CHARACTERISTIC ANALYSIS OF PASSENGER CARS' SIDE IMPACT BASED ON IN-DEPTH ACCIDENT RESEARCH IN CHINA

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ABSTRACT

Based on the in-depth accident study of 138 cases occurred in Shanghai, China, in which a passenger car got side impact, the characteristics of human - vehicle/equipment - environment factors were analyzed in order to reveal the causation and damage/casualty consequence of these side impact accidents. The results show that the average deformation of these side struck passenger cars was 22.4cm. Furthermore, the deformations caused by large striking vehicles (trucks and buses) were 52% larger and the ratio of critical casualty consequence (serious injury or death) hovered at 22%. On the other hand, the highest mortality occurred at both sides of rear seats, and was nearly 13%. The head and neck were the most prominent injured parts of the body, which occupied narrowly 64% of the casualties. These above objective characteristics of side impact accidents provide a reliable basis for the development and application of occupant protection system and collision avoidance technology in China.

INTRODUCTION

Both of the accident rate and the injury rate of side impact accidents are highest among all the collision modes all over the world[1][2]. In the 2004 report of American Fatal Accidents, 22% of the road accidents were due to side impact and the cost of its damage exceeded 3 billion dollars every year[3]. Another statistical data collected by IHRA (International Holocaust Remembrance Alliance) also showed that about one third of the traffic accident casualties were caused by side impact[4]. Therefore, side impact accident has become a hot issue which needs to be further analyzed and dealt with. This paper analyzes the characteristics of side impact through concrete real-wold road traffic cases, to investigate the influencing factors of occupant protection and collision avoidance technology on the basis of the full research on motion response and injury severity in such accidents.

SAMPLING CRITERIA

The research data were collected by Shanghai United Road Traffic Safety Scientific Research Center (SHUFO), which included 1097 serious traffic accidents[1] in Jiading district of Shanghai, China between June 2005 and March 2013. 23% of these accidents were side impact accidents, which is the leading collision mode.
The sampling criteria for this study is presented as followed: 1. Just two vehicles were involved; 2. A passenger car (included A00, A0, A, B, C and D segment) got side impact; 3. The first collision in the accident was side impact. According to the criteria, 138 accident cases involving 217 occupants in the struck cars (the positions of the 209 occupants were confirmed) were sampled.

[1] Sampling Criteria of SHUFO: 1. at least one accident vehicle was generally or seriously damaged, or any airbag of one accident vehicle was deployed; 2. at least one person involved in the accident was seriously injured or dead.

STATISTICAL ANALYSIS

Among the 217 occupants in the struck cars, 88 of them were not injured and 91 of them were slightly injured, while 10 of them were seriously injured and 13 were dead. The above injury severities accounted for 40.6%, 41.9%, 4.6% and 6% of the total respectively. The injuries of the other 15 occupants were unconfirmed.

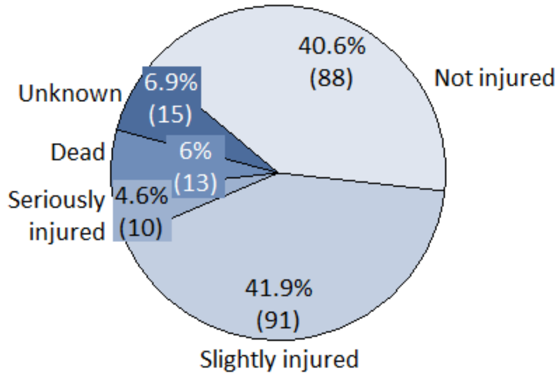


Figure 1 distribution of occupants' injuries in struck car (N=217) *

****Annotation: "Slightly injured" represents the not life-threatening injuries, such as bruises, fractures, etc. "Seriously injured" represents the life-threatening but not fatal injuries.***

CHARACTERISTIC ANALYSIS OF SIDE IMPACT

Accident Cause

About 81.9% of the side impact accidents were caused by violating traffic signal or right of way, which means that these accidents were mainly influenced by the subjective factors of driver.

