration value, and the validity of the assumption of constant acceleration. Real-world crash analysis often involves more complex and detailed models to better understand the dynamics of the collision.

Descriptive analyses were conducted to gain insights into the distribution and profiles of the data. Additionally, statistical analyses, such as inferential analysis and odds ratio calculations, were performed using the Statistical Package for the Social Sciences (SPSS) software. These statistical methods are employed to draw meaningful and statistically significant conclusions from the data.

The findings resulting from these analyses serve as the basis for the conclusions drawn in the study. They provide valuable insights into the various aspects of side-impact collisions involving passenger vehicles, including the role of restraint usage, the nature of injuries sustained, and other critical factors that influence the safety of occupants in such crashes.

3. RESULTS AND DISCUSSION

3.1 General Information

The analysis was conducted by using descriptive analysis to describe and summarize the investigated cases covering passenger vehicles involved in side impacts and the results, as illustrated in Table 1. The results of the analysis, as presented in Table 1, provide a comprehensive overview of various parameters related to side-impact crashes involving passenger vehicles. Nearly half of the occupants (45.9%) were nearside occupants, while the remaining 54.1% were far-side occupants. This distribution indicates that side-impact crashes affect both sides of the vehicle. A significant portion (63.5%) of the occupants involved in the crashes were not wearing their safety seatbelts during the collision, and only 12% of the cars involved in the crashes were equipped with side airbags.

For the frequency of crash partners, sedans were the most frequent crash partners in side-impact collisions, accounting for 60% of the cases. Meanwhile, the PDoF analysis revealed that direction numbers 8, 9, and 10 (20%) were the most common, followed by direction number 2 (12%). For the impacted side, most side impact cases (76%) involved impacts on the nearside of the vehicle. In terms of time of crash occurrence, a significant proportion of side impact collisions (52%) occurred during nighttime hours, and finally, the highest number of crashes occurred on federal roads (60%), while the least occurred on expressway roads (8%).

TABLE 1: Descriptive information of the crashes investigated

Risk Factor	Frequency (%)	Risk Factor	Frequency (%)
Occupant Exposure		**Impacted Side**	
Nearside	39 (45.9)	Nearside	19 (76.0)
Far side	46 (54.1)	Offside	6 (24.0)
Seatbelt Wearing		**Time of Accident**	
Restraint	31 (36.5)	00:00-05:59	5 (12.2)
Unrestraint	54 (63.5)	06:00-11:59	12 (29.3)
Side Airbag Availability		12:00-17:59	10 (24.4)
Yes	3 (12.0)	18:00-23:59	14 (34.1)
No	22 (88.0)	**Type of Road**	
Crash Partner		Expressway	7 (17.1)
Sedan	15 (60.0)	Federal	20 (48.8)
MPV/Van	3 (12.0)	State	14 (34.1)
4WD	3 (12.0)	**Fatalities**	
Hatchback	2 (8.0)	Fatal	54 (63.5)
SUV	2 (8.0)	Injured	31 (36.5)
Principal Force of Direction (PDOF)			
2	3 (12.0)	8	5 (20.0)
3	2(8.0)	9	5 (20.0)
4	1(4.0)	10	5 (20.0)
5	2 (8.0)	11	2 (8.0)

3.2 Estimation of Total Weight and Impact Speed of Striking Vehicles

The SPSS was used to calculate the mean, median, and standard deviation (S.D.) for the estimation of both the total weight and impact speed of the striking vehicle in side-impact collisions, as illustrated in Table 2. These statistics are valuable for analyzing and understanding the characteristics of side-impact collisions involving striking vehicles, particularly in terms of the weight and speed of the striking vehicle. From the analysis, the mean and median weight of the striking vehicle are 1,453.08 kg and 1,482.00 kg, respectively, while the S.D. of 379.20 kg shows variability in the weights, with higher values indicating more significant variation.

The mean impact speed is 58.96 km/h, which represents the average speed at which the striking vehicle collides with another vehicle in side-impact collisions. The median impact speed of 58.93 km/h is very close to the mean, indicating that the distribution of impact speeds is relatively symmetric. The S.D. of 13.43 km/h measures the spread of impact speeds, with higher values suggesting more variation in the speeds at which these collisions occur.

3.3 Vehicle Damage Profiles and Crush Extent

Collision Damage Classification (CDC, per SAE MAR80 J224) is an excellent tool to provide a clear and concise description of the principal direction of force (PDoF) onto a motor vehicle during a crash investigation and reconstruction. The CDC was used for analyzing vehicle damage profiles and crush extent is a common and valuable approach in crash analysis. The division of crush extent into nine zones (zones 1 to 9) allows for a more detailed assessment of the damage sustained during a collision as shown in Figure 2. In this study, it was found that zone 4 had the highest number of cases, accounting for 40.0% of the crush extent.

