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The Study on Injury Prediction of Driver Based on EDR Data

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Abstract: By using EDR (Event Data Recorder) data such as airbag deployment time, pretensioner deployment time, impact velocity, use of driver's seat belt and longitudinal ΔV (longitudinal acceleration after derivation) in eight real road traffic accidents as the boundary input conditions of the driver restraint system, the process of injury to a driver is reconstructed and the kinematical response of a driver under different initial and boundary conditions is obtained. Based on the head and chest response of a multi-body dummy, the head HIC_{36} and HIC_{15} and chest VC and CTI are figured. The injury to the head and chest of a driver is then predicted according to the human head and chest tolerance limit and injury risk curve. The results indicate that for a frontal impact accident, the kinematical response of a driver can be obtained through reconstruction of the driver's injury process by directly considering EDR data as initial and boundary conditions, which coincide with the findings of in-depth investigations; the dummy head HIC_{36} and HIC_{15} and chest VC and CTI obtained from reconstruction of the driver's injury process can be used to accurately predict the severity of injury to the head and chest of the driver, which coincides with that of the real injuries to drivers in accidents. Those findings lay the foundation for post-accident prediction of driver injuries by use of EDR data and rapid, tiered responses of medical assistance, which accurately match the severity of the in-jury.

Keywords: EDR, Injury Prediction, Accident Reconstruction, In-depth Investigation

1 Introduction

Traditional studies involving driver injury risks are based on: 1) obtaining reconstruction data of the accident scene through in-depth investigations into traffic accidents; 2) Obtaining the initial and boundary conditions of driver injury reconstruction via the reconstruction of the accident process, on the basis of scene reconstruction, and; 3) carrying out the reconstruction of the injury process[1]. This indicates that injury predication and evaluation will undergo three reconstructions, and inaccuracy of any link during the process will have a significant impact on the results. In this study, the airbag deployment time, pretensioner deployment time, impact velocity, use of driver's seat belt and longitudinal ΔV (longitudinal acceleration after obtaining the derivative) read by EDR (Event Data Recorder) are directly used as the boundary input conditions of the driver restraint system. Furthermore, the kinematical responses and head and chest injuries of drivers in eight frontal impact accidents of Toyota passenger cars are investigated with MADYMO, a multi-body dynamics software.

2 Evaluation of Head and Chest Injury

In a road traffic accident, severe head injury is one of the main causes of occupant death; therefore, in a vehicle frontal impact accident, head injury is the most important indicator for the evaluation of occupant injury[2]. There is also a high incidence of occupant chest injury, which mainly occurs during frontal vehicle impact or recombination impact, due to contact of the chest with parts inside the vehicle. This kind of injury is known as injury by blunt instrument impact. So, the study will emphasize the process of injury to the driver's head and chest in frontal impact accidents.

2.1 Tolerance Limit of Head Injury

To study the characteristics of head responses to different forces, many researchers have carried out several head impact tests, and proposed the tolerance limit of different areas of the skull to impact force. The threshold values for fracture of the front[3][4][5] and side parts[6][7] and occipitalia[8] of the skull are respectively 4kN ~6.2 kN, 2 kN~5.2kN and 12.5kN. Based on the results of numerous head acceleration experiments, researchers have established the Wayne State Tolerance Curve (WSTC)[9], which indicates the relationship between load duration, linear acceleration and human head tolerance limit, and provides the basis for determination of head injury. The curve has been verified by several experiments. Later, researchers in Japan put forward the Japan Head Tolerance Curve (JHTC)[10], based upon the WSTC.

Meanwhile, some researchers have also performed rotational acceleration experiments involving the heads of volunteers, corpses and primates, so as to investigate the tolerance limit of the human head as it pertains to rotational acceleration. The findings show that the rotational acceleration tolerance of the human head within a short duration reaches 25000rad/s2[11]. Other researchers have studied the tolerance limit of human intracranial pressure, brain and other effect forces with different experimental methods[12][13].

2.2 Head Injury Criterion

The WSTC-related criterion HIC (Head Injury Criterion) has become a widely used indicator for evaluation of vehicle safety, on the basis of studies involving the injury tolerance limit of the human head .

$$HIC = \max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} R(t)dt\right]^{2.5}(t_2 - t_1) \quad (1)$$

Where, t_1 and t_2 are corresponding time nodes of HIC.