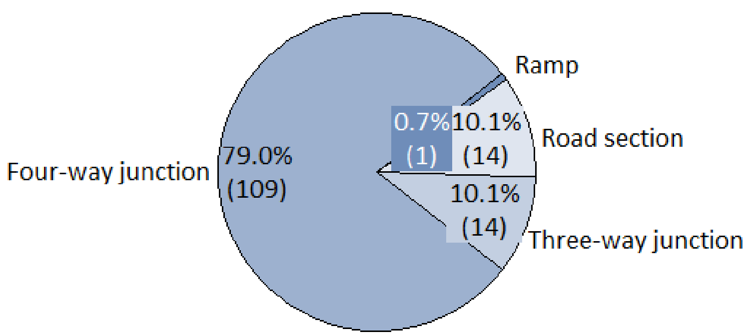


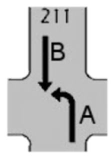
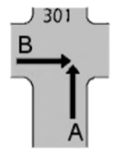
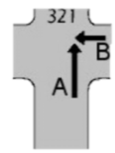
Figure 2 distribution of accident sites (N=138)

It is shown in the Figure 2 that 89.1% of the accidents happened at junction. Therefore, collision avoidance technology, such as Intersection Braking System[5], and IOV (Internet of Vehicles) [6] could improve the traffic safety in such conditions.

Conflict Mode

73% of the accident cases concentrated on the three conflict modes: UTYP211, 301 and 321 (See Table 1). In the 24 accident cases of UTYP211, most of them were caused by A car's violating right of way. In this conflict mode all the A-cars were struck car. Generally speaking, in this conflict mode, the velocity of A-car (the left-turning vehicle) is remarkably lower than the velocity of B-car (the straight driving vehicle). If B-car get left side impact, such collisions are usually slight, which would not be collected in the database of SHUFO according to the sampling criteria of SHUFO. 22 accident cases of UTYP211 (accounting for 92%) took place at the intersections with at least four lanes in each direction, while 18 accident cases among them happened at the intersections without an independent left-turn signal, where the A-cars drivers are more likely to violate right of way of B cars during left turning. Therefore, side impact accidents could be effectively reduced with the installation of independent left-turn signal.

Table 1 distribution of conflict modes (N=101)

UTYP	211	301	321
Accident Amount	24	77	
Driving Direction	Straight driving + Left turning	Straight driving + Straight driving	
Sketch			

Most of the 77 accident cases with UTYP301 and 321 were caused by violating traffic signal. 34 cases (accounting for 44%) took place at the intersections with at most three lanes in each direction. At small intersection drivers are easier to lose vigilance, and the risk and severity of the side impact accidents could be increased by the unintentional or intentional violation of traffic lights. Otherwise, greenbelt on city road, which might influence driver's visibility to the side, was proved to be one of the influencing factors in the 35 accident cases (accounting for 45%). For the above two situations, IOV[6], which could provide effective conflict warning for driver, combined with Intersection Braking System[5] would contribute a lot to traffic safety at intersection. Meanwhile, regular safety education for driver and proper design and maintenance of greenbelt are necessary as well.

Impacted Part

Side impact accidents could be divided into three types according to the different impacted parts[2]. The collision, in which B-pillar is directly involved, is defined as middle-part-impact, while the collision in which B-pillar is not directly involved is defined as front-part-impact or rear-part-impact as shown in Figure 3.

(a) Front-Part-Impact ***(b) Middle-Part-Impact*** ***(c) Rear-Part-Impact***

Figure 3 classification of side impacted parts

The statistics show that the right-side struck cars accounted for about 61.6% of the total, while the left-side struck cars accounted for 38.4%. The obvious difference between right and left side were mainly inluenced by the conflict mode UTYP211, in which all target cars were right-side impacted. When the striking vehicle was passenger car, SUV or van, the impacted part of the struck car concentrated mostly on front part (See Figure 4). When the striking vehicle was bus or truck, the impacted part of the struck car concentrated mostly on middle part, which could be due to the large width of bus and truck.

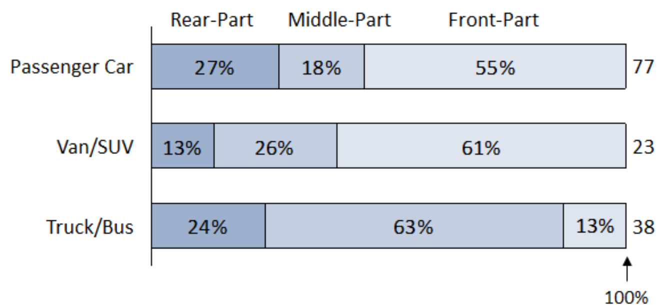


Figure 4 distribution of impacted parts based on different striking vehicles (N=138)

54.5% of the middle-part-impact accidents occurred when the striking vehicle was heavy vehicle (truck or bus), and in such accidents B-pillar was the main force-carrying component of the struck car. Improving the strength and stiffness of B-pillar is an essential issue of vehicle safety in side impact.