TABLE 2: Estimation of total weight and impact speed of striking vehicles

No. of Case	Type of Car (Striking)	Total Weight	Estimation Impact Speed	Type of Car (Struck)	No. of Occupants	No. of Fatalities
1	4WD	1965	62.63	Sedan	3	2
2	Sedan	1257	61.33	Sedan	2	2
3	Sedan	1100	45.43	Sedan	2	0
4	Sedan	1030	53.23	Sedan	5	4
5	Hatchback	1004	62.93	Sedan	2	1
6	Hatchback	1050	80.43	Sedan	1	0
7	Sedan	1071	45.55	Sedan	5	1
8	Sedan	1495	35.93	Sedan	6	3
9	Sedan	1328	45.13	Sedan	6	5
10	Sedan	1608	54.83	Sedan	3	3
11	Van	1920	58.93	Sedan	6	6
12	Sedan	1040	48.10	Sedan	1	0
13	Sedan	1620	53.73	Sedan	4	4
14	MPV	1740	75.73	MPV	5	3
15	Sedan	1675	45.71	Sedan	3	2
16	Sedan	1030	48.33	Van	6	2
17	4WD	2505	62.13	Sedan	3	2
18	MPV	1482	57.93	Sedan	5	3
19	Sedan	1355	70.73	Hatchback	1	1
20	SUV	1815	99.33	Sedan	5	5
21	Sedan	1137	53.63	Sedan	4	2
22	Sedan	1150	60.52	Hatchback	3	2
23	Sedan	1560	60.00	4WD	1	0
24	4WD	1695	59.70	4WD	1	0
25	SUV	1695	72.10	Hatchback	2	1
	Mean	**1453.08**	**58.96**		**3.40**	**2.16**
	Median	**1482.00**	**58.93**		**3.00**	**2.00**
	S.D.	**379.20**	**13.43**		**1.80**	**1.70**

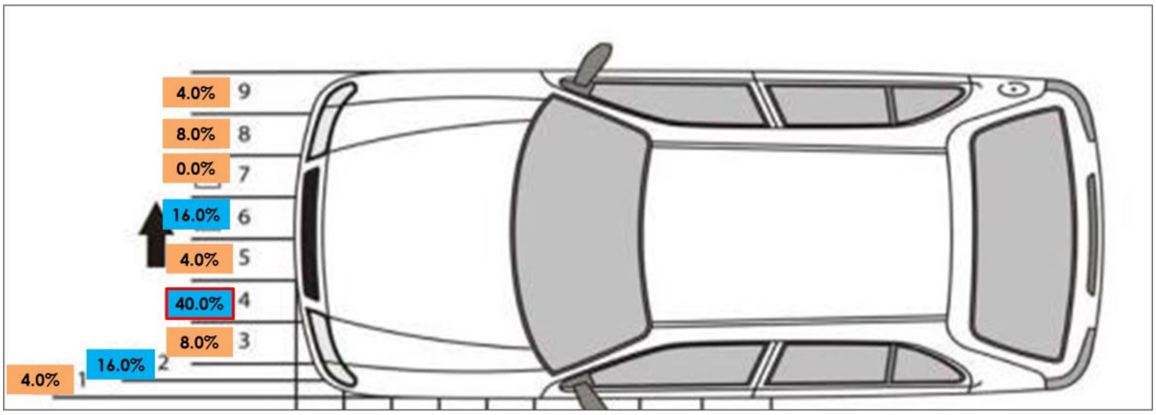

FIGURE 2: Vehicle crash extents

3.4 Occupant Injury Severity Levels by Impact Speed

The association between the severity of injuries sustained by occupants and the speed of impact during a collision is depicted in Table 3. The data indicates that there is a greater rate of fatalities among occupants involved in collisions with speeds over 50 km/h, as compared to collisions with speeds equal to or less than 50 km/h. In particular, the percentage of occupant fatalities occurring at impact speeds over 50 km/h is seen to be 28.4% greater than those occurring at speeds equal to or less than 50 km/h. This finding suggests that higher velocities of impact are associated with a significantly elevated likelihood of occupant fatalities. Through the utilization of the statistical program SPSS, it has been ascertained that the p-value is below the threshold of 0.001. This finding indicates a substantial association between the speed of impact and the occurrence of deaths among occupants involved in side-impact collisions.

TABLE 3: Injury severity of occupants by impact speed

Impact Speed (km/h)	Injury Severity (%)		p-value	Odds Ratio
	Fatal	Non-Fatal		
>50	41 (73.2)	15 (26.8)	<0.001	3.36 (>50 : <=50)
<=50	13 (44.8)	16 (55.2)		

The odds ratio (OR) is reported as 3.36, suggesting that there is a 3.36 increase in the probability of occupant fatality when the impact speed surpasses 50 km/h, in comparison to collisions occurring at speeds below or equal to 50 km/h. This finding illustrates a significant escalation in the likelihood of mortality associated with greater impact velocities. To summarize, the results derived from Figure 6 and the corresponding analysis indicate that the velocity at which a collision occurs is a crucial determinant in the severity of injuries sustained and the likelihood of fatalities among individuals involved in side-impact crashes. When a vehicular collision transpires at velocities over 50 km/h, the probability of occupant fatalities is notably augmented in comparison to collisions transpiring at lesser velocities. The statement highlights the significance of managing and decreasing vehicle impact velocities as a means to enhance the safety of occupants involved in side-impact collisions.

