EFFECT OF VISIBILITY AND PEDESTRIAN PROTECTION PERFORMANCE ON PEDESTRIAN ACCIDENTS

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ABSTRACT

The pedestrian accident is an important accident type that should be studied to reduce the number of accidents worldwide. The factors in pedestrian accidents should be quantitatively clarified in order to get clues to reduce the number of pedestrian accidents. In an effort to address this issue, two vehicle-related areas: visibility around A-pillar and pedestrian head protection performance, were analyzed to clarify their influences on the number of pedestrian accidents with the fatality or the injured for each vehicle model in this study.
Macro accident data based on the police data from the year of 2008 through 2011 was compiled by ITARDA (Institute for Traffic Accident Research and Data Analysis) in Japan for around 24,000 pedestrian accidents on 39 vehicle models.
The number of pedestrian accidents with fatal/serious/minor injury per 10,000 registered vehicles for each vehicle model was utilized as objective variables to determine the probability of the accidents. The relationships between each of the vehicle-related factors described above and the objective variables were carefully scrutinized with use of scatter charts, correlation analyses and multiple regression analyses.
It was successfully clarified that the pedestrian accident would be more likely to occur when the angle of hindrance due to A-pillar is larger. It was also captured that the larger horizontal angle of view through the windshield would reduce the occurrence of pedestrian accident.
Furthermore, it was clarified that the influence of visibility on the occurrence of pedestrian accident was different among the straight going maneuver, the right-turn maneuver, etc. It was possible to predict the number of fatality or injured in the pedestrian accidents to a certain degree of probability, with use of the combination of visibility indices.
In addition, it was clearly captured that the better pedestrian head protection score in the JNCAP test would lead to the decrease in the number of pedestrian accidents with the fatality or the injured.
Furthermore, the combination of visibility indices and pedestrian head protection score in the JNCAP test successfully provided much better prediction of the number of fatality or injured in the pedestrian accidents. In other words, it was clarified that the optimization of parameters in visibility indices and pedestrian head protection could lead to the decrease in the number of pedestrian accident.
The effects of the pedestrian head protection score in the JNCAP test on the number of pedestrian accidents with the fatality or the injured were elaborately scrutinized from the viewpoint of danger-cognitive velocity and vehicle maneuver, i.e., straight-going, right-turn and left-turn. The results demonstrated that the pedestrian head protection score in the JNCAP test is highly correlated with the pedestrian accident especially in the case of pedestrian's being impacted by vehicle body not a tire nor road, and furthermore in the straight going maneuver at over 40km/h of danger-cognitive velocity.
In-depth accident analysis with data of ITARDA and CIDAS (China In-depth Accident Study) was conducted in Japan and China. The result showed that JNCAP would be effective especially in the crash velocity range of 31-50km/h, which accounts for as much as 40% of total 115 occurred in five major cities in China.

INTRODUCTION

As to fatalities in traffic accidents in Japan, the number of pedestrian has exceeded that of vehicle occupants, consisting of more than 35% of all fatalities [1].
It was said that the number of fatalities of pedestrian in China was 9,891 in 2011, which was equivalent to 16% of all fatalities, 62,387 [2].

A lot of NCAP operations around the world have been introducing pedestrian protection performance tests first on the head, and then on the lower extremities in order to reduce the injury in the pedestrian accidents [3] [4] [5] [6] [7].
Some car manufacturers started to introduce the pop-up hood and the external pedestrian airbags. On the other hand, from the viewpoint of active safety, some automatic emergency braking systems for pedestrians have been promoted by EuroNCAP, etc. [8].
In the present study, the factors in pedestrian accidents should be quantitatively clarified in order to get clues to reduce the number of pedestrian accidents in accordance with the following steps.
1. Visibility performance for each vehicle model was examined in comparison with pedestrian accidents because better visibility seems to be one of the most important factors for avoiding pedestrian accidents.
2. The correlation between pedestrian head protection performance and pedestrian accidents was examined.
3. The combination of visibility and pedestrian head protection performance was studied for good prediction of the number of injured pedestrians. This can be said as the unified theory of visibility and pedestrian head protection performance.
4. Effect of the pedestrian head protection score in the JNCAP test on pedestrian accidents was elaborately scrutinized from the three viewpoints: injuring objects, danger-cognitive velocity and vehicle maneuver, i.e., straight-going, right-turn and left-turn.
5. In-depth Accident Data in China and Japan was employed for the purpose of clarifying the characteristics of pedestrian accidents.

DATASET

Visibility parameters

Figure1 and 2 indicate the definitions of visibility parameters discussed in this study. There are four parameters: Angle of Hindrance at Driver's side (AHD), Angle of View at Driver's side (AVD), Angle of Hindrance at Passenger's side (AHP) and Angle of View at Passenger's side (AVP). The eye points were defined based on American Anthropomorphic Male 50 percentile dummy (AM50).

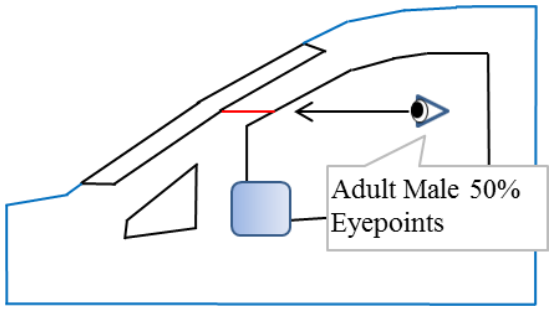

Figure1. Definitions of visibility parameters (side view).

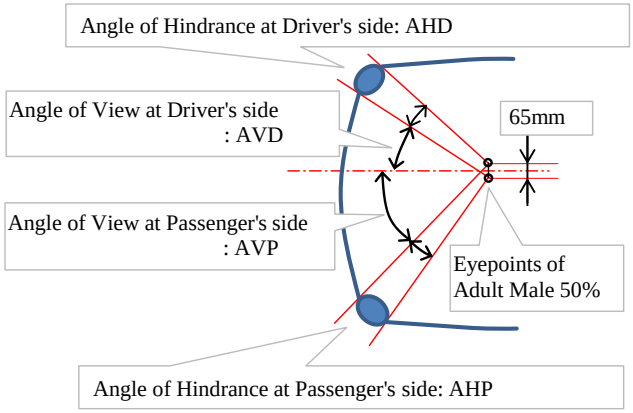

Figure2. Definitions of visibility parameters (top view).

Pedestrian Head Protection Performance

The score of pedestrian head protection performance evaluated by JNCAP was utilized as a parameter of passive safety performance. The projecting speed of the head impactor is 35km/h, and the equivalent velocity of vehicle was 44km/h. HIC, or head injury criteria, was measured. The integrated final score is converted to “0” through “4” [9].

Pedestrian Accident Data

Macro Accident Data in Japan Macro pedestrian accident data based on the police data was compiled by ITARDA (Institute for Traffic Accident Research and Data Analysis) in Japan. The following parameters were categorized in the present study.

Accident investigated period: the year of 2008 through 2011
Injury severity: Minor, Serious, Fatal
Danger-cognitive velocity: 20km/h or less, 20-40km/h, more than 40km/h
Injuring objects: Vehicle body, Tire, Road, Others

Here, the fatal injury is defined as death within 24hours after the accident, and the serious injury is defined as the one which needs the treatment more than 30 days before the recovery.
Macro accident data based on the police data from the year of 2008 through 2011 were compiled by ITARDA in Japan for 24,086 pedestrian accidents on 39 vehicle models.
The number of pedestrian accidents with fatal/serious/minor injury per 10,000 registered vehicles for each vehicle model was utilized as objective variables to determine the probability of the accidents.
When the relationships among visibility, pedestrian head protection performance and pedestrian accident was analyzed, the vehicle models with the registered number more than 300,000 in four years were selected because the vehicles with the low volume have the wide confidence interval and could lead to fallible conclusions.

As to the 19 models of these focused vehicle models, the visibility parameters were available. As to the 29 models of them, the pedestrian head protection score in the JNCAP test was available. As to the 14 models of them, both parameters were available.
The registered numbers of each vehicle model utilized as a denominator was calculated based on sales volume in each month. The contribution rate for the sale year and the vehicle survival rate were taken into consideration.
The numbers of pedestrian accidents with fatal/serious/minor injury per 10,000 registered vehicles for each vehicle model, which was obtained by dividing the number of accidents during four years by the number of registered vehicles during four years, was adopted as objective variables to determine the probability of accidents per year.