Effective Impact Velocity

The effective impact velocity is defined as the value of the striking vehicle's collision velocity in the y direction of the struck car. The distribution of effective impact velocities in the sample cases is shown in Figure 5. It could be found that side impact happened mostly with the effective impact velocity ranging from 45km/h to 60km/h, which accounting for 28.7%, followed by the velocity categories of 30km/h to 45km/h and of 15km/h to 30km/h.

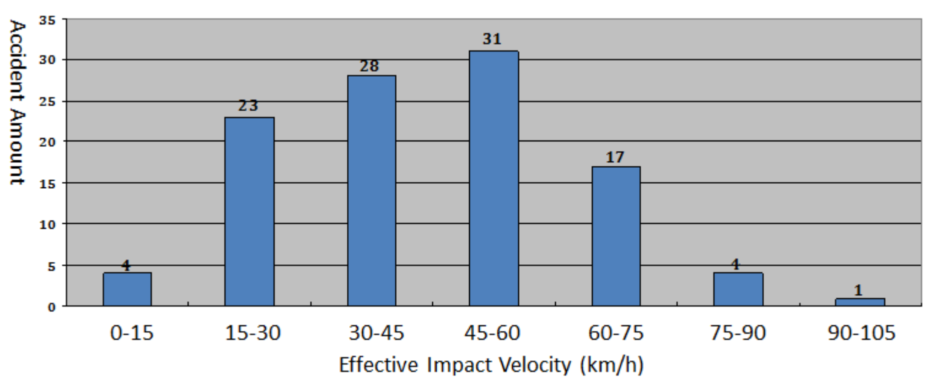


Figure 5 distribution of effective impact velocities (N=108) *
****Annotation: The effective impact velocities of 30 cases in the sample were unconfirmed.***

In the Side Impact Regulations of China, the testing velocity is determined as 50km/h[7]. The coverage of this velocity in the sample accident cases was 64%, while around 36% of the cases happened with the impact velocity higher than 50km/h. Higher impact velocity could lead to more serious accident consequences (will be analyzed in the following chapters). Therefore, side impact with high impact velocity deserves further attention.

Maximum Deformation of Struck Car

The maximum deformation of struck car mainly occurred at L2 and R2 in horizontal plane and LB and RB in vertical plane of struck car, as is shown in Figure 6. The maximum deformation position of struck car is mainly due to the impacted part and the structure and rigidity of the struck car in the accident. B2 region occupied 28.3% of the maximum deformations in the sample accidents, highest among all the positions. It is noteworthy that chest and abdomen of occupants are corresponded to B2 regions, which are the main impacted parts in Side Impact Test[7] as well.

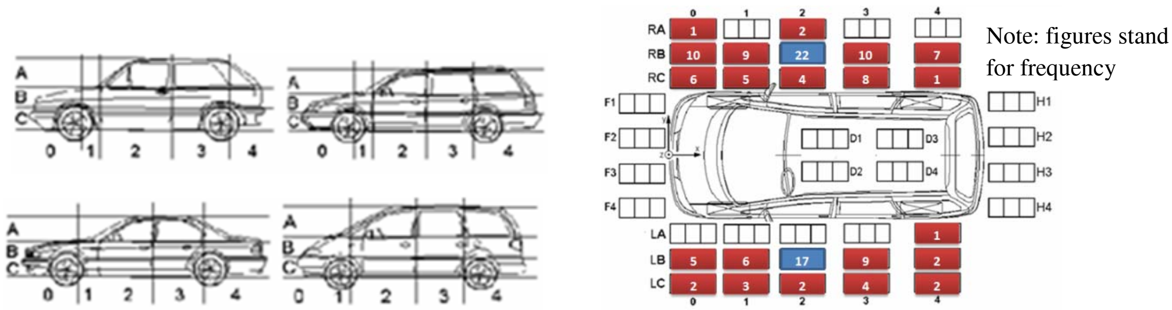


Figure 6 distribution of struck cars' maximum deformations (N=138)

