

CONSIDER OF OCCUPANT INJURY MITIGATION THROUGH COMPARISON BETWEEN CRASH TEST RESULTS IN KNCAP AND REAL-WORLD CRASH

Siwoo KIM

Korea Automobile Testing & Research Institute (KATRI)
Korea, Republic of

Yohan PARK, Wonpil PARK

Samsung Traffic Safety Research Institute
Korea, Republic of

Jaewan LEE, Byungdo KANG

Korea Automobile Testing & Research Institute (KATRI)
Korea, Republic of

Myungwon SUH

School of mechanical Engineering, Sungkyunkwan Univ.
Korea, Republic of

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ABSTRACT

The objective of this study was 2-fold : the first, to compare with the joint probability of injury of the dummy seated on driver & passenger seat for introducing the FFRB(Full Front Rigid Barrier) impact test, ODB(Offset Deformable Barrier) frontal impact test and MDB(Moving Deformable Barrier) side impact test in KNCAP; and the second, to propose the direction of improving protocols of crash test in KNCAP(Korea new car assessment program) according to the review of real-world crash data in Korea.

The effectiveness of improvement for the injury criteria of dummy from introducing crash test in NCAP was reviewed by comparison with the average joint probability of injury for each vehicle in case of FFRB impact test, ODB frontal impact test and MDB side impact test. The average joint probability of injury for each vehicle was calculated by average of injury criteria for dummy response on driver and passenger seat. The analysis of real world crash data in Korea was used the data of domestic insurance company. In order to analyze of injuries severity through star rating of KNCAP, MAIS was used. The comparison of MAIS between 3- star and 4+ star rated vehicles case of frontal, offset frontal and side impact crash test in KNCAP was performed. It was reviewed that the reduction of the average joint probability of injury for dummy according to the implement of crash test in KNCAP. The average joint probability of injury on FFRB impact test is dropped gradually from 21.17% in 2003 to 11.21% in 2016. In case of ODB frontal impact test, the average value for each year value of tested vehicles fell to 8.43% in 2016 from 10.76% in 2009. Through the review of insurance company's data, frontal crash accidents, rate of MAIS3+ is 2.88% for vehicles that obtain 4+ star at KNCAP and 4.36% on 3- star. In ODB frontal impact test, rate of MAIS3+ is 2.62% for vehicles that obtain 4+ star at KNCAP and 14.28% on 3- star. In MDB side impact test, rate of MAIS3+ is 1.9% for vehicles that obtain 4+ star at KNCAP and 2.8% on 3- star.

The effectiveness of injury mitigation at FFRB impact test, ODB frontal impact test and MDB side impact test according to the implementation of KNCAP is demonstrated by the analysis of real-world crash data. And also the rate of MAIS3+ injury rated 4+ star vehicle is lower than 3- star in similar accident. Through this research, 4+ star rated vehicle is safer than 3- rated vehicle in Korea. In order to improve vehicle safety, female and child occupant safety will be introduced in crash test protocols from 2017. Also, the next roadmap will be considered in a near future to upgrade vehicle crash safety in Korea.

INTRODUCTION

With the development of motor vehicles, the safety of motor vehicles has been steadily developed. In particular, the safety of occupants in the event of vehicle collision accidents has dramatically improved with the development of seat belts and airbags, and continues to evolve. This development is considered to be the result of the willingness of the manufacturer to secure safety and the efforts of governments around the world to improve vehicle safety standards. Motor vehicle safety standards are the most basic and mandatory regulations to ensure the safety of vehicles.

In 1978, the United States firstly introduced the new car assessment program(NCAP) in order to induce production to be safer than vehicles developed by regulations. Europe began in 1995 with the support of EuroNCAP committees in European countries and automobile clubs. Since 1999, under the superintendence of Ministry of Land, Infrastructure and Transportation, Korea Automobile Testing and Research Institute(KATRI) has been publicizing results of car safety assessment. In August 2002, the Motor Vehicle Management ACT was amended to include the provision of the NCAP for the continuous enforcement of the Korean New Car assessment Program(KNCAP). It was from 2003 that the KNCAP officially started.

