Assessment of Occupants' Fatality Rate in Single-Passenger Vehicle Crashes – Analysis of Malaysian Crash Investigation Data

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Abstract- Single-vehicle crashes rank among one of the most severe road traffic accidents and is an alarming matter. From the Malaysian national road accident database, these crashes accounted for about 25% of the overall serious injury cases and contributed to more than 40% of total vehicle occupant fatalities in year 2006. Previous studies on single-vehicle crashes for Malaysian situation were mostly done using retrospective approach, by utilizing crash data from the police database. In the present study, a sample of 74 fatal single-passenger vehicle crashes from individual real-world crash investigation data extracted from the MIROS Crash Analysis and Reconstruction Database System (MiCARS) was utilised to explore the characteristics and the relationship between the selected parameters of the crashes and the occupants' fatality rate. From the analysis, it was that revealed vehicle occupants are exposed to higher rate of fatality in vehicle-road furniture impacts albeit the highest proportion of crashes involved collision with trees. Crashes which involved vehicle rolling over have higher fatality rate than non-rollovers and mostly involved passenger vehicles other than cars such as SUVs and MPVs. The minimum fatality rate for crashes with vehicle’s deformation extent more than 5 increased by up to 0.4 as compared to crashes with lower deformation extents. An upwards trend for fatality rate was observed in higher value of Delta-V but the rate decreases with larger exit angles. Additionally, vehicles leaving the roadway on the nearside carries higher fatality rate as compared to offside and crashes involving perpendicular impacts were more common for higher fatality rate as compared to non-horizontal impacts.

Keywords- Crash investigation, delta-V, fatality rate, injury severity, MiCARS, object struck, single-vehicle crashes

Introduction

The reasons for a single-vehicle crash to occur varies and among others include avoiding other vehicle, object, or an animal in the travel lane; over-correction during driving; driving inattention due to distraction, fatigue, sleep or alcohol; the effects of weather; and travelling exceedingly fast. An errant vehicle experiencing a single-vehicle crash will be more likely to leave the road and have a collision with the road shoulder or median. In these circumstances, the collision could involve fixed objects, crash barriers, steep slopes or cliffs. The Malaysian national road accident database showed that single-vehicle crashes accounted for 25.7% of the overall serious injury cases [1] and contributed to 45% of total vehicle occupant fatalities in year 2006 in Malaysia [2]. Eurostat referred single-vehicle crashes as to result over 33% of the overall fatalities in European traffic accidents [3]. Meanwhile, a study in Taiwan revealed that single-vehicle crashes accounted for 31.8% of total fatalities [4].
In terms of fixed object collision, studies in Europe have shown that 31% of all fatal accidents involved collisions with road shoulder objects, with trees and utility poles being the most frequently struck objects [5]. In the United States, more than 20% of fatalities in vehicle crashes resulted from a vehicle leaving the road and hitting a fixed object [6]. Injury outcomes in fixed object collisions are typically worse than in car-to-car crashes because in fixed object collisions, 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 [7].

Having said that, limited source of information for vehicle damage and object struck in the national road accident database has confines for a more extensive study of single-vehicle crashes to be carried out using retrospective approach. Thus, an in-depth crash investigation method is utilized for the current study. The aim of this paper is to study the characteristics and contributing factors of fatal single-vehicle crashes in Malaysia by exploring the important parameters of the crashes towards occupants’ rate of fatality. This study intends to provide better understanding of single-vehicle crashes and compliments the previous studies on single-vehicle crashes done by the same author which utilized crash data from the national database.

**Methodology**

*Crash Investigation*

The real-world crashworthiness investigation was conducted by the Malaysian Institute of Road Safety Research (MIROS) based on the information source from local newspapers through a specifically dedicated database system. The data collection process covers all types of road crashes nationwide involving all types of vehicles. The investigation classifies the needs to analyze a crash case according to national interests, including special inquiries from the Minister. However, due to resources constrain, the investigation only focuses on crashes involving three fatalities and above which is defined as the nation’s high profile cases. Up to date, approximately 439 crashes had been investigated and analysed since MIROS started its operation in March 2007.