In-depth Accident Data in Japan and China For Japan, the data collected by ITARDA through investigation on accidents around Tsukuba City, Ibaraki Prefecture was used. This data includes three body types: sedans, SUVs, and station wagons, and three driving maneuvers: straight-going, turning right or turning left. The data was collected for about 19 years from 1993 through 2011.
On the other hand, for China, the data collected by CIDAS through investigation on pedestrian accidents in Beijing, Ningbo, Changsha, Weihai and Foshan. The same body types and vehicle maneuvers as these of ITARDA's are covered. The data was collected for about 2 years from 2011 to 2012.

METHODOLOGY

The relationships among each of the vehicle-related factors described above and the objective variables were carefully scrutinized with use of scatter charts, correlation analyses and multiple regression analyses.

RESULTS

Big Pictures of Pedestrian Accidents

The distribution of casualties classified as a vehicle maneuver for each degree of injuries is depicted in Figure 3. Minor injury is a major part of injured pedestrian accidents with injuries. A lot of accidents occur in the straight-going maneuver and the right-turn maneuver, in contrast with the left-turn maneuver.

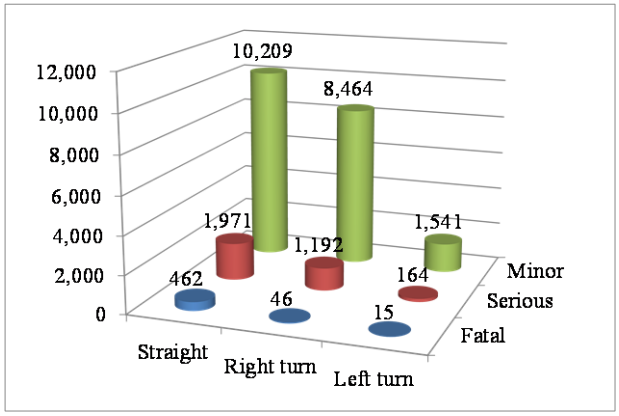

Figure3. Pedestrian accident for vehicle maneuver and degree of injury.

Figure4 demonstrated the percentages of straight-going, right-turn and left-turn for each degree of injuries. The percentage of straight-going in fatal accidents was as high as around 90%. On the other hand, however, the percentage of right-turn for each of serious injury and minor injury was around 30%, 40%, respectively, whereas the percentage of left- turn remained small for each degree of injuries.

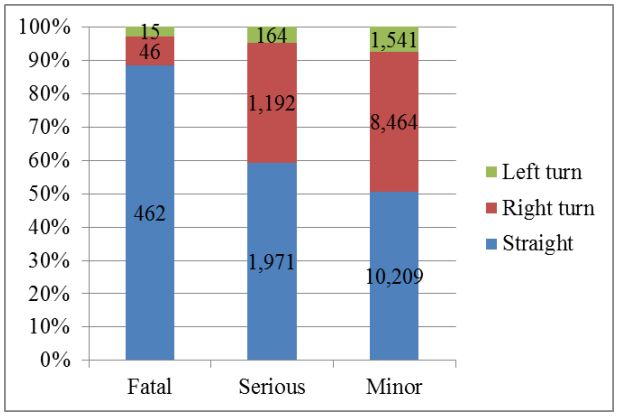

Figure4. Rates of vehicle maneuver for each degree of injuries.

Visibility Effects on Pedestrian Accident

The result of relationship between visibility and the number of all (fatal/serious/minor) injured pedestrians per 10,000 registered vehicles in the right-turn maneuver is illustrated in Figure 5. The horizontal axis indicates the angle of hindrance at driver's side (AHD) as defined in Figure 2, described above. It was clarified that the more the AHD is, the more likely it is for the injured accident to occur in the right-turn maneuver.

There were two points around 11 degrees of angle of hindrance at driver's side in Figure 5. The number of injured pedestrians for one model was more than 7, but the number for the other model was less than 3. One of the factors for this difference was considered to be another visibility parameter; angle of view at the driver's side. In fact, the former model had a relatively small angle of view at driver's side; 21 degrees, and the latter model had a large angle; 25 degrees (See in Figure 6).

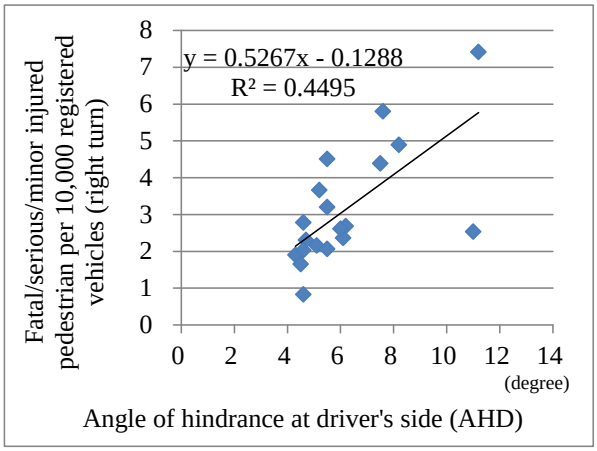

Figure 5. Relationship between the number of fatal/serious/minor injured pedestrians per 10,000 registered vehicles and angle of hindrance at driver's side in the right-turn maneuver.

Another visibility parameter, i.e. angle of view at driver's side (AVD) is adopted as horizontal axis in Figure6. It depicted that the more the AVD is, the less the number of injured pedestrians is in the right-turn maneuver.

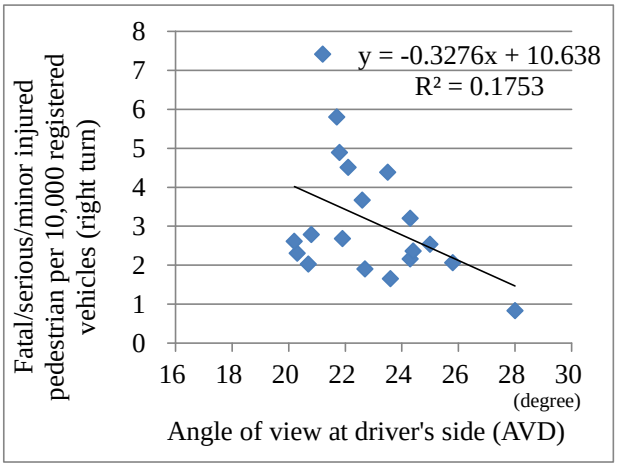

Figure 6. Relationship between the number of fatal/serious/minor injured pedestrians per 10,000 registered vehicles and angle of view at driver's side at right turn.

Correlation coefficients, which are defined to be square root of coefficients of determination and have plus and minus, for relationships among the number of fatal/serious/minor injured pedestrians and four visibility parameters were summarized in Figure7.

This detailed examination provided different results about effects of visibility in each case of the straight-going maneuver and the right-turn maneuver.

Angle of view at passenger's side (AVP) was also found to be important in the straight-going maneuver because a larger AVP would provide a wider horizontal view through windshield.

Angle of hindrance at driver's side (AHD) and angle of view at driver's side are crucial in the right-turn maneuver as described before. AHP showed relationship to some extent, but this was because AHP had relationship with AHD.

Angles of view at both sides (AVD, AVP) were also found to be important even in the total case because a larger angle of view would provide a wider horizontal view through windshield.

In short, it can be said that the pedestrian accident would be more likely to occur when the angle of hindrance due to A-pillar is larger, and also when the angle of view is small. These results seemed to be reasonable when driving scene was imagined.

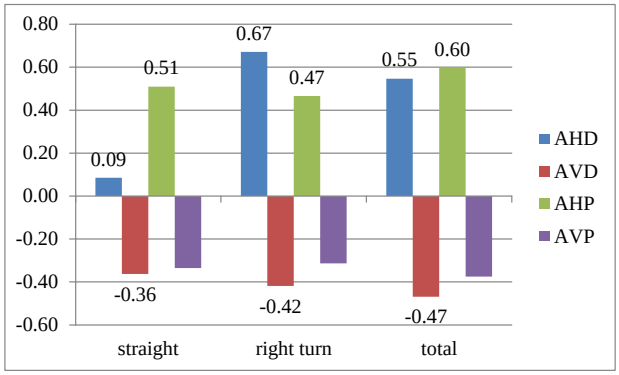

Figure7. Correlation coefficients for relationships among the numbers of fatal/serious/minor injured pedestrians per 10,000 registered vehicles and visibility indices for each driver's maneuver.