According to the Side Impact Regulations of China[7], the test collision angle of side impact is 90°.In this study the collision angles in the sample accidents have been divided into 3 categories, 80°-100°, less than 80° and more than 100°. The category 80°-100°, which is corresponding to the test collision angle, accounted for aroud 49%. Meanwhile, the accidents cases with the impact angle of less than 80° or more than 100° still accounted for about 40% in the sample data, as shown in Figure 7, which would be mainly due to the steering maneuver of driver for collision avoidance before the impact and the influence of the conflict mode UTYP211. The oblique side impact collision is not covered in the Side Impact Regulations of China yet. In oblique side impact collision the motion response and the force direction of the struck car would be different, which could lead to sideslip, rotation and even rollover of the struck car after the impact. Then the motion response of the occupants in the struck car would be changed as well and different safety problems in side impact would be raised.

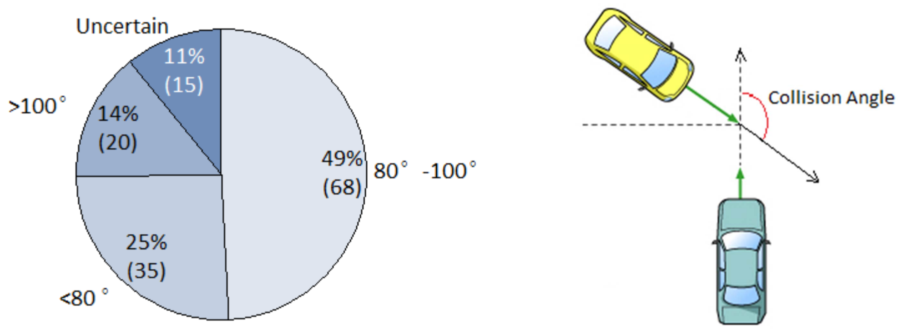


Figure 7 distribution of collision angles at struck car's maximum deformation position (N=138)

The results in Figure 8 and Figure 9 show that the maximum deformations of the struck cars were mainly less than 30cm (71%), with an average value of 22.4cm. Only 7% of the maximum deformations were more than 50cm. When the striking vehicle was passenger car, 62% of the maximum deformations were less than 20cm. When the striking vehicle was van or SUV, 52% of the maximum deformations were between 20cm and 40cm. When the striking vehicle was truck or bus, 39% of the maximum deformations were more than 40cm.

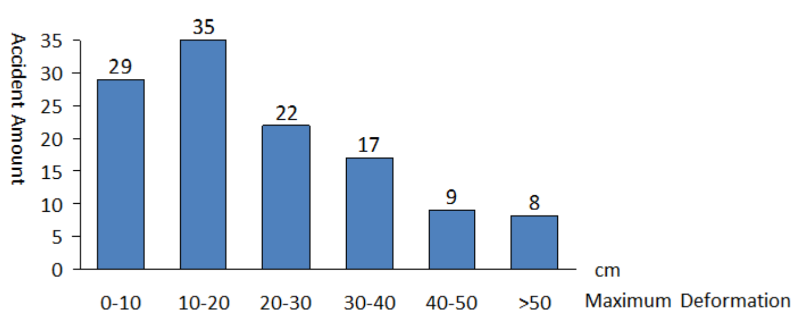


*Figure 8 frequency distribution of struck cars' maximum deformations (N=120) **

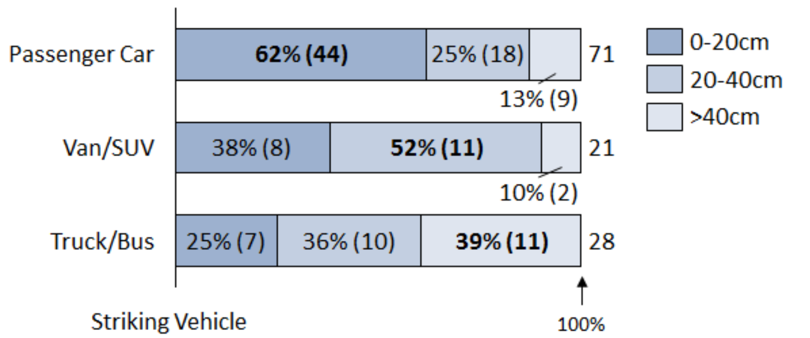


Figure 9 distribution of struck cars' maximum deformations based on different striking vehicles (N=120) *
****Annotation: The maximum deformations of 30 cases in the sample were unconfirmed.***

Therefore, with the increase of striking vehicle's height, width and weight, the maximum deformation of struck car rose rapidly, i.e. more serious the accident consequence would be.