A primarily trained team with special equipment will be dispatched to the crash site to collect physical data and evidence related to the crash configuration, crashed vehicles, road profile and injury details with the help of Traffic Investigation Officer of the police. Photographing of all physical evidences; assessing major evidences such as skid and gouge marks; sketching the crash scene and taking notes from the police were also carried out. Those data and evidences are then used to reconstruct the accident and to acquire the cause and to find any room of improvement to avoid such accident from recurring.

*Database*

The national road accident database statistics has limited information especially in term of vehicle damage details object struck information. Thus, for the
purpose of managing the data from the real-world crash investigation in order to accommodate the deficiencies of the vital information, the MIROS Crash Analysis and Reconstruction (MiCARS) database was developed in 2010. Currently, the database stores data from a total number of 439 investigated crash cases with more than 1000 variable fields.

**Crash Data Analysis**

The study focuses only on fatal single-vehicle crashes from the MiCARS database involving passenger vehicles which includes cars, vans, four wheel-drives (4WD), multi-purpose vehicles (MPV) and sport-utility vehicles (SUV) consisting of 74 cases. The related crash data were analysed and reconstructed to determine the important parameters such as the exit angles and exit attitudes of the vehicle prior to impact.

A computerized system which is the AI Damage software is used to estimate the change of velocity (Delta-V) upon impact utilizing the damage profiles of the crashed vehicle. The programme can be used for the analysis of all types of crashes but is the most appropriate for single-vehicle collisions with rigid objects. The Collision Deformation Classification (CDC) of deformation extent was used to analyse the maximum deformation sustained by the vehicles on front, side and top regions of vehicles. Additionally, photogrammetry techniques were also utilized to verify dimensions gathered during crash investigation. The relationship between each selected parameters i.e. Delta-V, exit angle, object location, Principle Directional of Force (PDoF) and deformation extent to the vehicle occupants' rate of fatality is then presented and thoroughly discussed in the following section of the paper.

**Results and Discussions**

![Figure 1: Single – Passenger Vehicle Crashes by Object Struck](image)

From the investigated cases, it was known that single-vehicle crashes comprised 31.2% of the overall investigated cases of which 55% (74 cases) involved passenger vehicles. From that total number of cases, 31%, which made up the highest proportion from single-passenger vehicle crashes, involved collision with trees, as shown in Figure 1. Crashes with kerbs and drain located at the vicinity of the roads made up 26% while crashes involving pedestrian or animals had the
lowest number in term of frequencies (3%). The result shows some similarities with other studies which also found that tree is overrepresented in term of object struck [5], [6], [8]. Whilst it is hypothesised that vehicle-tree crashes may become higher due to the tropical climate weather which might result in more trees to be in the vicinity of the roads, although this cannot be verified through data analysis.

Also, it is to be noted that the low frequency of vehicle-pedestrian impact might have been due to the focus of the investigation itself which is emphasised more on crashes involving high number of fatalities (three and above). Where else, in vehicle-pedestrian impacts, pedestrian as the vulnerable road user (VRU) has more probability of suffering fatal injuries rather than the occupants inside the vehicle, thus resulting in a lower number of fatalities.

![Fatality Rate by Object Struck](image.png)

Figure 2: Fatality Rate by Object Struck

However, contrast to the pattern showed in Figure 1, the importance of passenger vehicles to road furniture (crash barriers, kerbs and drains) impacts is significantly increasing with fatality rate as shown in Figure 2. Fatality rate is defined as ratio between the numbers of fatal occupants to the total numbers of occupants onboard the vehicle, and is divided into three categories with similar interval. As shown in the graph, the largest proportion for occupants having the highest rate of fatality were the ones involved in impacts with kerbs and drains, followed by collisions with crash barriers and trees.