<u>Combination of Visibility indices: AHD and AVP</u>

The number of all (fatal/serious/minor) injured pedestrian per 10,000 registered vehicles including three vehicle maneuver: straight-going, right-turn and left-turn was estimated by combination of visibility indices.

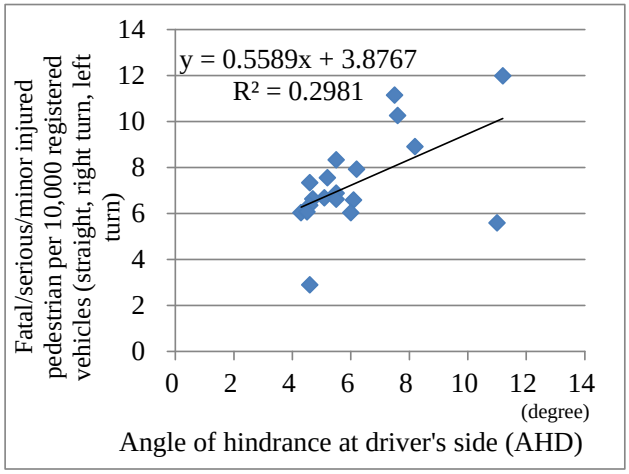

Figure8. Relationship between the number of fatal/serious/minor injured pedestrian per 10,000 registered vehicles and angle of hindrance at driver's side in straight going, right turn, and left turn.

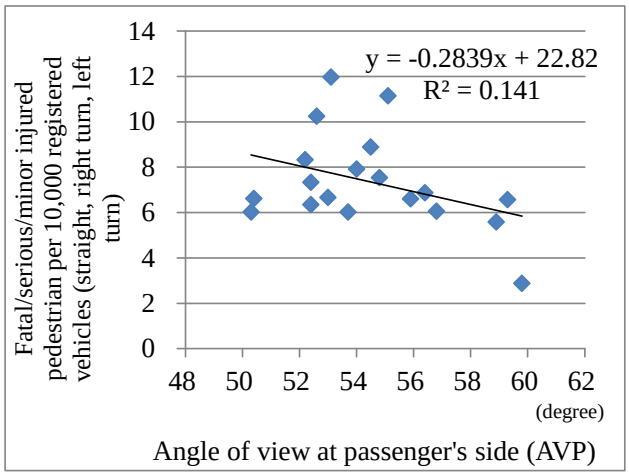

Figure9. Relationship between the number of fatal/serious/minor injured pedestrian per 10,000 registered vehicles and angle of hindrance at driver's side in straight going, right turn, and left turn.

Four visibility parameters were taken into consideration at first, and then backward elimination method was utilized in order to determine the best combination of visibility parameters. As a result, the combination of AHD and AVP was selected. Before describing the result of the combination, the relationships between the number of injured pedestrians and AHD, and the relationship between the number of injured pedestrians and AVP were depicted in Figure8 and Figure9, respectively. Some correlations were found, but there were some unexpected plots.

The result of multiple regression analysis utilizing AHD, AVP was shown in Figure 10. The multiple regression equation was obtained as follow (Equation 1):

Estimated values = 0.6298*AHD-0.3530*AVP+22.676 (1).

P values were 0.0031, 0.0178 for AHD, AVP respectively, which were less than 0.05. F value of the equation was 0.003256. Hence, this analysis could be said to be significant. Standard regression coefficients for AHD, AVP were 0.62, -0.47, respectively. AHD had a little greater effect than AVP. The coefficient of determination could indicate to account for the numbers of accidents to around 50 percent degree. It was captured that visibility has significant relationships with pedestrian accidents. The knowledge like this result could be a clue to decrease the number of pedestrian accidents.

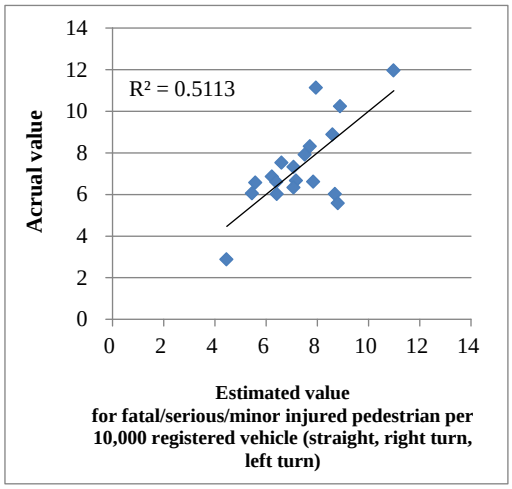

Figure10. Relationship between actual values and estimated values for the number of fatal/serious/minor injured pedestrians per 10,000 registered vehicles, which are estimated by combination of angle of hindrance at driver's side and angle of view at the passenger's side.

Combination of Visibility and Pedestrian Head Protection Performance

The combination of the visibility and the pedestrian head protection score in the JNCAP test was scrutinized in order to estimate the number of fatal/serious/minor injured pedestrian accidents including three vehicle maneuvers: straight-going, right-turn and left-turn. Out of 19 vehicle models, both of the visibility parameter and the pedestrian head protection score in the JNCAP test were available only for 14 vehicle models.
The result of multiple regression analysis showed that the combination of angle of hindrance at driver's side and the pedestrian head protection score in the JNCAP test (PHPS) was the best one.
The effect of angle of hindrance at driver's side on the number of all injured pedestrians was illustrated (See Figure 11).

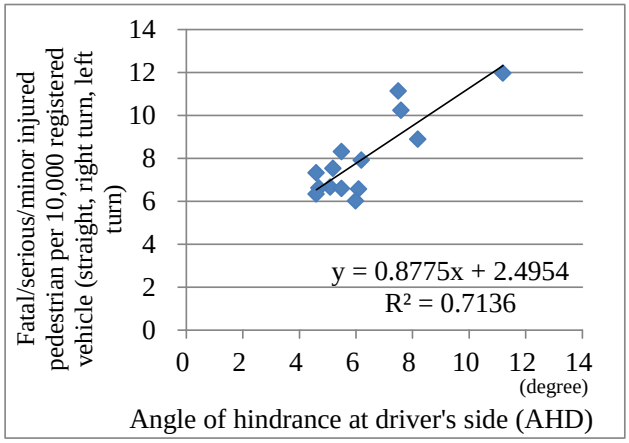

Figure11. Relationship between the number of fatal/serious/minor injured pedestrians per 10,000 registered vehicles and angle of hindrance at driver's side in straight-going, right-turn, left- turn.

The good relationship between the pedestrian head protection score in the JNCAP test and the number of injured pedestrians by vehicle models was clearly shown in Figure 12.

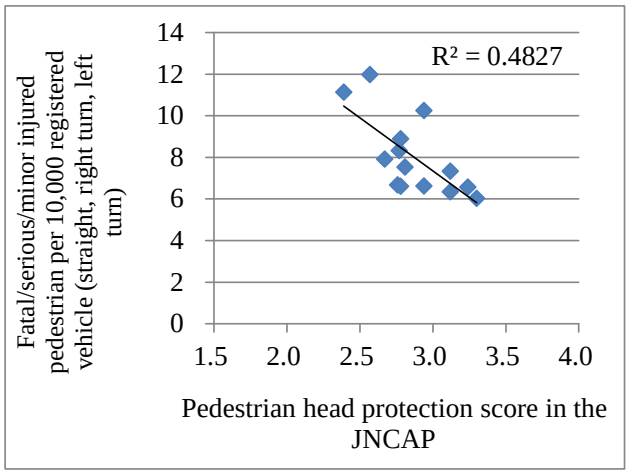

Figure12. Relationship between the pedestrian head protection score in the JNCAP test and the number of fatal/serious/minor injured pedestrian per 10,000 registered vehicles.

The multiple regression equation was obtained as follow (Equation 2):

Estimated values
= 0.6900*AHD-2.7692*PHPS+11.6231 (2).

It was successfully captured that the combination of visibility and pedestrian head protection performance, which were in different areas, could estimate the number of the real–life pedestrian accidents at high accuracy. Relationship between actual values and estimated values was shown in Figure 13.

