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Vehicle-to-vehicle rear crashes in China – a study of accident characteristics to provide input to active safety system design

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Abstract: To develop an AEB assessment method working well in Chinese real world traffic situation, it is necessary to understand the detailed accident characteristics about vehicle-to-vehicle rear end crashes based on Chinese real world accident data. Therefore, the objective of this study was to understand the vehicle-to-vehicle rear end accident characteristics in detail, focusing on parameters important for design of active safety systems. Two current Chinese real world accident databases were queried for vehicle-to-vehicle rear end crashes. In total, 102 cases were selected for further detailed study regarding accident scene, lighting conditions (daytime and night), target vehicle status before the crash, and crash offset. In Chinese real world rear end accidents with passenger car as rear (striking) vehicle, passenger cars and trucks are most common collision opponents. The car-to-truck accident is the most severe rear end accident type, since under-ride occurs frequently. To protect more occupants in passenger cars in rear end accidents, more attention should be paid on the car-to-truck rear end accidents. A possible effective countermeasure is an AEB system able to detect both cars and trucks, trucks preferably also in night conditions.

Keywords: AEB system design, passenger car, rear end crashes, car-to-truck under-ride.

1 Introduction

Passenger car safety has improved steadily over the past few decades with much improvement of vehicle crashworthiness performance in real world. Passive safety features, such as seat belt and airbag, have saved many lives worldwide every day. In addition to the passive safety systems which mitigate the consequences and injury outcomes of an accident, active safety systems aiming to prevent and mitigate their consequences have become increasingly important.

Autonomous Emergency Braking (AEB) system, one of advanced active safety techniques designed to warn, support adequate braking and/or ultimately stop the vehicle, has gained much interest among car manufacturers and vehicle safety research organizations. In 2014, Euro New Car Assessment Program (ENCAP) released the first test protocol to evaluate the AEB performance focusing on rear end crashes, which currently includes two parts: low speed car-to-car AEB City test and higher speed car-to-car AEB Inter-Urban test [1].

As stated in official statics for Germany and some European countries, rear end crashes are one of the most common accident types [2]. In Germany, of all accident involving injuries, around 20% were caused by cars in rear end crashes [3]. In US, the share of rear end crashes with stationary or moving vehicles was up to 28% in 2006 [4]. Schram et al. (2013) suggested that AEB systems ought to reduce rear end crashes by more than 25% [5]. Schittenhelm quoted in his study that Distronic plus and the Brake Assist System (BAS) could avoid 20% of all passenger vehicles causing rear-end collisions [6].

In china, with the rapid development of urbanization and motorization in the past few decades after joining the World Trade Organization (WTO) in 2001, vehicle population has increased substantially. Until the end of 2014, motorized population reached up to 264 million, of which 154 million were passenger cars [7]. At the same time, the number of licensed passenger car drivers exceeded 246 million [8]. Under such great exposures to the road traffic, traffic safety has become an important issue in China.

China-New Car Assessment Program (C-NCAP), led by China Automotive Technology and Research Center (CATARC) since 2006, takes the responsibility to encourage significant safety improvements to new car design in China [0]. In alliance with other NCAPs worldwide like E-NCAP, C-NCAP has also considered to develop AEB test protocol representing Chinese real world traffic situation in its 2018 version.

The setting of parameters for the development of active safety systems should be based on real-life accident conditions, i.e most common accident scenarios and circumstances in real world. Up to now, limited studies have considered to develop active safety systems based on real world rear end accident characteristics in China.

Based on this concept, the aim of the work presented in this study is to describe the vehicle-to-vehicle rear end accident characteristics, with the focus of the development of parameters important for design of active safety systems especially for rear striking passenger cars based on Chinese accident data.

2 Methods

2.1 Database and inclusion criteria

Two current Chinese accident databases were used in this study: China In-Depth Accident Study (CIDAS) and a database from Shanghai United Road Traffic Safety Scientific Research Center (SHUFO). Both of them are joint projects supported by enterprises, i.e. Autoliv, universities, hospitals and research organizations.

As shown in table1, CIDAS, initiated by the China Automobile Technology and Research Center (CATARC) in 2011, aims to collect 500~600 cases per year in China. Currently, there were 6 cities involved in the project, from north of China to South: Changchun, Beijing, Weihai, Ningbo, Chengdu and Foshan. The investigation team, working within 24 hours, went to the accident scene with the traffic police if there is any person injured and at least one four-wheeled vehicle was involved. On-scene measurement, sketch drawing, and driver interview were conducted on the scene of accident. The technical personnel then went to the accident vehicle parking lot for vehicle deep investigation, i.e. vehicle body information, damage information, safety system equipment. Medical injury information was provided by the victim in a medical report. In total, up to 2700 variables of data were coded in the database to illustrate the case.