Other studies revealed otherwise. Crashing into ditches and culverts were found to increase the propensity towards non-injury while crashing into a tree increases the propensity toward fatal injuries [9]. A study in the United Kingdom (U.K) found that crashes with trees had higher possibility of causing fatality to vehicle occupants as compared to crashing with kerbs, culverts or crash barriers [8]. Engineering aspects could be the reason for differences in terms of findings with overseas studies. Difference between design standards used and installation deficiencies of road furnitures could have resulted in different severity outcome of the crashes.
Besides the vehicle leaving the roadway and striking an object, vehicle rolling over is one of the principal hazards that resulted in single-vehicle crashes [8]. The consequences of rollover often lead to either severe injuries or death to vehicle occupants and very extreme damage to vehicles, even though it does not occur as frequently as other types of crashes such as head-on and side collisions. For this study, rollover case is defined as the vehicle experiencing quarter (1/4) rotation or more during the rollover event. The vehicle type is categorised into two: car and others, which comprise MPV, SUV, 4WD and van.

From the MiCARS database, approximately one-third of the fatal single-passenger vehicle crashes investigated involved rollover (24 cases). Of the total cases, rollover was more prominent for ‘Others’ category (45.5%) as compared to car (30.6%) albeit the total studied single-passenger vehicle crashes for both types of vehicles is unequal. The significant difference of rollover cases is perhaps due to dissimilarity of Static Stability Factor (SSF), which was introduced by the National Highway Traffic Safety Administration (NHTSA) to predict probability of rollover, exists between both categorised types of vehicles. SSF for other types of passenger vehicles mentioned earlier is highly influenced by location of centre of gravity (CG) which is generally higher than for cars. Statistics from the NHTSA show that pickup has about two times higher of chances of rollover than passenger car [16]. The finding supports the fact that vehicles with higher CG and lower SSF such as MPVs and SUVs tend to experience rollover in single-vehicle crashes [15] more than cars which generally have lower CG and higher SSF.

<table>
<thead>
<tr>
<th>Occupant Fatality Rate</th>
<th>Rollover</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (N = 50)</td>
<td>Yes (N = 24)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>%*</td>
<td>Count</td>
</tr>
<tr>
<td>0.00 – 0.33</td>
<td>11</td>
<td>22.0</td>
<td>3</td>
</tr>
<tr>
<td>0.34 – 0.66</td>
<td>15</td>
<td>30.0</td>
<td>9</td>
</tr>
<tr>
<td>0.67 – 1.00</td>
<td>24</td>
<td>48.0</td>
<td>12</td>
</tr>
</tbody>
</table>

**Note:** *Proportion is calculated based per total count, N*
As described in Table 1, larger proportion of occupants having the highest range of fatality rate (0.67 – 1.00) is observed for rollover cases (50.0%) rather than non-rollover cases (48.0%). However on the contrary, the percentage of occupants having the lowest range of fatality rate (0.00 – 0.33) is lower for rollover cases as compared to non-rollover cases.

Study by NHTSA [16] found that midsize SUVs have the highest occupant fatality rate among all passenger vehicles in term of rollover. The findings are aligned with this study where it is noted that for occupants onboarding cars who were involved in rollover during single-passenger vehicle crashes, have lower occupant fatality rate as compared to those in larger passenger vehicles such as SUVs and 4WDs.

Figure 4: Deformation Extent by General Deformation

For the analysis, the Collision Deformation Classification (CDC) of deformation extent up till zone eight (maximum is zone nine) is divided into three new categorised zones namely 1-2, 3-5 and 6-8 as shown in Figure 4. The extent was used to analyse the maximum deformation sustained by the vehicles on front, side (either near or far side) and top (as a result of rollover) regions. Nevertheless, it is to be noted that for front region, the deformation might include damage resulted from collision with pedestrian.