From the viewpoint of statistics, P values were 0.0008, 0.0248 for AHD, PHPS respectively, which were less than 0.05. F value of the equation was 7.44E-05. Hence, this analysis could be said to be significant. Standard regression coefficients for AHD, AVP were 0.66, -0.38, respectively. AHD had a little greater effect than PHPS.

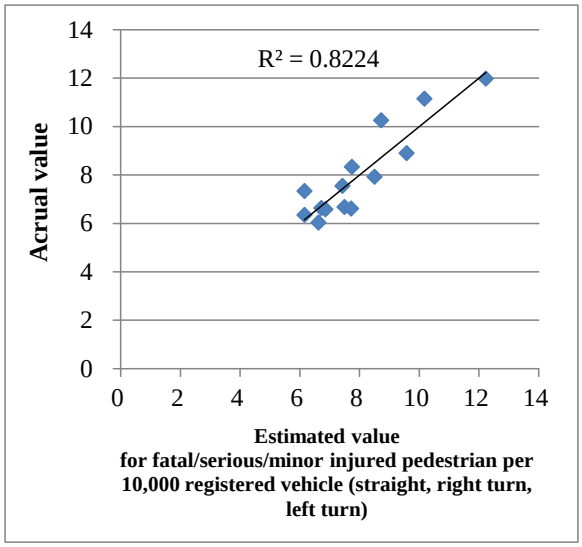

Figure13. Relationship between actual values and estimated values for the number of fatal/serious/minor injured pedestrians per 10,000 registered vehicles, which are estimated with use of angle of hindrance at driver's side and the pedestrian head protection score in the JNCAP test.

Although the multiple regression analysis here cannot be said to be absolutely excellent because of the limited number of vehicle models, it should be stressed that the concept and procedure could be very useful for improving real-world safety for pedestrian from the viewpoint of vehicle.

Detailed Analysis for Pedestrian Accidents

Pedestrian accidents were analyzed in more detail for each danger-cognitive velocity: 0-20, 20-40, over 40km/h and the injuring objects on pedestrian: vehicle body, tires, road, others. The accident data of 39 vehicle models during four years: 2008-2011 were utilized.

Danger-cognitive velocity In fatal injured cases, the situations of straight-going and higher velocity had the majority of the accidents (See Figure 14). In serious cases, the situations of right turn and lower velocity increased (See Figure 15).
As to minor injured cases, the situation of "20km/h or less" occupied a large part of the pedestrian accidents (See Figure 16).

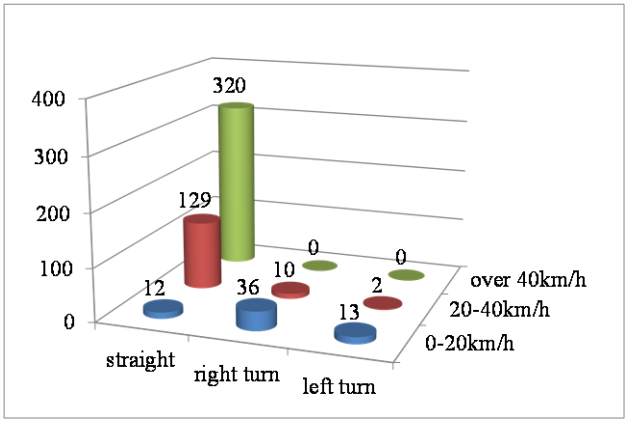

Figure14. The number of **fatal** injured pedestrian for each of vehicle maneuvers and danger- cognitive velocity.

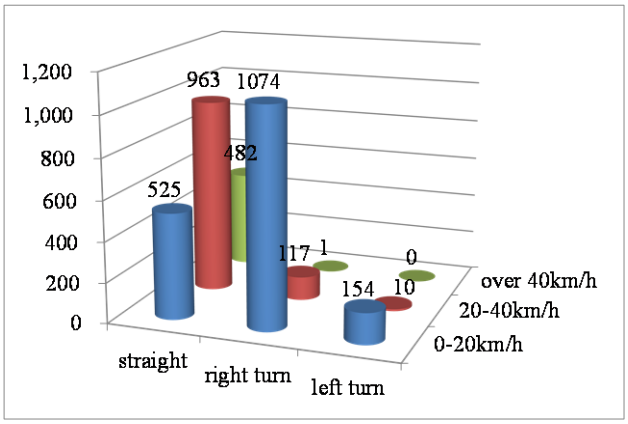

Figure15. The number of **serious** injured pedestrian for each of vehicle maneuvers and danger- cognitive velocity.

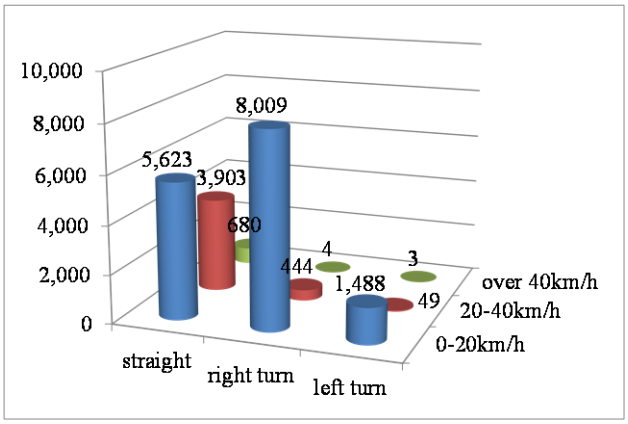

Figure16. The number of **minor** injured pedestrian for each of vehicle maneuvers and danger-cognitive velocity.

Injuring objects on pedestrians Although macro accident data had only four categories about injuring objects injury on pedestrians: vehicle body, tires, road, others, the percentages of injuring objects were studied.
In fatal cases, the percentage of vehicle body was as high as 75% and the percentage of road around 20% in the straight-going maneuver (See Figure 17). On the other hand, the percentages of tires and road were higher in right-turn maneuver and left-turn maneuver because it was presumed that vehicles would roll up a pedestrian with a tire or push down and made a pedestrian hit road surface in many cases.

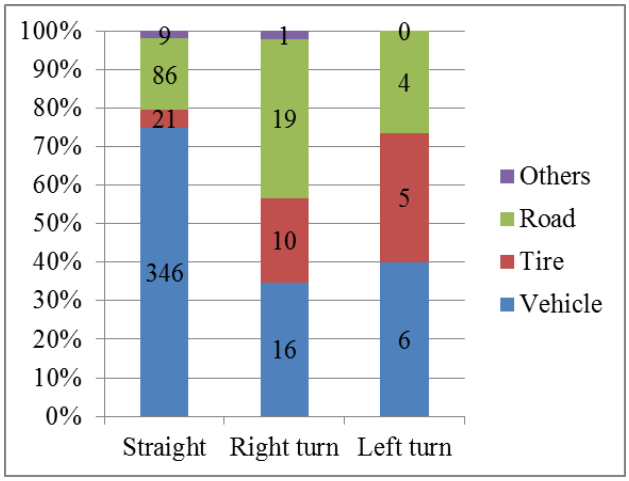

Figure17. The number of **fatal** injured pedestrian for each of vehicle maneuvers and injuring object.

In serious injured cases, the percentage of vehicle body in straight-going maneuver was lower than in fatal cases, while the percentage of road was around 30% (See Figure 18).

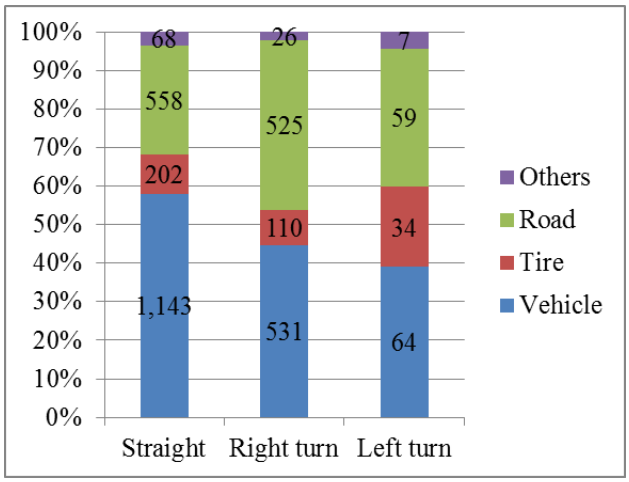

Figure18. The number of **serious** injured pedestrian for each driver's maneuver and injuring object.