HIC_{36}[14] and HIC_{15}[15] are two specific applications, and respectively correspond to 1000 and 700 as the tolerance limit for the 50th percentile male. HIC is still the most frequently used injury criterion for evaluation of vehicle safety, though it has some defects (specifically only considering the linear acceleration, but not the rotational velocity, and limiting the duration). For example, Figure 1 shows the relationship between the probability of head AIS≥2 and value of HIC_{36}.

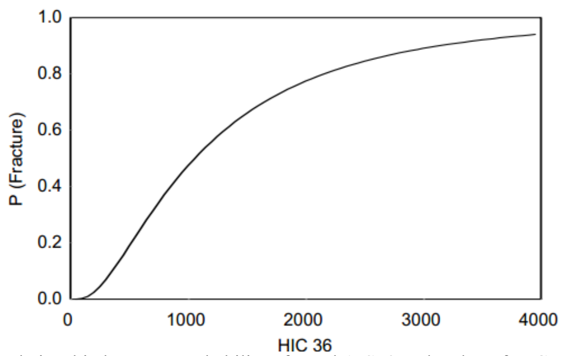

Figure 1 Relationship between Probability of Head AIS≥2 and Value of HIC_{36}[16]

2.3 Tolerance Limit of Chest Injury

There exists several injury mechanisms at the time of impact to the chest by blunt instruments: deflection, viscous load and inertial load of organs. In order to measure biomechanical responses of the human chest towards acceleration, force, deformation and pressure, researchers have carried out many biomechanical experiments with volunteers and corpses, and determined the chest's tolerance limit to frontal impact. The threshold values for acting force to cause minimal injury to the sternum, as well as thorax and shoulder are respectively 3.3kN and 8.8kN[17]. The threshold value for chest displacement of rib fracture is 58 mm[18]; the threshold values for chest deflection of rib fracture and flail chest are 20% and 40%[19]; the threshold value for chest deflection rate is 1.0m/s and 1.3m/s[20] respectively when the probability of chest AIS≥4 is 25% and 50%.

2.4 Chest Injury Criterion

Through analysis of blunt instrument impact experiments, Kroell et al[21] arrived at the conclusion that the maximum chest deflection is closely related to AIS and unrelated to force and acceleration. The deflection criterion can be expressed using the following formula:

$$AIS = -3.78 + 19.56C \quad (2)$$

The maximum allowable chest deflection of the 50th percentile male dummy in frontal impact is 76mm in accordance with FMVSS208 (Federal Motor Vehicle Safety Standard).

Viscous Criterion (VC) is also known as soft tissue criterion, which is the chest injury criterion prepared by considering that the soft tissue injury depends on the deflection and deflection velocity. VC value (m/s) is the maximum product of momentary values of chest deformation velocity and chest deformation[22] ECE (Economic Commission for Europe) R94 (in frontal impact) requires VC≤1.0m/s.

Combined Thoracic Index (CTI) is a method that measures chest injury, and combines the maximum chest deformation and the maximum of 3 ms resultant acceleration of the upper spine, Amax[23]. CTI can be determined by using the following formula:

$$CTI = (A_{max}/A_{int}) + (D_{max}/D_{int}) \quad (3)$$

Where, Aint and Dint are dummy-related constants. For the 50th percentile Hybrid Ⅲ dummy, Aint is 85g and Dint is 102mm. Figure 2 indicates the relationship between the probability of chest AIS≥3 and value of CTI.