From the investigated cases, side deformation constitutes the highest count, with 25, as compared to other regions (front = 23; top = 19). In term of categorised zone for each region, the highest proportion of deformation extent on the crashed vehicles was exclusively in the zone of 3-5 with 73.9% for front, 66.7% for side, and 47.4% for top. Zone 3-5 for each region is defined as maximum damage affecting the area in front of the A-pillar, deformation occurring till half of the crashed vehicle measured from lateral and vertical crush damage impacting the area above the bonnet, for front, side and top, respectively. For front and side regions, the deformations might be attributed to impacts with roadside objects such as concrete wall, pole and tree which in general, are more rigid than vehicle structures. Whereas for top region, such deformation might be due to vulnerable roof structure, which is mainly built of sheet metal, and supporting pillars that could not sustain greater vertical impact force during rollover event. These severe deformations, when occurred, can cause serious and especially fatal injuries to vehicle occupants when the passenger compartment is affected.
Figure 5 shows the relationship between deformation extents of the crush vehicle to the fatality rate for the occupants inside the vehicle. As presented in the graph, the distribution of fatality rate gradually changes and became more protruding as the deformation reached above zone-5. As demonstrated in Figure 4, for frontal direction impacts, zone-5 refers to the section at the A-pillar of the vehicle, which is close to the foot well. For side impacts, zone-5 starts from the middle width of the vehicle as for impact from top direction, starts from the front windscreen glass level upwards, which both consists of survival cabin.

From the graph, the minimum fatality rate for crashes with vehicle's deformation extent more than 5 increased by up to 0.4 compared to crashes with vehicles having lower deformation extents. The main findings of interest demonstrate that injury outcomes appear to be more severe when there is involvement of intrusion to the survival cabin, as also highlighted in another study [7]. Top impacts with zone-5 intrusion increases the risk for head injuries and leaves no survival space for the occupants while frontal impacts with zone-5 deformation extent causes risk of intrusion to the foot well and increase the chance of lower extremity injuries.

Figure 6: Delta-V by Fatality Rate

The velocity change on impact (Delta-V) is the difference between a vehicle's immediate pre-impact velocity and post-impact velocity at the moment of separation [10] and in this particular study, Delta-V was estimated using the computer software of Al Damage. The injuries sustained by occupants depend largely upon this rate of change of velocity during the impact phase which related to the forces acting on their body and their tolerance to those injuries. Obviously, during a normal braking, no
injury would be caused. However, in an impact, the deceleration is rapid and most injuries are caused within the first 50 msec, i.e. in a twentieth of a second [11].

The graph in Figure 6 demonstrates the values of Delta-V in kilometer per hour (kph) which were calculated based on the depth of crushed (C1-C6) sustained by vehicles involved in the crashes. The trend seems to show an increment in rate of fatality for occupants for higher value of Delta-V. As can be seen from the graph, the fatality rate is no more below than 0.5 when Delta-V value reached 48 kph. As Delta-V increases, there is less human divergence in Delta-V and human injury thresholds. At present, there are no absolute impact severity parameters that have been established in a large enough database to provide any accurate Delta-V threshold for specific AIS injuries [10].

![Figure 7: Exit Angle by Fatality Rate](image)

The vehicle exit angle or in some literatures refers as the departure or encroachment angle, is defined as the angle at which the vehicle leaves the roadway [12] and often been associated to vehicle’s travelling speed. Finding from previous studies shows that vehicles travelling at higher speed experience lower exit angle [13]. In this particular study, the author is interested to find out how the exit angle relate with the occupants’ fatality rate in a vehicle.

As illustrated in Figure 7, the rate of fatality rate seems to be decreasing with larger exit angles. This finding compliment to the result from previous studies’ mentioned earlier [13]. At lower exit angles, higher vehicle speed will cause rapid deceleration which will increase the injury severity level of the occupants. In terms of distribution, large number of vehicles was spotted having exit angle below 30° as compared to higher angles. Additionally, the distribution trend also seems to have some similarities with the findings from a study done in the U.K. that lower number of vehicles was found out leaving the roadway at angles more than 20° [8].