In Europe, the several studies on the effect of the implementation of the NCAP and the expansion of the protocols on the casualty reduction in actual traffic accidents were conducted. In Korea, however, few such studies have been conducted since its implementation. The study by Lie et al.(2001) published a study showing a significant correlation between EuroNCAP scores and Folksam car model safety injury ratings where 4 star rated Euro NCAP cars had a lower risk of serious injury than 2 and 3 star rated cars. The Swedish Transport Administration published a study on the correlation between Euro NCAP results and injury risk based on real-world crashes in 2002(Lie and Tingvall). Injury indicators in Police reports were used as the injury descriptors. It demonstrated the possibility to use police data for this purpose. In this study, they identified a consistent correlation when the risk of a fatal and serious injury was the dependent variable, although no correlation was found for minor injuries. The study by Famer(2005) in Insurance Institute for Highway Safety (IIHS) published a study of the relationship between IIHS frontal offset crash test ratings and real-world fatality rates. A trend for good rated vehicles to have lower fatality rates was found, although the correlation was not uniform across all vehicle groups. In 2002, the Swedish Transportation Authority and the Monash University Traffic Accident Research Center in

Australia conducted a study on the effects of EuroNCAP(frontal and lateral collision safety assessment) on injuries in actual traffic accidents. The study shows that the probability of AIS3+ injury for 3 to 4 star rating is approximately 30% lower than that for 1 to 2 star rating. It also shows that one star in AIS3+ injury represents a 12 percent difference in probability.

The purpose of this study is to identify the trend in dummy-based AIS3+ injury probability using vehicle crash tests under the KNCAP, investigate the effectiveness of KNCAP results in the actual occupants safety in traffic accidents by analyzing accident data of Samsung Fire & Marine Insurance Company and make suggestions regarding how to improve the crash test in KNCAP.

ABOUT KNCAP

In KNCAP, 22 testing protocols are currently used, which are categorized into four parts: crash safety, pedestrian safety, driving safety and active safety. The scores for each protocol and the overall scores are publicized for all tested vehicles. To look at the expanding vehicle model of KNCAP, the first KNCAP was conducted on passenger cars in 1999. In 2005, the assessment program was expanded to include vans with gross vehicle weight (GVW) of no more than 4.5 tons and small size trucks in 2007, respectively.

For test protocols, the program adopted its first FFRB impact test in 1999. In 2001, it adopted a braking safety test under which the braking distance is measured after the test vehicle's brake is applied with full force at a speed of 100 km/h. In 2003, it adopted a side impact test where a moving deformable barrier is driven at 55 km/h to the side of the test vehicle at 90 degrees. In 2005, two test protocols were added: i) rollover test where the test vehicle makes a steep turn to determine what is the risk of rollover during drive and ii) head restraint measurement test where the height and clearance of the head restraint to reduce neck injury in the event of low-speed rear impact. In 2007, the program adopted pedestrian (head impact) test to estimate the potential risk of head injury when a pedestrian is struck by a vehicle. In 2008, it expanded the pedestrian test to include leg impact. In 2008, the program adopted a whiplash test where neck injuries are measured using a BioRIDII dummy placed in a seat and subject to rear impact at 16 km/h. This test was integrated with a head restraint measurement test and included in the area of crash safety. In 2009, the program adopted an ODB frontal impact test to estimate the structural rigidity of the test vehicle and the protection provided by the vehicle for the occupant. In 2010, it added a side pole impact test upon request from manufactures as part of an effort to help them

reduce casualties due to critical head injury. Altogether a total of 8 test protocols have been applied. In 2010, the program adopted the crash overall rating system based on the combined score for the five impact tests: frontal impact, offset frontal impact, side impact, side pole impact and whiplash test.