Since 2005, Shanghai United Road Traffic Safety Scientific Research Center (SHUFO) got started to collect accidents in Jiading, Shanghai covering 463 km2 with 1.31 million registered population. The accident inclusion criteria of SHUFO is at least one 4-wheeled vehicle involved with at least one airbag deployment in the passenger car or one medium injury like bone fracture without life threatening. With the support from universities, hospitals, car makers and dealers, until the end of 2014, 1,442 cases were investigated in a retrospective way with information about vehicle parameters, injury information, driver reaction and etc. In the end, an accident report for a case-by-case study was attached together with the accident database.

Table 1 Brief information of CIDAS & SHUFO

	CIDAS	SHUFO
Period	2011 July-2014 June	2005-2014 December
Investigation area	6 cities in China	Jiading District in Shanghai
Collected by	CIDAS research team	SHUFO research team
Inclusion Criteria	At least one 4-wheel motor vehicle involved; At least person is injured; The accident site should not be broken before the collection.	Involving at least one passenger car; With at least medium injury or airbag deployment
Number of Accidents	1,718	1,442
Way of investigation	On-scene	Retrospective investigation

Both CIDAS and SHUFO were queried for rear end crashes with the passenger car as the rear striking vehicle. Vulnerable road users involved accidents were excluded in this study, as well as rollovers. Cases with only 2 vehicles were selected, which means that single vehicle and multiple vehicles accidents were not included in the study. Besides this, cases with more than one impact between two vehicles were excluded. In CIDAS, of the total 1,718 cases available until 2014 June, by restricting the variable: VID1 (clock direction) in 11,12,1 for the rear striking vehicle and 5, 6, 7 for the front vehicle, 32 cases were selected. From SHUFO, until the end of 2014, there were 70 rear end cases with passenger car as rear striking vehicle. In summary, the following inclusion criteria were applied:

- Vehicle-to-vehicle rear-end crashes
- Single vehicle and multiple vehicles (>=3) accidents, rollovers were excluded
- Passenger car as rear striking vehicle with VDI2 in (11,12,1)
- VDI2 for the front target vehicle in (5,6,7)
- The front target vehicle hit only once by the rear striking vehicle

3 Results

3.1 Collision opponents - passenger car as rear striking vehicle

As mentioned in the method, vehicle-to-vehicle rear end crashes by restricting passenger cars as the rear striking vehicle were included in the study. Front target vehicles were divided into 3 groups: passenger cars, trucks and (mini)buses. Of the 102 front target vehicles, 46% (n=47) were passenger cars, followed by trucks (43%, n=44), and (mini)buses (11%, n=11) as shown in table 2.

Table 2 Front Target Vehicle (N=102)

	n	*%*
Passenger car	47	46%
Truck	44	43%
(mini)Bus	11	11%
Total	102	100%

As presented in figure 1, in CIDAS, the most common vehicle type of the front target vehicle is truck (56%), and passenger cars accounted for 28%. In SHUFO, the largest group comprising 54% of the whole sample is passenger car, and the second one is truck 37%, and the last minibus 9%.

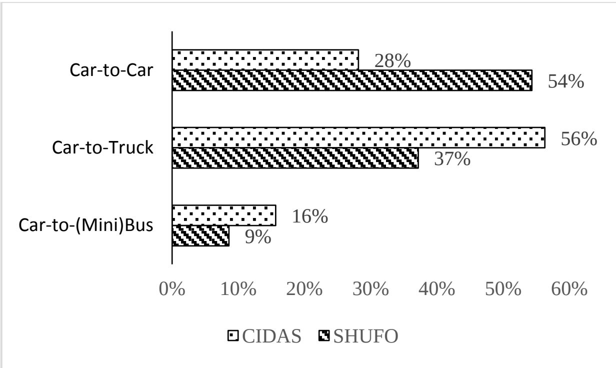


Figure1. Collision opponents in CIDAS and SHUFO

3.2 Accident location

3.2.1 Road type

As presented in table 3 as similar distributions of road types, the straight road comprised most of the road types, both in CIDAS (75%, n=24) and SHUFO (74%, n=52).