Table 2 distribution of struck cars' maximum deformations based on different striking vehicles with different effective impact velocities

	0-30km/h	30-50km/h	>50km/h	Avg. Maximum Deformations
Passenger Car	15.5cm	14.4 cm	24.8 cm	**18.8 cm**
Van/SUV	25.2 cm	18.8 cm	26.3 cm	**22.4 cm**
Truck/Bus	19.8 cm	33.6 cm	**42.7 cm**	**34.1 cm**
Total	**18.3 cm**	**19.2 cm**	**28.6 cm**	**22.4 cm**

On the other hand, with the increase of effective impact velocity, the maximum deformation of struck car rose rapidly as well (See Table 2). When the striking vehicle was truck or bus and the effective impact velocity was more than 50km/h, the maximum deformation reached to about 42.7cm, which was almost double of the overall average.

Injury

In the struck cars of the accident cases, the use rate of seat belt for driver was highest (25%) among all the occupant positions, while that for front passenger took the second place (11%). No rear occupants were confirmed to be belted (See Figure 10).

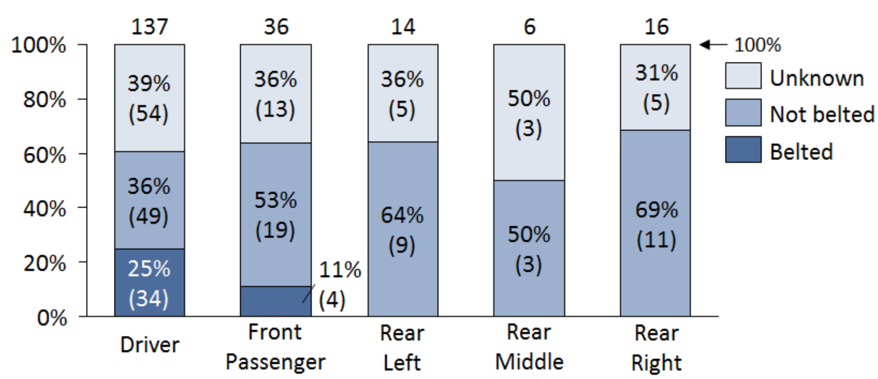


Figure 10 use of seat belt in struck car (N=209)

It is shown in Figure 11 that seat belt provided no definite protection for the occupants in struck car in side impact according to the injury distributions of the front occupants. The serious injury and death rates of the belted occupants and the unbelted occupants were similar.

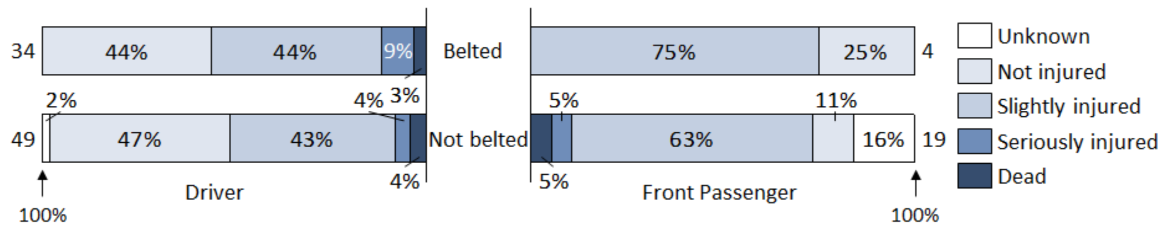


Figure 11 effect of seat belt in struck car based on front occupants (N=106)

Side airbag and inflatable curtain brought positive protection for the occupants in struck car, when the striking vehicle was passenger car. As Figure 12 shows, the occupants without the protection of side airbag/inflatable curtain in struck car were much more likely to get injured. Meanwhile there were no seriously or fatally injured occupants with the protection of side airbag/inflatable curtain.