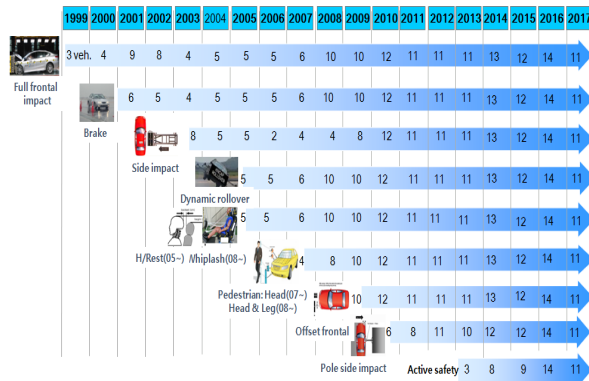


Figure 1. Annual enforcement protocols and number of tested vehicles

In 2013, it started to assess safety for female occupants in the FFRB impact test by using a hybrid 5% female dummy seated in the front passenger seat. In the same year, the overall rating system expanded the existing crash overall rating system to cover all four parts - crash safety, pedestrian safety, driving safety and active safety - to help consumers gain a better understanding and improve safety across all parts. In 2014, it adopted a test to determine the performance of an active pedestrian safety system, including the pedestrian airbag and active hood as part of pedestrian safety assessment. In 2015, the program changed the impact leg form to Flex-PLI for better bio-fidelity and adopted grid method to identify head impact points. In the same year, the weight of the moving barrier used for the side impact test increased from 950 kg to 1,300 kg, and the deformable barrier set up at the front of the barrier was replaced by AE-MDB.

These protocol changes were intended to take into account changes in vehicles launched in Korea in terms of vehicle weight, front shapes and etc. Starting from 2015, the method of impact in the side pole impact test changed from 29 km/h at 90 degrees to 32 km/h at 75 degrees. To cope with phenomenal development and emergence of state-of-the-art safety devices, 11 items such as AEB and etc. will be evaluated from 2017

METHODOLOGY

The improvement in probability of dummy injury resulting from the adoption of impact safety test protocol can be represented by the joint probability of injury calculated from AIS3+ injury risk for head, neck

and chest and AIS2+ injury risk for femur using a dummy placed in the driver's seat and the passenger seat, respectively, in the FFRB impact, ODB frontal impact and MDB side impact tests. The joint probability of injury risk is the average of those for the driver's seat and passenger seat.

The probability of dummy injury risk was used HIC₁₅, Nij, chest displacement and femur data. The joint probability of injury risk was calculated using the following formula (equation 1).

$$P_{\text{joint}} = 1 - (1 - P_{\text{head}}) \times (1 - P_{\text{neck}}) \times (1 - P_{\text{chest}}) \times (1 - P_{\text{femur}}) \quad (\text{Equation 1})$$

For FFRB frontal and ODB frontal tests, dummy data for the driver's seat and the front passenger seat were used to calculate the joint probability of injury risk and annualized to derive the average joint probability injury for the entire target vehicles. For FFRB impact tests, results from tests using a hybrid 5%ile female dummy adopted in 2013 were used. For MDB side impact tests, dummy data for the driver's seat was used. Comparison of the joint probability of injury in FFRB impact tests and MDB side impact tests was based on data from 2003 when the tests were officially adopted. The comparison for ODB frontal impact tests was based on the annual average joint probability of injury from 2009.