Table 3. Road type distribution (N=102)

Road Type	CIDAS % (n)	SHUFO % (n)	**Total % (n)**
Straight Road	75% (24)	74% (52)	**74% (76)**
Intersection	19% (6)	23% (16)	**22% (22)**
Curve road	6% (2)	3% (2)	**4% (4)**

Table 4 showed the road type information by collision opponents. Out of the car-to-car accident, 67% (n=32) occurred on the straight road. This ratio increase when it came to car-to-truck accidents (84%, n=36) and car-to-(mini)bus (73%, n=8).

Table 4. Road type by collision opponents (N=102)

Road Type	car-to-car % (n)	car-to-truck % (n)	car-to-(mini)bus % (n)	**Total %(n)**
Straight Road	67% (32)	84% (36)	73% (8)	**74% (76)**
Intersection	29% (14)	12% (5)	27% (3)	**22% (22)**
Curve road	4% (2)	5% (2)	0	**4% (4)**

3.2.2 Expressway

In China, based on the design, function and daily traffic flow, the traffic road is divided into five groups: expressway, the first-class road, the second-class road, the third-class road, and the fourth-class road. The term "expressway" refers to the traffic road with controlled exits which has 2 to 4 lanes on each direction with the traffic flow of 25,000 motorized vehicles per day.

In this part, all of the roads (n=102) were divided into two groups: expressway and others. Among the "others" group, it involved in all of the roads except the expressway: the first-class road, the second-class road, the third-class road, and the fourth-class road. From the table 5, it is shown that around half (48%, n=49) of the rear end crashes happened on the expressway by combining CIDAS and SHUFO together.

Table 5. Expressway Information (N=102)

Road Type	CIDAS % (n)	SHUFO % (n)	**Total % (n)**
Expressway	44% (14)	50% (35)	**48% (49)**
Others	56% (18)	50% (35)	**52% (53)**

Regarding to the collision opponents distribution by road types, it is indicated in the figure 2 that of the total rear end accidents which happened on expressways (n=49), car-to-truck accidents (49%, n=24) comprised the largest part, and car-to-car accounting for 43% (n=21), followed by a small proportion of car-to-(mini)bus accidents (8%, n=4). For other road types, different from on expressway, car-to-car was the most frequent accident type (51%, n=27), and 36% (n=19) were car-to-truck, 13% (n=7) car-to-(mini)bus.

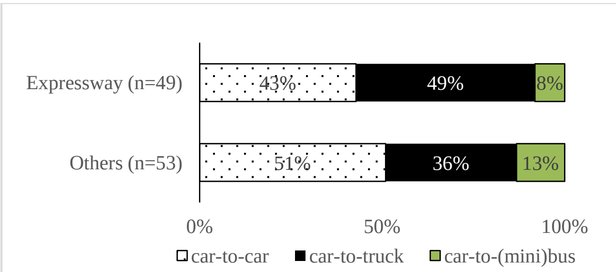


Figure2. Collision opponents by road type

3.2.3 Light condition

As shown in table 6, out of the total 102 rear end accidents in CIDAS and SHUFO, 56 (55%) happened at night, the other 46 (45%) occurred at daytime.

Table 6. Light condition (N=102)

Light	CIDAS % (n)	SHUFO % (n)	**Total % (n)**
Daytime	41% (13)	47% (33)	**45% (46)**
Night	59% (19)	53% (37)	**55% (56)**

Distribution of collision opponents grouped by light condition was analyzed in this part, as shown below in figure 3. Car-to-car rear end crashes distributed almost equally in daytime (n=27) and night (n=21). Regarding to the car-to-truck accident, more occurred at night (n=33) compared to daytime (n=10).

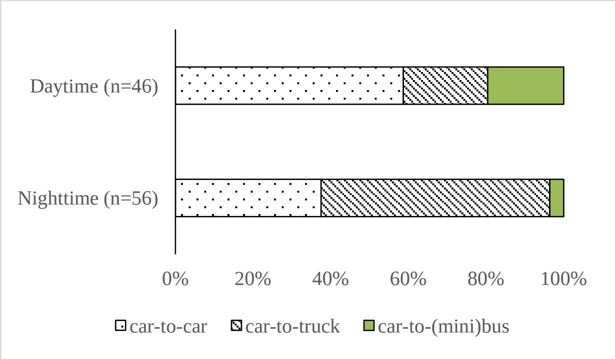


Figure3. Light condition by collision opponents

3.3 Injury information-occupants in rear striking cars

In CIDAS, injury severity was classified into 4 groups: uninjured, out-patient (less than 24 hours of medical treatment), in-patient (more than 24 hours of medical treatment) and dead (within 7 days of the accident). SHUFO has similar coding for the injury classification, but with 5 groups: uninjured, slightly injured, severely injured, seriously injured and fatal. In this study, all of injury severities in CIDAS and SHUFO were re-coded into four groups: uninjured, slightly injured, seriously injured and fatal.