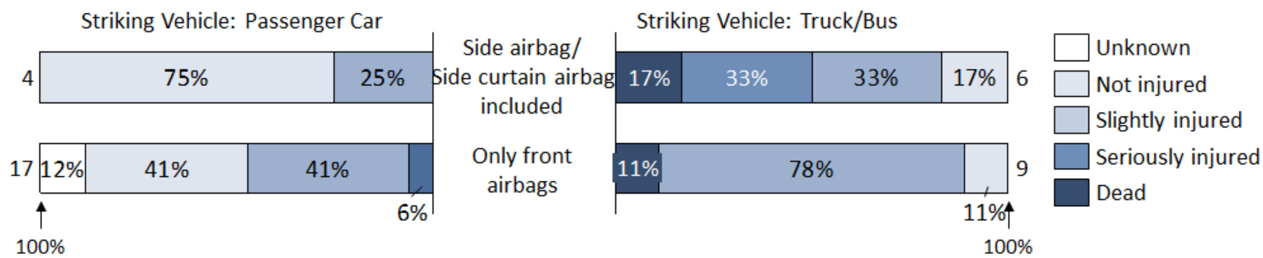


Figure 12 effect of airbag in struck car based on different striking vehicles (N=36)

However, when the striking vehicle was truck or bus, the protection of side airbag and inflatable curtain for the occupants in struck car was restricted. The serious injury and death rates of the occupants with the protection of side airbag/inflatable curtain were still very high. In the accidents stuck by heavy vehicle, occupants in struck car are easy to be involved in multiple collisions. Side airbag and inflatable curtain could provide at most once protection and could only protect the chest and abdomen of the occpuants. This protection seems to be not enough in such situation.

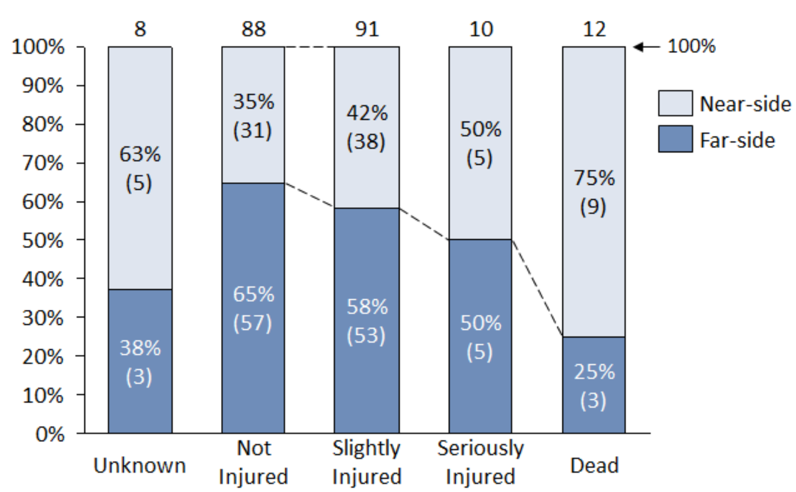


Figure 13 relationship between injury severity and near-side/far-side occupants in struck car (N=209)

It is defined that in left-side impact driver and left rear occupant in struck car are near-side occupants and in right-side impact front passenger and right rear occupant in struck car are near-side occupants. The other occupants in struck car are defined as far-side occupants. There were totally 88 near-side occupants and 121 far-side occupants, as Figure 13 shows.

75% of the fatally injured occupants in the side impact accidents were near-side occupants. Near-side occupants are seated close to the collision position and are much more likely to collide with door, window and interior of the struck car directly and suffer more serious injuries.