For a review of real-world crash data, data from domestic insurance companies were used. Data on traffic accidents reported to insurers in the 16 cities and provinces of Korea between 2011 and 2013 that involved a repair cost of 2 million won or more were used. The severity of accidents was determined using photos of the crash extent. Relevant data were collected, such as models, model years, ages of occupants, gender, position in the vehicle, whether seat belts were used or not, diagnosis, AIS, duration of treatment including days of hospitalization. The data of the accident investigation were from cases in which the insurance of the accident vehicle was terminated. Because of the impossibility to measure actual vehicles involved, we classified the SAE CDC using the vehicle damage photographs. The depth and height of damage in each occurrence were subjected to the same standards while, for orientation, the depth of damage was analyzed for each damage point. In addition, collected data were categorized according to the direction of the accidents to identify frontal and side impacts. For example, an accident is defined as frontal impact if the direction of impact is 11 o'clock, 12 o'clock or 1 o'clock while it is defined as side impact if the direction of impact is 2 o'clock, 3 o'clock or 4 o'clock, or 8 o'clock, 9 o'clock or 10 o'clock. The figure below shows how to categorize

crash part and extent in vehicles damaged by frontal impact and side impact.

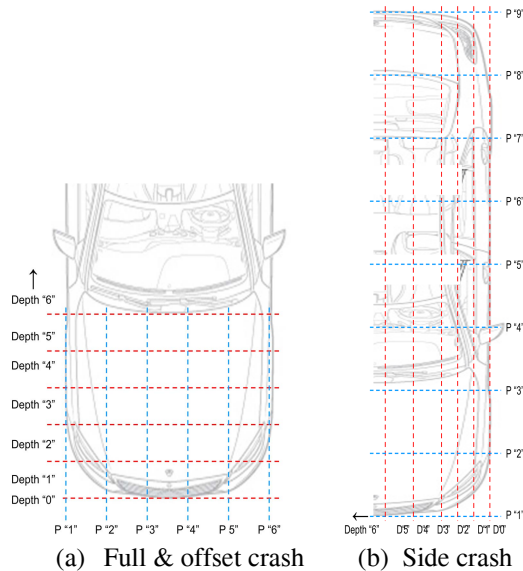


Figure 2 Method of accident crash extent classification.

For accident injury data, the Maximum Abbreviated Injury Scale (MAIS) was used. MAIS comparison was made against 4+ star rated vehicles and 3- star rated vehicles with respect of FFRB impact, ODB frontal impact and MDB side impact test.

MATERIALS

KNCAP started in 1999, conducting a FFRB impact test only on three models. Through to 2016, a total of 153 models including 146 passenger car models, 5 van models and 2 truck models were assessed in the crash test. For FFRB impact test, 153 models were tested and 120 models were tested in MDB side impact test and 94 models were tested in ODB frontal impact test. The FFRB impact test data used for this study are those from tests on 129 models between 2003 and 2016. For MDB side impact, tests on 120 models were used while for ODB frontal impact tests on 94 were used.

The real-world accident data used for this study are from domestic insurance companies. Data on traffic accidents reported to insurers in the 16 cities and provinces of Korea between 2011 and 2013 that involved repair cost of 2 million won or more were used to the extent that the crash part and scope can be identified through photos of the vehicles involved. Analyzed data on frontal impact accidents including offset frontal impact ones reported to domestic insurance companies are from 5,638 vehicles, while the data on side impact accidents are from 4,136 vehicles. Analyzed data on injury in frontal impact accidents,

including offset frontal impact ones for injury analysis are from 6,400 people and data on injury in side impact accidents are from 5,415 people to the extent that they used seat belts at the time of their accidents.

Table 1. Analyzed accident data

Category	frontal impact accidents	Side impact accidents
No. of vehicles	5,638	4,136
Injured person	8,195	6,347
Injured person with belt	6,400	5,415

RESULTS

The annual decrease in the dummy-based average joint probability of injury was confirmed by implementation of crash test in KNCAP. For FFRB impact, the annual average probability of injury for all the vehicles tested in each year dropped gradually from 21.7% in 2003 to 11.21% in 2016. For ODB frontal impact test, the average fell to 8.43% in 2016 from 10.76% in 2009, while it dropped for MDB side impact to 4.00% in 2016 from 18.63% in 2003.