In minor injured cases, the percentages of four kinds of injuring objects were not so different among three types of vehicle maneuvers (See Figure 19).

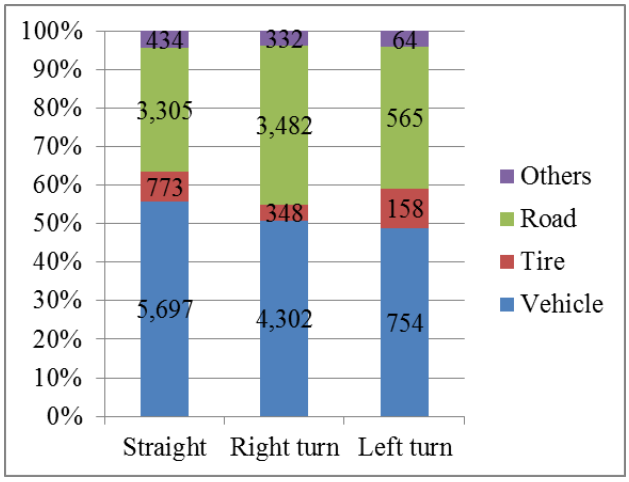

Figure19. The number of **minor** injured pedestrian for each of vehicle maneuvers and injuring object.

Detailed Analysis for Effect of NCAP Performance on Pedestrian Accidents

The effects of the pedestrian head protection score in the JNCAP test on the number of injured pedestrian were scrutinized by danger-cognitive velocity and injuring objects on a pedestrian.

Out of 39 vehicle models, 29 vehicle models which the pedestrian head protection score in the JNCAP test is available for, and had the vehicle registered volume more than 300,000 during four years, were evaluated for the purpose.
The correlation between the pedestrian head protection score in the JNCAP test and the number of fatal injured pedestrians in the collisions at danger-cognitive velocity of over 40km/h colliding with all objects was analyzed (See Figure 20). Focusing on vehicles body as the injuring object, the coefficient of determination increased from 0.1957 to 0.269 (See Figure 21).

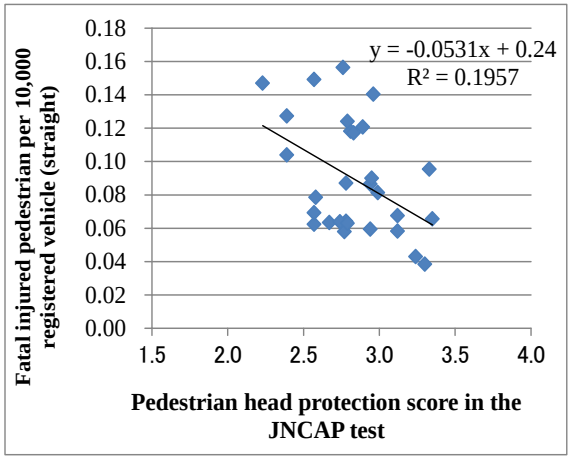

Figure20. Relationship between "the pedestrian head protection score in the JNCAP test" and "the number of **fatal** injured pedestrian per 10,000 registered vehicles" under the condition of danger- cognitive velocity that is **over 40km/h**, in cases where a human body collided with any injuring object **(vehicle body, tires, road, others)**.

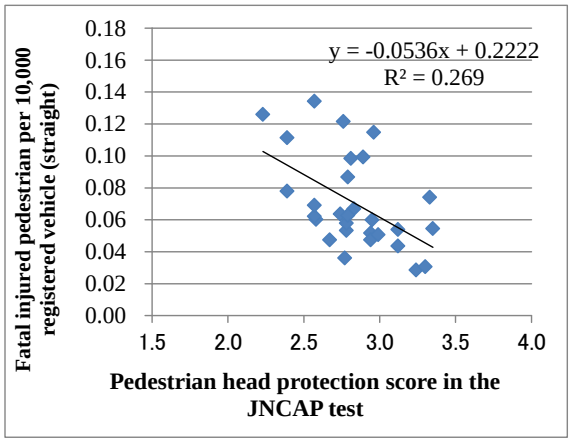

Figure21. Relationship between "JNCAP score for pedestrian head protection performance" and "the number of **fatal** injured pedestrian per 10,000 registered vehicles" under the condition of danger- cognitive velocity that is **over 40km/h**, in cases where a human body collided with **vehicle body**.

In fatal/serious and fatal/serious/minor injured cases as well as fatal ones, this study was conducted and summarized (See Figure 22). Focusing on vehicle body as the injuring object, i.e. excluding tires, road and others, the effect of the pedestrian head protection score in the JNCAP test was made clearer in fatal/serious cases.

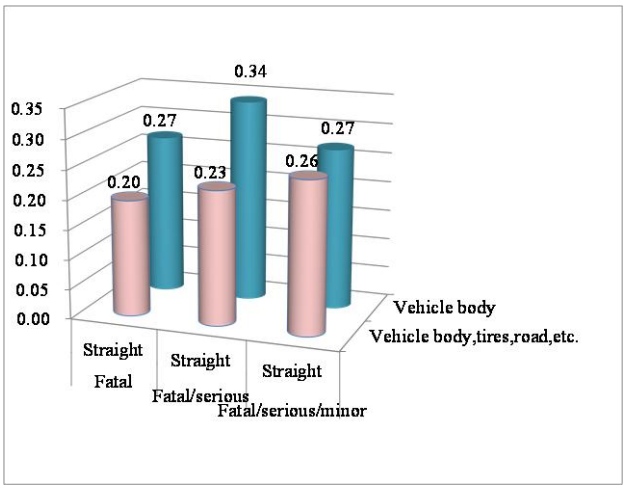

Figure22. Coefficients of determination for relationships between "the number of injured pedestrian per 10,000 registered vehicles" and "the pedestrian head protection score in the JNCAP test" under the condition of danger-cognitive velocity that is **over 40km/h** in the straight-going maneuver.

The correlation between the pedestrian head protection score in the JNCAP test and the number of fatal injured pedestrians was analyzed for each danger-cognitive velocity: 20km/h or less, 20-40km/h, over 40km/h in the cases where a vehicle body was the injuring object in the straight-going maneuver. The summarized figure showed that the higher the velocity was, the more the effect of the pedestrian head protection score in the JNCAP test on the number of injured pedestrians was (See Figure 23).

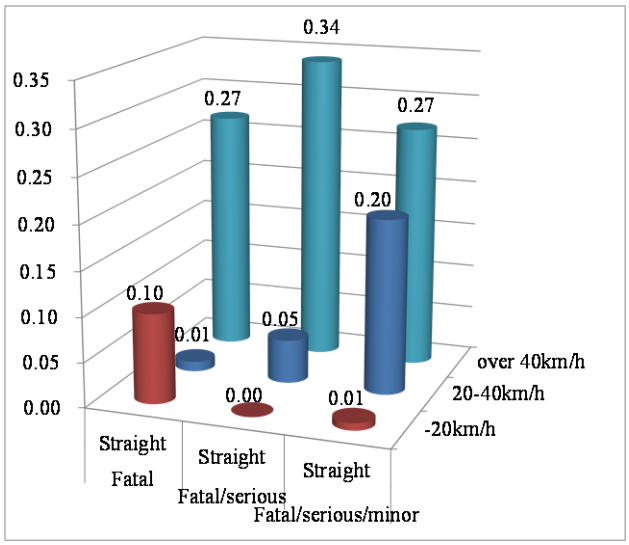

Figure23. Coefficients of determination between "the number of injured pedestrians per 10,000 registered vehicles" and "the pedestrian head protection score in the JNCAP test" in cases where a human body collided with vehicle body.