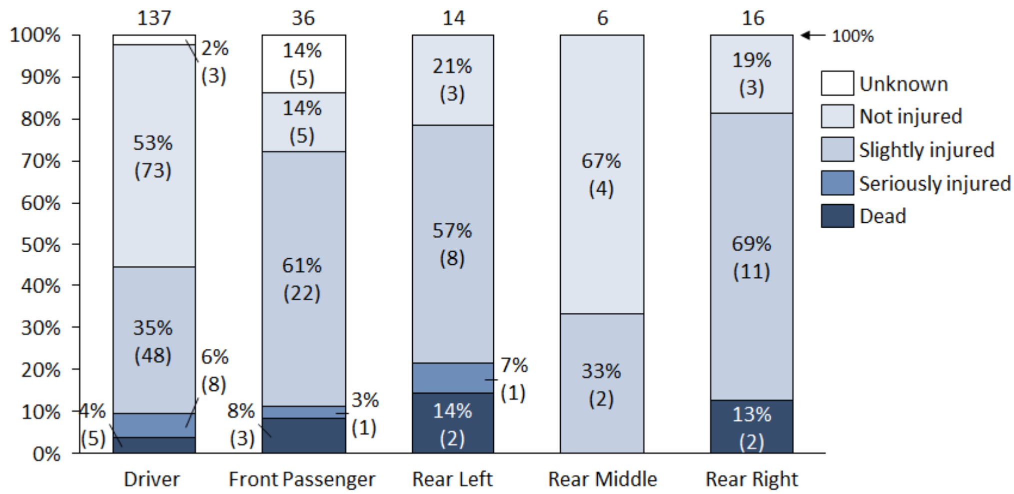


Figure 14 relationship between injury severity and seat positions in struck car (N=209)

The death rates of the rear left and rear right occupants in struck car were highest (14% and 13% respectively) among all the positions (See Figure 14). Compared to the front seats, most of the struck cars were not equipped with airbag at rear side seats. Meanwhile both of the rear side occupants are located at near-side positions and are very easy to get injured. Therefore, the protection for rear side occupants in struck car need to be improved.
On the other hand, the non-injury rates of the rear middle occupants and the drivers were highest, accounting for 67% and 53% respectively (See Figure 14). Rear middle occupants were always seated between the rear side occupants in the struck cars of the accident cases, which were the corresponding collision objects for the rear middle occupants in side impact as well. The corresponding rear side occupants are less stiffer compared to car componets and could work as a buffer during the collision, which would reduce the injury risk of the rear middle occupants. The driver position in struck car was relatively safer as well, for the driver in struck car were usually protected with restraint systems.

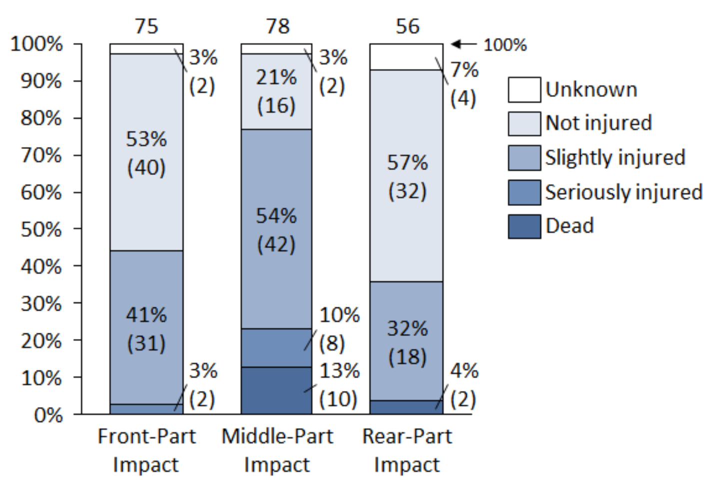


Figure 15 relationship between impacted part and injury severity in struck car (N=209)

Compared to front- and rear-part-impact, the injury risk and serverity of middle-part-impact were much higher. The injury risk of middle-part-impact reached to nearly 77% and the ratio of critical casualty consequences (serious injury or death) in middle-part-impact hovered at 23% (See Figure 15).72% of the seriously injured or dead occupants were involved in middle-part-impact. According to the previous analysis, these middle-part-impact accidents, which led to serious accident consequences, were mostly struck by heavy vehile (bus or truck).

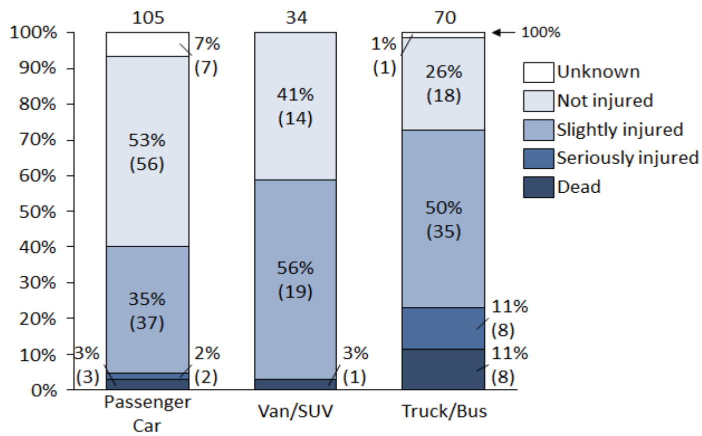


Figure 16 relationship between striking vehicle and injury severity in struck car (N=209)

As is shown in Figure 16, the injury risk and serious injury/death rate reached to respectively 72% and 22%, when the striking vehicle was heavy vehicle. 73% of the seriously injured or dead occupants were involved in this situation.