Table 2. Annual average joint probability of injury

Year	FFRB test	ODB test	SIDE test
2003	21.17%	Non test	18.63%
2004	12.70%	Non test	32.60%
2005	19.15%	Non test	3.80%
2006	23.70%	Non test	19.50%
2007	18.07%	Non test	8.25%
2008	11.80%	Non test	14.00%
2009	8.49%	10.76%	10.50%
2010	12.84%	9.79%	5.42%
2011	12.67%	13.26%	4.73%
2012	11.38%	10.00%	4.00%
2013	11.77%	9.34%	3.09%
2014	11.26%	8.81%	3.00%
2015	10.96%	8.46%	3.58%
2016	11.21%	8.43%	4.00%

In the case of FFRB impact, even though the annual average the joint probability of injury decreased, the value is converged to around 10%. It has been confirmed that neck injuries are the most influential injury over the last five years' data. At 6.33% to 7.32 %, the probability of a neck injury (AIS 3+) is twice as high as that of HIC₁₅ or chest deflection. Although the figures not high, there is a need to reduce neck injuries

as represented by the dummy through an improvement of safety devices(safety belts, airbags, etc.).

As far as ODB frontal impact test is concerned, the annual average joint probability of injury continued to fall, but started to converge to around 8%. Over the last five years, the probability of injury is 9.01% on average, around 20% lower than that for FFRB impact test, which stands at 11.32%. This suggests that driver and passenger occupants in offset frontal crash are less likely to cause serious injury than full frontal crash in real-world accident. As far as MDB side impact test is concerned, the probability of injury is converging around the 3% by introducing the side airbags. The average joint probability of injury for the last 5 years is 3.53%, a figure significantly lower than that for dummy-based FFRB and ODB frontal impact test. There will be variability depending on the adoption of WorldSID.

The average crash extent for vehicles involved in frontal impact accidents in Korea was 2.03. The accident occurred the offset frontal impact slightly greater than that for full frontal impact. As far as offset frontal impact accidents are concerned, the principle direction of force (PDOF) of the driver side was 28.9% and the passenger side was 29.4%. It shows little difference between them. The crash extent of the vehicle analysis subject to side impact accidents was 1.73. Cases where only the passenger room was damaged, which KNCAP covers, account for only 6.5% of the total while cases including those where the passenger room is included in the damaged part account for 50.8% of the total. This means that half of the total side impact accidents involve partial or full damage to the passenger room. Crash extent level 3 was applied to the real-world frontal crash data to get 1,434 accidents. From these accidents, a total of 1,798 occupants out of 2,099 who had got injured while seated in the first row were selected for analysis. A total of 456 were found to get injured in full frontal impact accidents, while 674 were injured in the driver's seat offset frontal impact, and 668 in passenger seat offset frontal impact. Female occupants were found to be 1.37 times more likely to get serious injury than their male counterparts when seated on the driver's seat and twice as likely when seated on the passenger seat. Comparison of crash extent between the same class vehicles shows that the good rating, the less likely it is for MAIS 3+ injury to occur. Comparison between vehicles with the same rating shows that the greater the crash extent, the more likely it is for MAIS 3+ injury to occur. At a low crash extent, the good overall rating, the less likely it is for severe injury to occur. As far as crash extent in offset frontal impact accidents are concerned, analysis of the rate of MAIS 3+ shows that the good rating in KNCAP is, the less likely it is for the occupant to get MAIS 3+ injury. In addition, in terms

of crash extent, the vehicles with good rating in offset frontal impact test have been identified the less likely for the occupant to get MAIS 3+ injury

Analysis of frontal impact accidents shows that the ratio of those who have suffered an MAIS 3+ injury seated in vehicles having 4 to 5 star rating in full and offset frontal impact test is 66.1% in the case of full frontal impact and 18.3% in the case of offset frontal impact. These figures are 1.5% and 11.7% lower than those for vehicles having 3- star rated. Due to the insufficient number of 3-star rated vehicles in case of offset frontal impact accidents, it was compared with the unrated models in additional analysis.