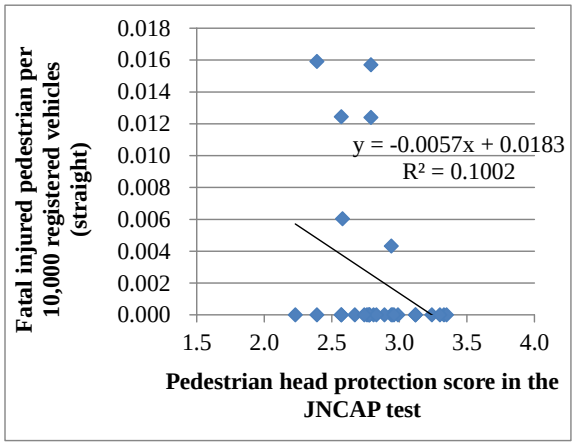

Figure24. Relationship between "the pedestrian head protection score in the JNCAP test" and "the number of **fatal** injured pedestrian per 10,000 registered vehicles" under the condition of danger-cognitive velocity that is **20km/h or less**.

The scatter chart under the situation of fatal injury and at the danger-cognitive velocity of 20km/h or less, depicted the coefficient of determination i.e.0.10 as meaningless (See Figure 24).

Two scatter charts under the situation of fatal/serious injury at the danger-cognitive velocity of "20-40km/h" and "over 40km/h" exemplified that the higher the velocity was, the more

the effects of the pedestrian head protection score in the JNCAP test was (See Figure 25, 26).

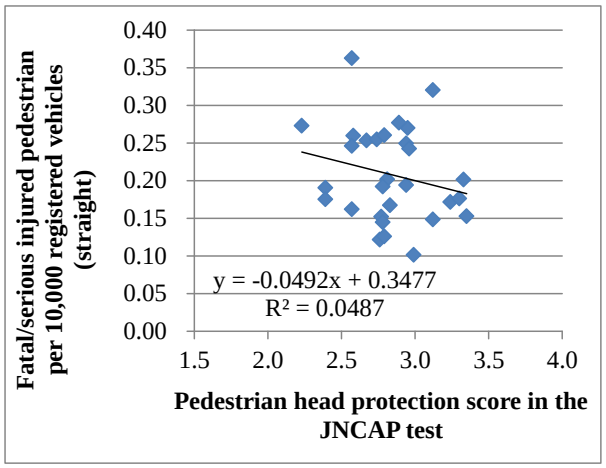

Figure25. Relationship between "the pedestrian head protection score in the JNCAP test" and "the number of **fatal/serious** injured pedestrians per 10,000 registered vehicles" under the condition of danger-cognitive velocity that is **20-40km/h**.

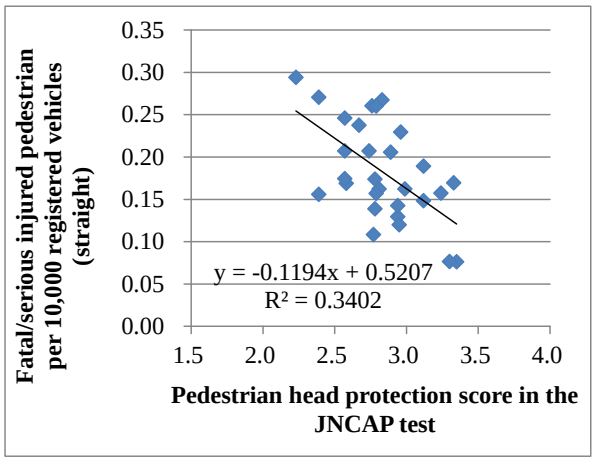

Figure26. Relationship between "the pedestrian head protection score in the JNCAP test" and "the number of **fatal/serious** injured pedestrian per 10,000 registered vehicles" under the condition of danger-cognitive velocity that is **over 40km/h**.

Comparison between Japan and China for Velocity Distribution of Pedestrian Accidents

Figure 27 shows danger-cognitive velocity in pedestrian accidents that occurred with passenger vehicles, freight vehicles, and minivans in 18 years from 1990 through 2007. In total, 390,000 cases were analyzed. In Japan, 11-20km/h velocity range is dominant while 60km/h velocity range accounts for only 1% of total accidents.

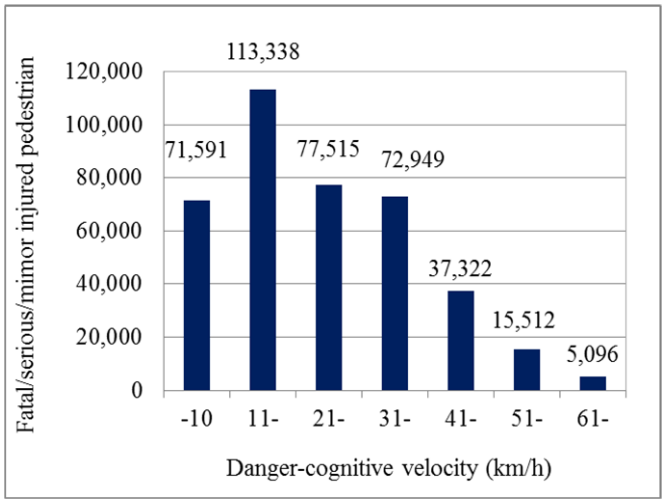

Figure27. Distribution of danger-cognitive velocity of pedestrian accidents in Japan.

CIDAS data was analyzed using PC-Crash. The resultant velocity distribution of 115 cases is shown in Figure 28. The peak is in 31-40km/h velocity range, which is higher than that of Figure 27 by 20km/h. The velocity range over 60km/h accounts for 23% or 1/4 of total cases.

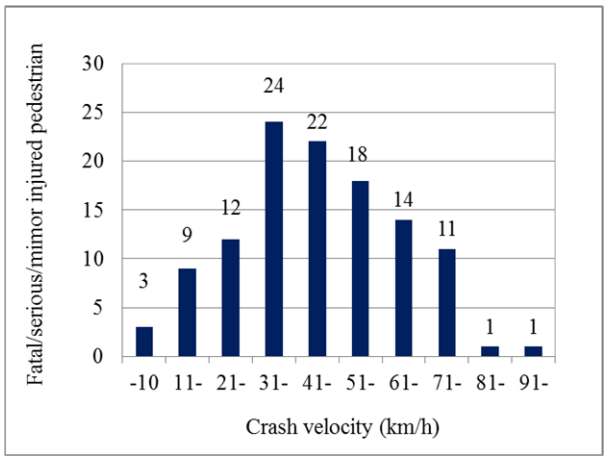

Figure 28. Velocity distribution of pedestrian accidents in China calculated by PC-Crash.

As shown in the previous section, the more the velocity, the more the effects of the pedestrian head protection score in the JNCAP test on the number of injured pedestrian. Therefore it follows that JNCAP would be effective especially in the crash velocity range of 31-50km/h, which account for 40% of total 115 in China.

In-Depth Analysis

In-Depth accident analysis was performed for pedestrian accidents. The purpose of the analysis is to analyze pedestrian accidents in Japan and China and identify the similarities and differences so as to extract challenges in the efforts to reduce pedestrian accidents in China by utilizing CIDAS data.
Table 1 shows the data used for the analysis and the number of cases. For Japan, the data collected by ITARDA through investigation on accidents in Tsukuba City, Ibaraki Prefecture are shown. This data includes three body types: sedans, SUVs, and station wagons, and three driving maneuvers: straight-ahead driving, turning right or turning left. The data was collected for about 19 years from 1993 through 2011. The number of injury in the accidents amounts to 1129 cases.
On the other hand, for China, the data collected by CIDAS through investigation on pedestrian accidents in Beijing, Ningbo, Changsha, Weihai and Foshan. The same body types and driving maneuvers as these of ITARDA's are covered. The data was collected for about 2 years from 2011 to 2012. The number of injury in the accidents amounts to 452 cases.
The objects that hit and injured pedestrians are categorized into body, tire, road surface, and others. As we did for comparison with JNCAP, the objects that belong to vehicles were extracted. The number of accidents with sedans, SUVs, or station wagons during straight-going, turning right or turning left was 670 in Japan and 313 in China. For the reasons of sample size, the number of accidents were narrowed down to cases with sedans during straight-going: 391 in Japan and 203 in China respectively. Out of them, the number of accidents where a head, which is tested in JNCAP, hits a vehicle is 124 in Japan and 95 in China respectively.