It is clear that under the influence of heavy weight, high stiffness and large size of heavy vehicle, it would be very difficult to prevent the occupants in struck car from injury, when struck by heavy vehicle. Therefore, it would be necessary to aim to avoid such accidents from the perspective of accident avoidance technology, which could fundamentally reduce the loss of such accidents.

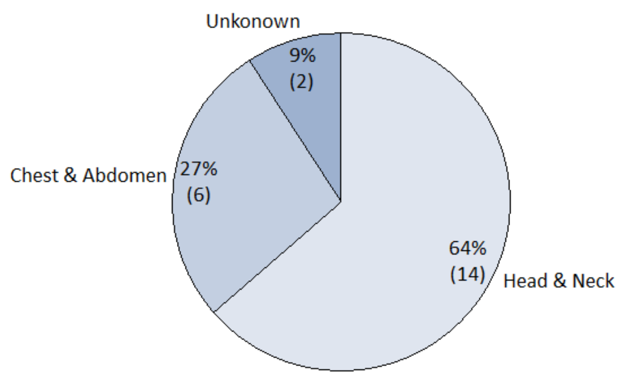


Figure 17 distribution of seriously injured parts of the occupants in struck car (N=22)

The distribution of occupants' seriously injured parts in struck car is shown in Figure 17. Head and neck, followed by chest and abdomen were the most prominent injured parts of the occupants in struck car in side impact, which occupied narrowly 64% and 27% of the casualties. The main causes for these injuries could be the collisions between occupant's head and door or window of the struck car, and the collisions between occupant's chest and abdomen and the deformed door of the struck car. Side airbag and inflatable curtain could provide good protection for head, neck, chest and abdomen of the occupants in side impact, which have been proved to be effective.

SUMMARY AND CONCLUSIONS

Through the in-depth accident research of 138 side impact cases, the objective characteristics of these accidents could be obtained based on the impacted parts, the striking vehicles and the casualties of the occupants. The results could be concluded as follows:

1. 89.1% of the side impact accidents happened at junction and the drivers' violating traffic law was the most common cause (accounting for 81.9%).
2. With the increase of effective impact velocity, the severity of accident consequence rose rapidly. 36% of the side impact accident cases happened with more than 50km/h impact velocity. When the effective impact velocity was more than 50km/h, the maximum deformation of the struck car reached to about 28.6cm. These side impact accidents with high effective impact velocity should not be ignored during development process. Collision avoidance technology, such as Intersection Braking System, could function in these situation throug the reduction of the striking vehicle's velocity, to mitagate the severity of the accident or even avoid the impact.
3. 27.5% of the side impact accidents were struck by heavy vehicle and these accidents usually brought about serious accident consequences. In this situation the average deformation of the struck cars reached to 34.1cm. Meanwhile the injury risk and the ratio of critical casualty consequence (serious injury or death) reached to respectively 72% and 22%. It is clear that under the influence of heavy weight, large rigidity and large size of heavy vehicle, it would be very difficult to prevent the occupants in struck car (especially near-side occupants) from casualty, when struck by heavy vehicle. The application of IOV, which help remind the drivers when conflicting with heavy vehicle, could make a positive effect and fundamentally reduce the loss of such accidents.
4. Head and neck, followed by chest and abdomen were the most prominent injured parts of the occupants in struck car in the side impact accidents, which occupied narrowly 64% and 27% of the casualties. The main causes for these injuries could be the collisions between occupant's head and door or window of the struck car, and the collisions between occupant's chest and abdomen and the deformed door of the struck car. Side airbag and inflatable curtain could provide good protection for head, neck, chest and abdomen of the occupants during side impact, which have been proved to be effective.

ACKNOWLEDGMENT

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