![Table 2: Exit Attitude by Fatality Rate](image)

<table>
<thead>
<tr>
<th>Occupants’ Fatality Rate</th>
<th>Exit Attitude</th>
<th>Nearside (N=46)</th>
<th>Count</th>
<th>%*</th>
<th>Offside (N=21)</th>
<th>Count</th>
<th>%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.33</td>
<td>Nearside</td>
<td>6</td>
<td>13</td>
<td>7</td>
<td>33.3</td>
<td>6</td>
<td>28.6</td>
</tr>
<tr>
<td>0.34-0.66</td>
<td>Nearside</td>
<td>14</td>
<td>30.4</td>
<td>6</td>
<td>28.6</td>
<td>14</td>
<td>30.4</td>
</tr>
<tr>
<td>0.67-1</td>
<td>Nearside</td>
<td>26</td>
<td>56.5</td>
<td>8</td>
<td>38.1</td>
<td>26</td>
<td>56.5</td>
</tr>
</tbody>
</table>

Note: *Proportion is calculated based per total count, N
Vehicle's exit attitude or as departure attitude as mentioned in some previous studies, is defined as the side of road on which the vehicle left the roadway [8]. The incidence of vehicle leaving the roadway on the nearside is higher than on the offside as shown in Table 2. Additionally, both exit attitudes consist higher proportion at straight stretches as compared to at curves. The higher fatality rate of vehicle departures on the nearside of the roadway suggests that the errant vehicle leaving the roadway on nearside has virtually very little room to regain control before impact. On the other hand, vehicles leaving the roadway on the offside still have the width of the adjacent lane within which to regain control.

Table 3: PDoF by Fatality Rate

<table>
<thead>
<tr>
<th>Occupants' Fatality Rate</th>
<th>Principle Direction of Force (PDoF)</th>
<th>11-1 (N=23)</th>
<th>2-4 (N=14)</th>
<th>5-7 (N=0)</th>
<th>8-10 (N=12)</th>
<th>0 (N=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.33</td>
<td>(4) 17.4%</td>
<td>(3) 21.4%</td>
<td>0%</td>
<td>(4) 33.3%</td>
<td>(2) 11.1%</td>
<td></td>
</tr>
<tr>
<td>0.34-0.66</td>
<td>(7) 30.4%</td>
<td>(5) 35.7%</td>
<td>0%</td>
<td>(1) 8.3%</td>
<td>(8) 44.4%</td>
<td></td>
</tr>
<tr>
<td>0.67-1</td>
<td>(12) 52.2%</td>
<td>(6) 42.9%</td>
<td>0%</td>
<td>(7) 58.3%</td>
<td>(8) 44.4%</td>
<td></td>
</tr>
</tbody>
</table>

Note: Percentage is calculated based per total count, N

Table 3 shows fatality rate to vehicle occupants according to single passenger-vehicle crashes in which the PDoF was divided into 5 categories. In the overall distribution, crashes which are considered to be more perpendicular in nature (PDoF of 11-1) made up the highest distribution (N=23). Of interest is the fact that those crashes also comprise the highest proportion for highest level of fatality rate (0.67-1) when compared to crashes with non-horizontal impacts (PDoF of 0) which generally involves vehicle rollovers (52.2% to 44.4% respectively).

Conclusion

From the study, it was found that 55% of the investigated single-vehicle crashes involved passenger vehicles. Of the total number of cases, the highest proportion involved collision with trees. Nonetheless, the importance of vehicles-road furniture (crash barriers, kerbs and drains) impacts significantly increased with fatality rate. Rollovers are most common for fatal single-passenger vehicle crashes and mostly involved other passenger vehicles other than cars such as SUVs, MPVs and 4WDs. Those crashes also display larger proportion of occupants having the highest fatality rate (0.67 – 1.00).

In term of vehicle damages, the highest proportion of deformation extent was exclusively in the zone of 3-5. The minimum fatality rate for crashes with vehicle's deformation extent more than 5 increased by up to 0.4 as compared to crashes with vehicles having lower deformation extents. Moreover, an upwards trend for occupants fatality rate was observed for higher value of Delta-V and the rate is no more below than 0.5 when Delta-V value reached 48 kph. However the rate of fatality decreases with larger exit angles, and for exit attitude, vehicles leaving the roadway on the nearside carry bigger proportion and higher fatality rate as compared to on the offside. Perpendicular crashes (PDoF of 11-1) were more common for higher fatality rate when compared to crashes with non-horizontal impacts.
Nevertheless, the author would like to point out the limitations of this study which is the size of data sample used for the analysis. A larger sample size would apparently allow for more robust conclusions to be reached but the data do at least allow for an initial assessment of the issue to be made.

References