Table 1.
The number of injury

	Japan	China
All injury data	1,129	452
Impacted by vehicle	670	313
Vehicle Type : sedan Accident Type : straight	391	203
Contact area : Head	124	95

Comparison of Pedestrian Accident Velocity

As a great contributor to the reduction of fatal accidents, pedestrians' crash velocity was compared between Japan and China. The results are shown in Figure 29. The crash velocity was calculated based on danger-cognitive velocity in case of Japan and by PC-Crash in case of China. The analysis included accidents with station wagons, SUVs, and sedans during straight-going, turning left, or turning right.
Accidents at a crash velocity over 40km/h are dominant: accounting for 60% of total 670 cases in Japan and 80% of total 313 cases in China respectively. The proportion of accidents at a velocity over 40km/h is higher in China.

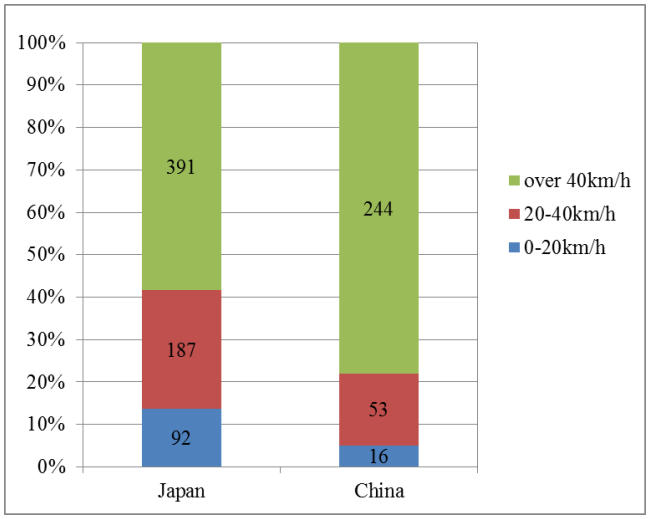

Figure 29. Proportion of pedestrian crash velocity station wagon, SUV, and sedan during straight-going, turning left, or turning right.

Pedestrian crash velocity was further analyzed by the types of vehicles. As the sample size was too small for station wagons and SUVs, the data on accidents with sedans during straight-going was focused in the analysis. Accidents at a velocity over 40km/h shown in Figure 30 accounts for 65% of total 391 cases in Japan and for 85% of total 203 cased in China: 5% higher respectively.

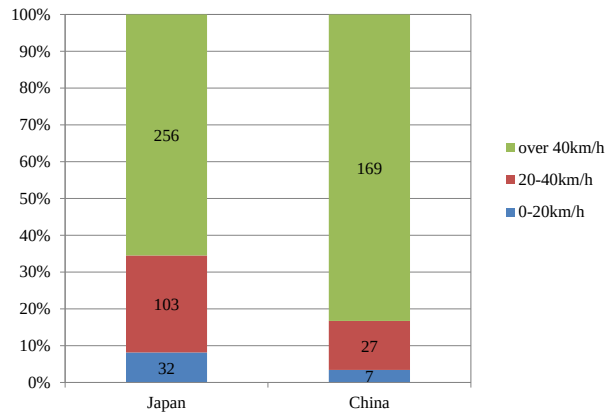

Figure 30. Proportion of pedestrian accident velocity with sedans during straight-going.

Distribution of velocity range was compared focusing on accidents in which a head hits a vehicle body and leads to fatal injury. The results are shown in Figure 31. The proportion is similar to that of Figure 30. This means that a head tends to hit a vehicle body in an accident at a speed over 40km/h.

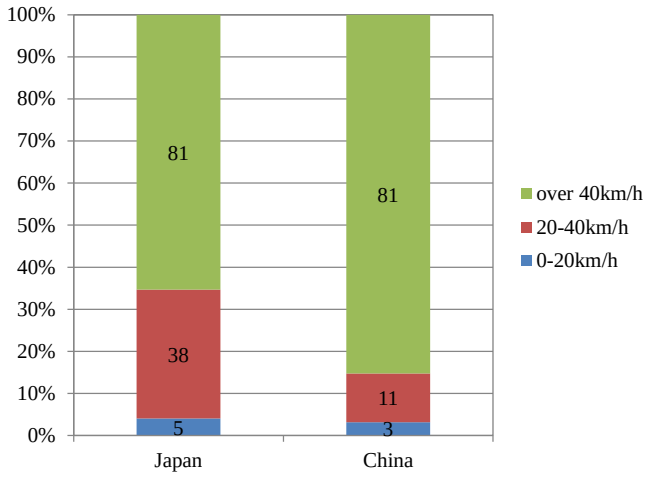

Figure 31. Proportion of pedestrian accident velocity (a head hits a body of sedan vehicle during straight-going).

Impacted Area of Vehicle

Impacted areas of vehicle were analyzed next. Figure 32 shows distribution of impacted areas for each AIS. The more sever the AIS injury is, the more likely the pedestrian hits the cowl or A-pillar. For all AISs, cases where the pedestrian hits the hood account for 30%.

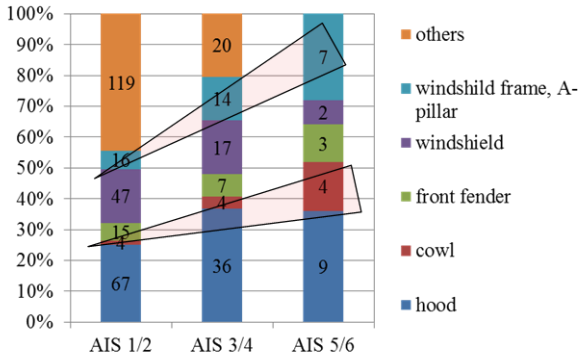

Figure 32. Injury level and impacted areas of vehicle body (Japan).

Figure 33 shows the relation between injury level and impacted areas in China. The more sever the AIS injury level is, the more likely the pedestrian hits the windshield and less likely it hits the hood. Presumably, the higher the crash velocity is, the more likely pedestrian bounces and hits the windshield and head injury leads to fatal injury because of a high velocity.

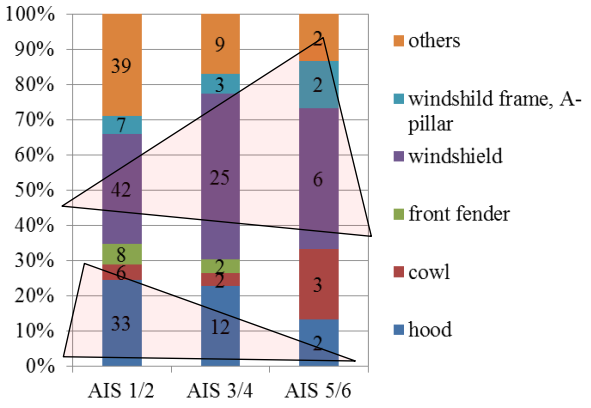

Figure 33. Injury level and impacted areas of vehicle body (China).

Injured Parts of Pedestrian

To exemplify the above assumption, injured areas of pedestrians were compared between Japan and China. Figure 34 shows the data on whole velocity range and Figure 35 shows the data at a velocity over 40km/h. Head accounts for 30% in Japan while it accounts for 50% in China. Figure 35 shows the distribution of injured areas in accidents at a velocity over 40km/h. The distribution is similar to that of Figure 34. In Japan, since the cases at a velocity below 40km/h are dominant, the velocity range over 40km/h is not so influential.

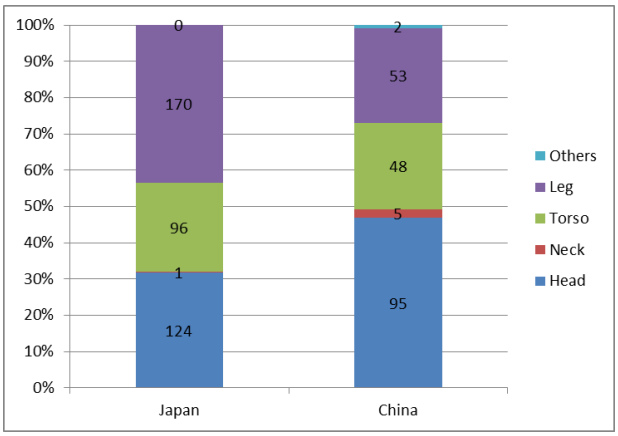

*Figure 34.*Comparison of injured areas over whole velocity range (Japan vs china).