In this study, of the 102 rear striking passenger cars, totally 160 occupants were involved in the injury analysis. For the injury severities of the occupants, 2 were excluded because of unavailability of injury information, which resulted in 158 occupants as shown in the figure 4 below. The fatal and seriously injured ratios of the occupants in the rear end crashes were 16% and 18% respectively, accounting for 34% (n=54) of the whole data sample. 47% (n=74) of the occupants were not injured in the rear end accidents, and 19% (n=30) sustained slightly injuries, in CIDAS and SHUFO.

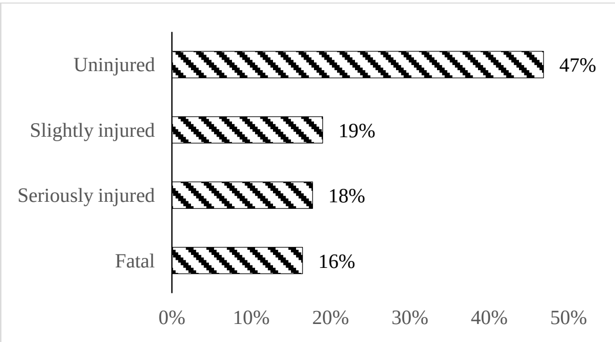


Figure4. Injury severity distribution

Of the total 158 occupants in the rear striking vehicle, 70 (44%) had an impact with a truck, comprising the largest part of the whole data sample, followed by 67 (42%) with passenger cars and 21 (14%) with (mini)buses as presented in table 7.

Table 7. Injury Severity by front vehicle type (N=158)

Front vehicle	Uninjured % (n)	Slightly injured % (n)	Seriously injured % (n)	Fatal % (n)	**TOTAL % (n)**
Passenger car	64% (47)	33% (10)	36% (10)	0	**42% (67)**
Truck	16% (12)	57% (17)	57% (16)	95% (25)	**44% (70)**
(mini)Bus	20% (15)	10% (3)	7% (2)	5% (1)	**14% (21)**

As shown in the figure 5, the injury severity distribution varied among different front vehicle types. In the car-to-car accidents, no passenger car occupant died, and 70% (n=47) got uninjured, 15% (n=10) got slightly injured and 15% (n=10) seriously injured. Similar distribution can be found in the car-to-(mini) bus rear end accidents: 5% (n=1) were fatal, and 71% (n=15) got uninjured. On the other hand, when it came to car-to-truck accidents, the fatal ratio increased to 36% (n=25), and 23% (n=16) got seriously injured, only 17% (n=12) got uninjured, the rest 24% (n=17) were slightly injured.

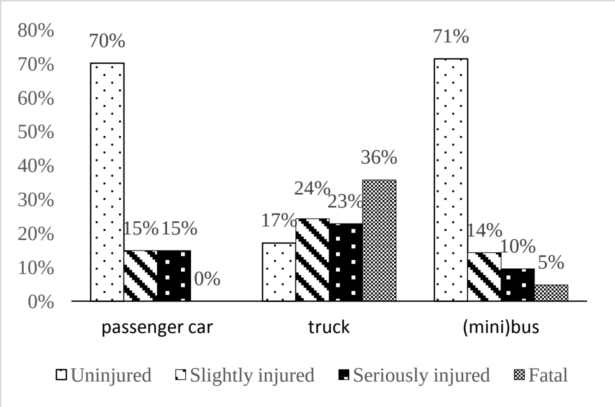
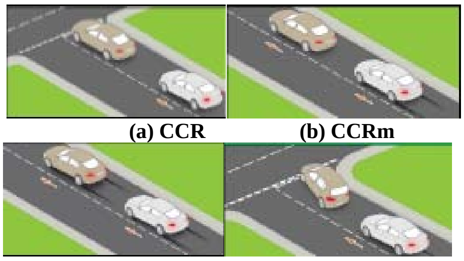


Figure5. Injury severity by front vehicle type

3.4 Target vehicle status

In this study, four types of test scenarios regarding to the front vehicle initial status were specified: car driving into a stationary vehicle (CCRs, figure 6 (a)), car driving into a slower moving vehicle (CCRm, figure 6 (b)), car driving into a braking vehicle (CCRb, figure 6 (c)), and car driving into a lead turning vehicle (CCRt, figure 76 (d)).