Crash extent level 3 was applied to the real-world side impact data to get 676 accidents. From these accidents, a total of 846 occupants out of 1,019 who had got injured while seated in the first row were selected for analysis. In this study, the crash extent level 2 was applied to get 2,579 accidents because of not much case of crash extent level 3 in the side impact accident data. From these accidents, a total of 4,037 occupants who had got injured while seated in the first row were selected for analysis. Comparison of crash extent between the same class vehicles shows that the good rating, the less likely it is for MAIS 3+ injury to occur.

Analysis of the side impact accidents shows that the ratio of those who have suffered an MAIS 3+ injury seated in vehicles having 4+ star rating are 53% lower than the vehicles having star rating of 3- star. Also far side occupants injury is more severe than near side.

Data from domestic insurance company were reviewed to gain insight into real-world crashes that occurred in Korea. The rate of MAIS3+ injury in frontal impact accidents involving KNCAP 4+ star rated vehicles is 2.88%, while the figure for 3- star rated vehicles is 4.36%. As far as offset frontal impact accidents are concerned, the rate for 4+ star rated vehicles is 2.62%, while the figure for 3- star rated vehicles is 14.28%. As far as side impact accidents are concerned, the rate for 4+ star rated vehicles is 1.9 % while the figure for 3- star rated vehicles is 2.8%.

DISCUSSION

Based on the annual average joint probability of dummy injury as shown in KNCAP results, the probability of an injury is gradually decreasing. This study, however, did not show to make comparison across different vehicle types such as sedan and SUVs. Even though, this study shows that the joint probability of injury is greater in FFRB impact test and frontal impact accidents than in ODB frontal impact test and offset frontal impact accidents.

In 2010, Swedish Transportation Authority and the Monash University Traffic Accident Research Center in Australia reached conclusion after comparison

between injury probability based on star rating and real-world data. Five-star rated cars were found to have 69 ± 32 % lower risk of fatal injury than 2-star rated cars. The corresponding risk reduction for fatal and serious injuries was found to be 23 ± 8 %. This is in contrast with the conclusion reached in this study based on the types of actual accidents.

Analysis of side impact accidents shows that MAIS3+ injury on near side occupants is similar among the good rated vehicle in MDB side impact test. However far side occupants are found to have increased in MAIS3+ injury. From this study, it seems necessary to introduce the far side impact test.

In this paper, the trend of the average joint probability of injury under the test protocols and the severity of accidents based on star rating is provided. Even though KNCAP star rating system is not based on injury probability, but vehicles that have received 4+ star ratings in test are found less likely to cause injury in real-world accidents. This suggests that KNCAP has a positive impact on it. The study of correlation between star ratings and real-world accidents will be improved if have official Korean in-depth accident study system. From this research, KNCAP was gradually strengthened through the test of female drivers and occupant seated on passenger side in the FFRB impact test and the test of children seated on rear seats in ODB frontal impact test. Furthermore, it is necessary to review the car to car and far side test protocols which is being promoted internationally, and to reinforce the safety of vehicles through the development of evaluation methods that can represent real car to car crash accidents in Korea.

CONCLUSION

This study demonstrated that the effect of injury reduction by FFRB impact, ODB frontal impact and MDB side impact test of KNCAP was confirmed based on real-world crash data analysis.

The injury of MAIS 3+ for 4+ star rated vehicles in full frontal crash accidents is 2.88% while that for 3- star rated cars is 4.355. As far as offset frontal impact accidents are concerned, the rate for 4+ star rated vehicles is 2.62%, while the figure for 3- star rated vehicles is 14.28%. As far as side impact accidents are concerned, the rate for 4+ star rated vehicles is 1.9 %,while the figure for 3- star rated vehicles is 2.8 %. With lower rate of MAIS3+ injury, 4+ star rated vehicles are found to be safer than 3- star rated ones in the similar type of accidents in Korea.

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