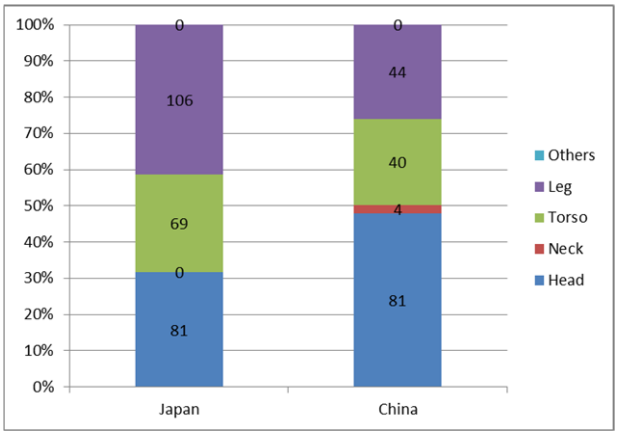

Figure 35. Comparison of injured areas at a velocity over 40km/h (Japan vs china).

Figure 36 shows the relationship between injured areas and impacted areas of vehicle over 60km/h in China. It was found that over 60km/h in China a head dominantly hits windshield.

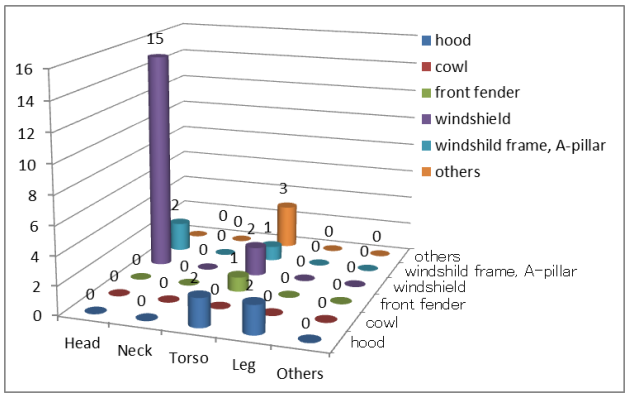

Figure 36. Injured areas and impacted areas of vehicle over 60km/h in China.

DISCUSSION AND LIMITATION

Visibility

With regard to visibility, a lot of factors except for the ones discussed in this study could be considered such as gradual section change of A-pillar according to change of height, size of structure around the lower part of A-pillar, size of gap between A-pillar and door mirror. Also, visibility would depend on whether a driver is long-waisted or short-waisted. Nevertheless, it is clear, to some extent, that angles of hindrance and angles of view have statistically significant effects on the number of fatal or injured pedestrian accidents.

Pedestrian Head Protection Performance

Pedestrian head protection performance test in the JNCAP is designed to simulate a crash at the collision velocity of 44km/h. With utilizing the danger-cognitive velocity in the current study which seems to be lower than the collision velocity, the effect of the pedestrian head protection score in the JNCAP test on the number of pedestrian accidents was more significant in higher speed zone. It was presumed that a lot of minor collisions in the danger-cognitive velocity of 20km/h or less could not depend on the pedestrian head protection score in the JNCAP test. On the other hand, pedestrian injury outcome at severe collisions with higher impact energy at the higher collision velocity could be much more affected by the pedestrian head protection performance.
The pedestrian head protection score in the JNCAP test s was studied here, while the accident data of pedestrian include not only head, but also chest, abdomen, lower extremity, etc. In spite of the fact, the good correlation between the pedestrian head protection score in the JNCAP test and the number of injured pedestrians would mean that the better energy absorption for head could be also effective for injuries on other part of human body.

Another Measure to Reduce Fatal or Injured Pedestrian Accidents

In an additional study, it was confirmed that the less the danger-cognitive velocity was, the less the fatality rate was (See Figure 37.) The fatality rate was defined here as the number of fatal injured pedestrians divided by the number of all fatal or injured pedestrians in each danger-cognitive velocity zone. The fatality rate was 24.8% in the danger-cognitive velocity zone of over 40km/h, 3.1% in the velocity zone of 20-40km/h, and 0.2% in the velocity zone of 20km/h or less. It was ascertained that the danger-cognitive velocity is another significant factor which could affect the severity of injury. Consequently, the systems such as automatic emergency braking systems against pedestrian have a big potential to avoid a collision with a pedestrian or to decrease a collision speed, leading to the decrease in the number of injured pedestrians. Under the circumstances, Although such a system would lessen the effect of visibility and pedestrian protection performance on the number of pedestrian accidents, the spread of such a system would be highly desirable for the real-world safety improvement.

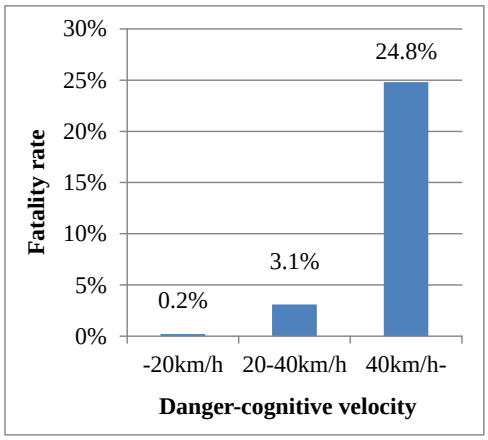

Figure37. Fatality rates in the three ranges of danger-cognitive velocity in cases where a human body collided with vehicle body in the straight-going maneuver.

Vehicle Models

The vehicle models scrutinized in the current study were the ones which had undergone full model changes during the period of 1999 through 2007. Although those models seemed to be little old, enough volumes of registered vehicles for each vehicle model was needed for statistical accident research. Hence, most of the vehicle models studied here are no longer sold in the market and have undergone full model changes improving visibility performance and pedestrian protection performance.

Method of Accident Research

It can be ascertained that the method of macro accident data analysis utilized in this study, which is based on the number of accidents per 10,000 registered vehicles for each vehicle model, is capable of studying relationships among the number of accidents and explanatory variables. This can be conducted because all accidents with injuries reported to police are compiled and connected to the vehicle models and types in Japan.

Number of In-depth Accident Data

As for in-depth accident data analysis both in China and Japan, although it cannot be said that the number of accident data was enough, the idea of distribution of injured part of human body and the injuring parts of vehicle body were captured. More data would be necessary for improving the accuracy. Two years have passed since the CIDAS project started. We would like to analyze accidents in more detail so as to contribute to the reduction of pedestrian accidents.

CONCLUSIONS

It was ascertained that the pedestrian accident would be more likely to occur when the angle of hindrance due to A-pillar was larger, and when the horizontal angle of view through the windshield was smaller.

Furthermore, it was clarified that the influence of visibility on the occurrence of pedestrian accident was different among the straight going maneuver, the right-turn maneuver.

It was possible to predict the number of fatality or injured in the pedestrian accidents to a certain degree of probability, with use of the combination of visibility indices.

The better pedestrian head protection score in the JNCAP test would lead to the decrease in the number of pedestrian accidents with the fatality or the injured.

The combination of visibility index and pedestrian head protection score in the JNCAP test successfully provided much better prediction of the number of fatality or injured in the pedestrian accidents. In other words, it was clarified that the optimization of parameters in visibility indices and pedestrian head protection could lead to the decrease in the number of pedestrian accident.

The effects of the pedestrian head protection score in the JNCAP test on the number of pedestrian accidents with the fatality or the injured were elaborately scrutinized from the viewpoint of danger-cognitive velocity and vehicle maneuver, i.e., straight-going, right-turn and left-turn. The results demonstrated that the pedestrian head protection score in the JNCAP test was highly correlated with the pedestrian accident especially in the case where a pedestrian was impacted by the

vehicle body, but not a tire nor road, furthermore in the straight-going maneuver at the danger-cognitive velocity of over 40km/h.

In-depth accident analysis with data of ITARDA and CIDAS was conducted in Japan and China. The result showed that JNCAP would be effective especially in the crash velocity range of 31-50km/h, which accounts for as much as 40% of total 115 occurred in five major cities in China.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

ITARDA: Institute for Traffic Accident Research and Data Analysis, a Japanese organization

CATARC: China Automotive Technology & Research Center

CIDAS: China In-depth Accident Study

AHD: Angle of Hindrance at Driver's side

AHP: Angle of Hindrance at Passenger's side

AVD: Angle of View at Driver's side

AVP: Angle of View at Passenger's side

PHPS: Pedestrian Head Protection Score in the JNCAP test