(a) CCR (b) CCRm

(c) CCRb (d) CCRt

Figure6. AEB test scenarios

CIDAS and SHUFO both showed similar distributions of initial status of the front vehicles that the most common type was the car driving into a slower moving vehicle, 56% of CIDAS, 30% of SHUFO. The second one was the car driving into a stopped vehicle (32% in CIDAS, 24% in SHUFO) followed by a car driving into a turning one (6% in CIDAS, 23% in SHUFO) and into a decelerating vehicle (3% in CIDAS, 23% in SHUFO), as present in table 8.

Table 8. Initial Status of the front vehicle

	CIDAS	SHUFO
Moving	56% (n=18)	30% (n=21)
Stop	34% (n=11)	24% (n=17)
Turning	6% (n=2)	23% (n=16)
Decelerating	3% (n=1)	23% (n=16)
Total	**32**	**70**

3.5 Damage overlap of rear striking car

The overlap of collision damage was evaluated by recording direct contact damage across the front of the rear striking car, with the front elevation divided into four equal segments. The lateral area of damage is displayed by recording the percentage of damage from the front corners of the vehicle. As presented in figure 7, in CIDAS, 25% damage overlap (44%, n=14) occurred more often than the 100% overlap (22%, n=7), 50% overlap (19%, n=6) and 75% overlap (16%, n=5). Different from CIDAS, SHUFO presented the 100% overlap with the largest proportion as 35% (n=24), followed by the 25% overlap (30%, n=21), 50% overlap (24%, n=17) and 75% overlap (11%, n=8).

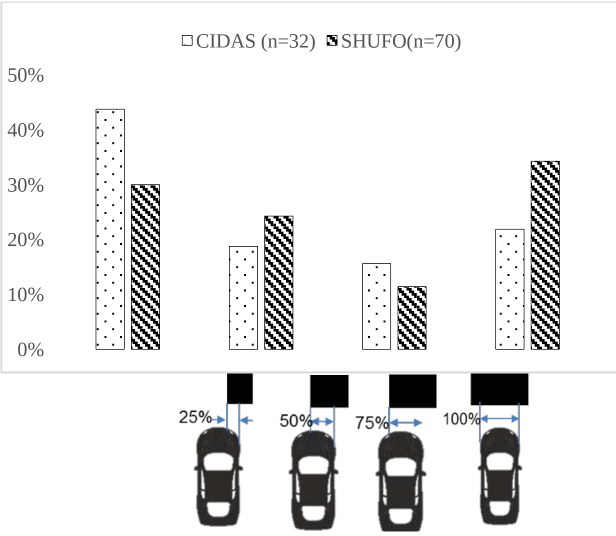


Figure7. Damage overlap of rear striking passenger car

3.6 Severe rear end accident analysis: car-to-truck rear end underride crash

Due to the large incompatibility between the rear of the truck and front of the car, the bumper of the small car does not make contact with any part of the heavy vehicle, therefore not utilizing the vehicle's crashworthy components in the car-to-truck rear end crashes. In CIDAS & SHUFO, of 44 Car2Truck rear end collisions, 43 (98%) were underride accidents. In this part, car-to-truck rear end underride accidents were analyzed case by case regarding to the accident time, front truck initial status, type of the truck, car occupant injuries, and safety equipment of passenger cars.

3.6.1 Light condition

Out of these 43 car-to-truck rear end underride accidents, 77% (n=33) happened at night, and 23% (n=10) in daytime. Compared to the whole passenger car rear end accidents stated in the previous study (n=102), more car-to-truck rear end undried accidents happened during night, as shown in figure 8.