3.5 Occupant Injury Severity Levels by Occupant Exposure

The finding from Table 4 shows that the proportion of fatalities among nearside occupants is 43.7% higher than among far-side occupants. This suggests that occupants sitting on the side of the vehicle that is closer to the point of impact (nearside) are at a higher risk of suffering fatal injuries in side-impact collisions. Inferential analysis revealed that occupant exposure has a significant association with the severity of injuries in side-impact collisions. The p-value of less than 0.001 indicates strong statistical significance, suggesting that being a nearside occupant is associated with more severe injuries. The odds ratio (OR) is provided as 8.84, indicating that nearside occupants are 8.84 times more likely to suffer fatal injuries compared to far-side occupants in side-impact collisions. This is a substantial increase in the risk of fatalities for nearside occupants.

The nearside occupants are at higher risk of fatality because they are seated closer to the point of collision. This proximity to the impact zone makes them more likely to directly collide with the door, window, and interior of the struck car, resulting in more serious injuries (Xu et al., 2015). Thus, the nearside occupants in side-impact collisions are at a significantly higher risk of suffering fatal injuries compared to the far-side occupants. This increased risk is attributed to their closer proximity to the collision point, which results in a more direct and severe impact on the vehicle's structure. These findings emphasize the importance of vehicle safety measures and occupant protection, particularly for nearside occupants in side-impact collisions.

TABLE 4: Injury severity of occupant-by-occupant exposure

Occupant Exposure	Injury Severity (%)		p-value	Odds Ratio
	Fatal	Non-Fatal		
Nearside (NS)	34 (87.2)	5 (12.8)	<0.001	8.84 (NS:FS)
Far-side (FS)	20 (43.5)	26 (56.5)		

3.6 Injury Severity of Occupants by Vehicle Crush Extent

Table 5 illustrates the relationship between the severity of injuries to occupants and the extent of vehicle crush. It indicates that the proportion of occupant fatalities for vehicle crush zones 3–9 is 55.6% higher than for zones 1-2. This suggests that when there is a more significant extent of vehicle crush (zones 3–9), occupants are at a substantially higher risk of suffering fatal injuries compared to cases with lesser vehicle crush (zones 1-2). This highlights the importance of vehicle structural integrity and safety features in mitigating the severity of injuries in side-impact collisions. Results of the SPSS analysis showed that vehicle crush extent was not significantly associated (p = 0.185) with the occupants' injury severity level during side-impact crashes. Measurement errors in the variables being studied can certainly lead to non-significant results. If the measurement of vehicle crush extent or injury severity is imprecise or subject to variability, it can make it difficult to detect a significant relationship. This could be due to issues with data collection methods, the accuracy of the measuring tools used, or the consistency of measurements across different cases.

TABLE 5: Occupant's injury severity levels by vehicle crush extent

Crush Extent	Injury Severity (%)		p-value
	Fatal	Non-Fatal	
Zones 3-9	42 (67.7)	20 (32.3)	0.185
Zones 1-2	12 (52.2)	11 (47.8)	

4. CONCLUSION

According to this study, occupants on the near and far sides of a vehicle are affected in almost similar amounts in side-impact crashes. A significant percentage of occupants involved in side-impact crashes were not wearing seatbelts, and only a small fraction of the cars were equipped with side airbags. The most common PDoFs were 8, 9, and 10, followed by direction number 2, and the majority of side impact cases involved impacts on the vehicle's nearside. The study also used the Collision Damage Classification (CDC) to analyze vehicle damage profiles and found that zone 4 had the highest number of cases of crush extent. From the analysis, the mean weight of the striking vehicle is 1453.08 kg, while the mean impact speed is 58.96 km/h, which represents the average speed at which the striking vehicle collides with another vehicle in side-impact collisions. The analysis revealed that the injury and death rates of occupants are higher when the collision occurs at a speed of more than 50 km/h compared to collisions at speeds less than 50 km/h. Impact speed was found to be significantly associated with occupant fatalities in side-impact crashes with an odd ratio of 3.36. Besides that, nearside occupants were found to be at a significantly higher risk (OR: 8.84) of suffering fatal injuries in side-impact collisions compared to far-side occupants. Finally, the study found that a more significant extent of vehicle crush (zones 3–9) was associated with a substantially higher risk of occupant fatalities. However, the SPSS analysis did not find a significant association between vehicle crush extent and occupant injury severity, possibly due to measurement errors in the variables during the data collection process.

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