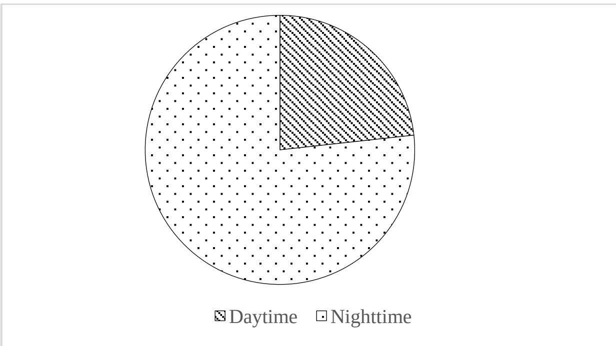


Figure8. Light condition of car-to-truck rear end underride accidents

3.6.2 Target vehicle status

Of the total 43 trucks, 58% (n=25) were moving before the crash with the car, followed by 30% (n=13) stopped, and the reasons for the stops of the 13 trucks were that, 11 had a stop because of the breakdown, the other 2 were waiting for the traffic light. 7% (n=3) were lane changing or turning around and only 5% (n=2) of them were decelerating as presented in figure 9.

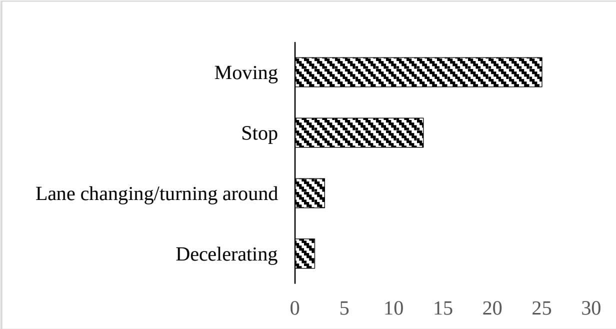


Figure 9. Initial status of front target truck

3.6.3 Intrusion of the passenger car

The intrusion of the passenger car was classified into 5 levels as shown in figure 10 from the front to the end: negligible, slight, moderate, severe and catastrophic. Accordingly, the intrusion of the whole 43 passenger cars were analyzed case by case here presented in the figure 11. Combining CIDAS and SHUFO, two most common degree of intrusion were severe (37%, n=16) and catastrophic (37%, n=16) intrusion, followed by moderate intrusion (26%, n=11). No negligible or slight intrusion was found in the 43 rear striking passenger cars.

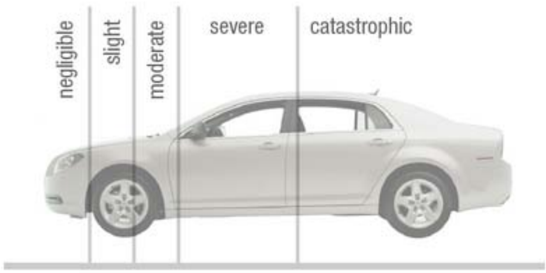


Figure10. Four intrusion levels of the passenger car

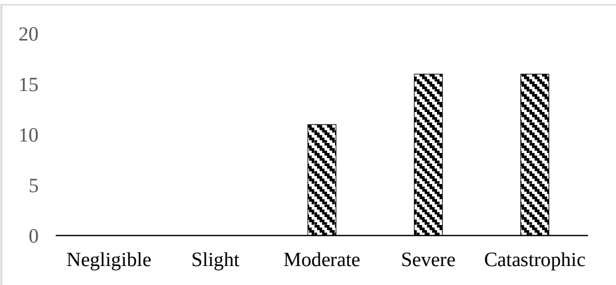


Figure11. Intrusion level distribution of the rear striking passenger cars

3.6.4 Injury severity of passenger car occupants

Out of the 43 car-to-truck rear end underride accidents, there were 71 passenger car occupants involved. As presented in the figure 12, 35% (n=25) died followed by 25% (n=18) with slight injuries, 25% (n=16) with serious injuries and 17% (n=12) with no injury.

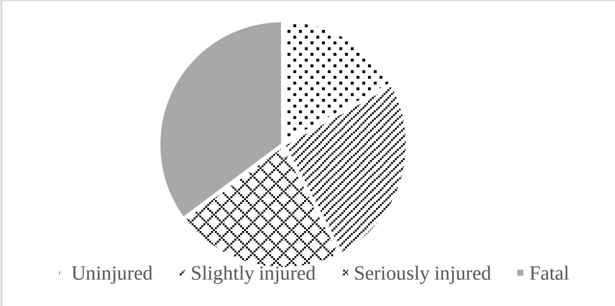


Figure12. Injury severity of the passenger car occupants

Injury severities of the passenger car occupants by passenger car intrusion and seating position were analyzed as shown in figure 13 and figure14. As presented in figure 14, serious and fatal injury risk increased as the intrusion of the passenger car intrusion increased, 85% (n=22) in the catastrophic intrusion level compared with 50% (n=13) in severe intrusion group and 31% (n=6) in the moderate intrusion. The highest fatal injury risk by seating position was 43% (n=6) out of 14 co-drivers followed 37% from the 43 drivers and 21% of the 14 at rear seats as presented in figure 15.

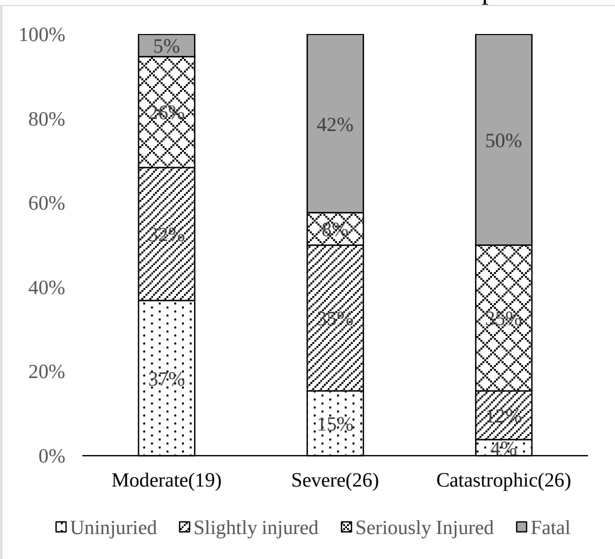


Figure13. Injury severity by underride extent

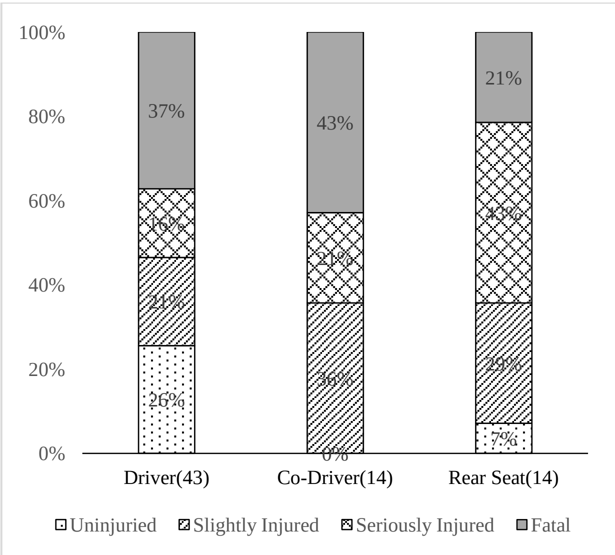


Figure14. Injury severity by seating position

3.6.5 Seat belt usage of the passenger car occupants

Out of the 71 occupants in the rear striking passenger cars, 9 were excluded due to the unknown information about the seat belt usage. In the rest of passenger car occupants (n=62), as presented in the figure 15, the majority (79%, n=49) of the passenger car occupants were unbelted, and only 19% (n=12) were found to be belted followed by 2% (n=1) without seat belt equipped.

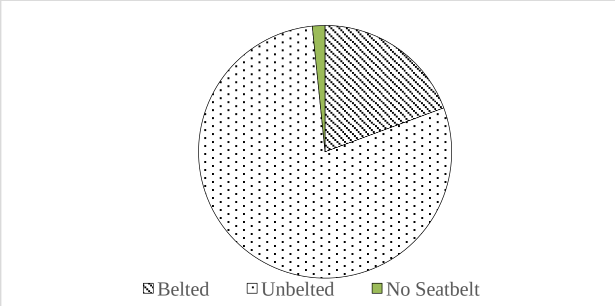


Figure15. Seat belt usage distribution

Here as shown in figure 16 is the injury severity distribution regarding to the seat belt usage of the rear passenger car occupants. Out of the total belted occupants (n=12), the majority of the occupants (75%, n=9) got uninjured or slightly injured, followed by seriously injured (17%, n=2) and fatal (8%, n=1). Among the unbelted passenger car occupants, 18 occupants (37%) were fatal, followed by 14 seriously injured occupants, 11 slightly injured and 6 uninjured.

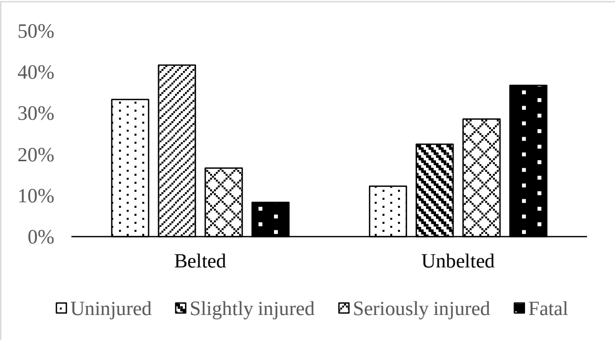


Figure16. Injury severity by seat belt usage

3.6.6 Accident Reasons

Of the total 43 cases, clear accident causes could be identified in 24 cases. For others, the reasons were indistinctly described as: failure in keep safe distance or improper driving behavior. Out of the 24 cases with clear accident cause, 1 was caused by the improper lane changing of the truck, the other 23 were caused by the passenger car as shown in figure17. The most common accident causes was fatigue driving/inattention (39%, n=9), followed by drunk driving (22%, n=5) and over speeding (22%, n=5), improper lane changing (9%, n=2) and poor driver view (9%, n=2).

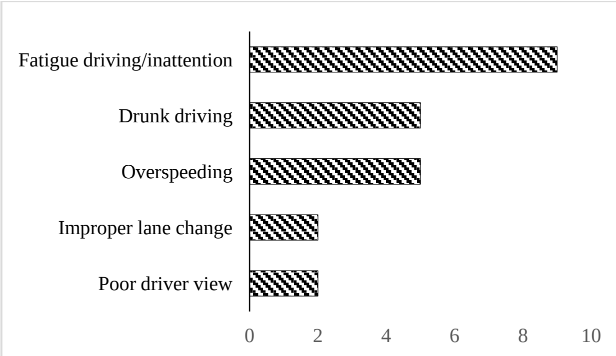


Figure17. Accident causes related to passenger car driver

4 Discussion

The results of this study show that taking into the real world accidents account, car-to-car crash is the most common accident type in the rear end accidents with passenger car as rear striking vehicle.

The majority of the rear end accidents with passenger car as rear striking vehicle happened on straight road. Almost half of rear end crashes were on expressway which caused more severe accidents compared with non-expressway, since more car-to-truck rear end crashes were involved.

Different distributions of collision opponents were shown compared CIDAS with SHUFO: in CIDAS, car-to-truck is the most common accident type and in SHUFO, it is car-to-car. One of the reasons is that most of the SHUFO accident investigation areas are located in city, and in CIDAS, not only in city area, they also investigate much on highways where there are more trucks. We therefore believe that the databases complement each other, so that the combined sample is likely a more representative dataset of Chinese traffic accidents.

For the accident time, half-to-half happened at daytime and night. However when it came to collision opponents, at night, more car-to-truck accident occurred.

The most common accident scenario is the passenger car driving into a slowly moving vehicle, both shown in CIDAS and SHUFO. The accident scenario: the car driving into a turning vehicle is also common in reality which might be considered into the AEB test scenarios.

Car-to-truck rear end accidents caused the highest fatal and serious injury risk compared with car-to-car and car-to-minibus accidents, due to the fact that most of them were underride accident with severe and catastrophic passenger car intrusion into the rear end of the truck. The results indicate that the belt has some protective effect even in the underride accidents, but low number of cases makes it difficult to draw a clear conclusion. From this point of view, promoting increased seat belt usage as well as introducing AEB systems should be encouraged. The setting of parameter for AEB like field of view, cut-off speed, should take the car-to-truck accidents characteristics into consideration. Since most of the car-to-truck rear end accidents were caused by the fatigue driving or inattention by the passenger car driver, so active systems which detect the drivers' attention can support the AEB functions better in real world.

5 Limitation

Accident severity level were not quantified precisely due to the unavailability of delta-V, so the information about road type: expressway or not of the accident location was used instead to indicate the speed of the vehicle.

Despite that the focus of the study was to understand the rear end accident characteristic, detailed injuries information like MAIS by different body locations were unavailable in the study, which means that injury mechanism of passenger car occupants in the rear end crashes could not be analysed in deep.

6 Conclusions

Based on Chinese real world rear end accidents with the passenger car as rear striking vehicle, car-to-car and car-to-truck are the two most common accident types. The most common accident scenario is the passenger car driving into a slow moving vehicle. The car-to-truck accident caused more severe and fatal injuries due to the frequent occurrence of underride of passenger cars into the rear end of the truck. While it is highly recommended to promote increased seat belt use, this may be complemented with autonomous emergency braking (AEB) systems. To protect more occupants in passenger cars in rear end accidents, effective AEB systems for Chinese traffic conditions should be able to detect both cars and trucks, trucks preferably under night conditions.

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