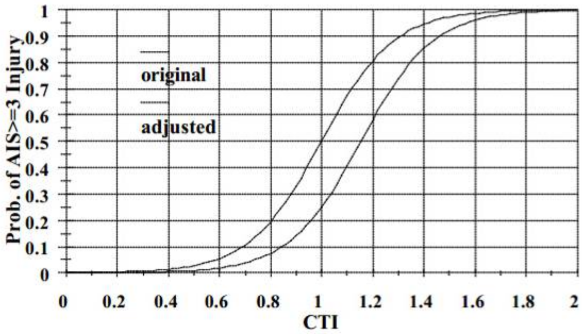

Figure 2 Relationship between Probability of Chest AIS≥3 and Value of CTI[24]

3 Reconstruction of Driver Injury Process

3.1 Typical Cases

In this study, all cases are collected based on the results from the Chongqing Bayi Judicial Expertise Center of Traffic Accidents and in accordance with standards of the National Automobile Accident In-Depth Investigation System. Each case includes vehicle, person and environment data at the time of accidents and EDR data information collected from the Toyota Passenger Car. The abstract of frontal impact cases of the Toyota Passenger Car collected is shown in Table 1.

Table 1 Abstract of Frontal Impact Cases of Toyota Passenger Car

Case	Object of Impact	Data State	V (km/h)	Max. ΔV (km/h)	Head AIS	Chest AIS
	Sedan	Freeze	42	30.9	0	0
2	Fixture	Freeze	96	74.5	3	5
3	Minivan	Freeze	96	30.1	1	0
4	Motorcycle	Unfreeze	68	21.0	1	0
5	Fixture	Freeze	62	48.1	3	4
6	Tree	Freeze	82	69.2	1	4
7	Fixture	Freeze	84	17.1	0	0
8	Sedan	Freeze	84	33.4	1	0

3.2 Vehicle and Human Model

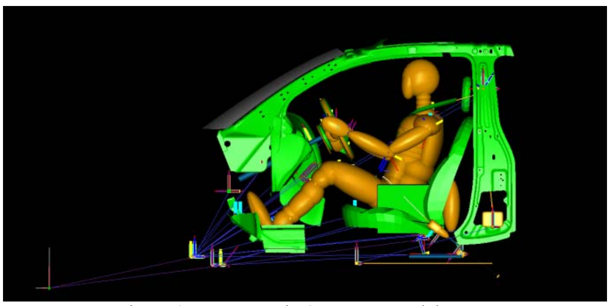
Figure 3 Toyota Yaris Occupant Model

The vehicle and human model used in this section is the Toyota Yaris Occupant Model downloaded from NCAC and the human model is the HybridⅢ50th percentile male dummy. To evaluate the EDR data-based prediction of driver injury in frontal impact, no changes are made in the dummy size, location of steering wheel and floor, and seat height, for which the unified initial values are used.

3.3 Initial and Boundary Conditions

Corresponding changes are made to the card INITIAL.JOINT_VEL in the models, according to the real impact velocity in each case. The deployment times DAB_TTF, Anchoragebuck leframe_TTF and ttf_retrpret in the card

CONTROL_ANALYSIS. TIME. are changed in light of the airbag deployment time and pretensioner deployment time in each EDR data. See Table 6.1 for specific initial and boundary conditions. Take the derivative of time for corresponding longitudinal ΔV of EDR in each case, to obtain the longitudinal acceleration curve, as shown in Figure 4.

Table 2 Reconstruction of Initial and Boundary Conditions

Case	Impact Velocity (km/h)	Airbag Deployment Time (ms)	Deployment Time of Pretensioner(ms)	Correct Use of Safety Belt
1	42	21	21	Yes
2	96	42	42	No
3	96	29	9	Yes
4	68	-	-	No
5	62	-	5	No
6	82	3	3	No
7	84	2	2	Yes
8	84	5	5	Yes

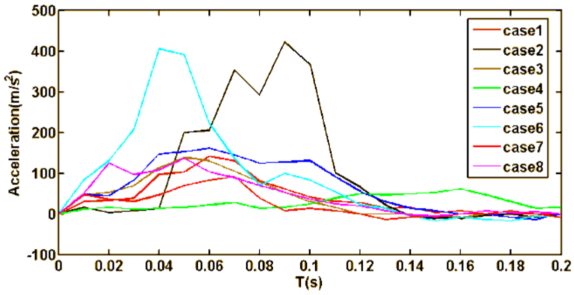

Figure 4 Longitudinal Acceleration Curves

4 Reconstruction Results of Driver Injury Process

4.1 Kinematical Responses of Driver

Eight cases of reconstruction results are compared with in-depth investigation results in Table 3. Detailed descriptions of Case 2 and 6 are given.

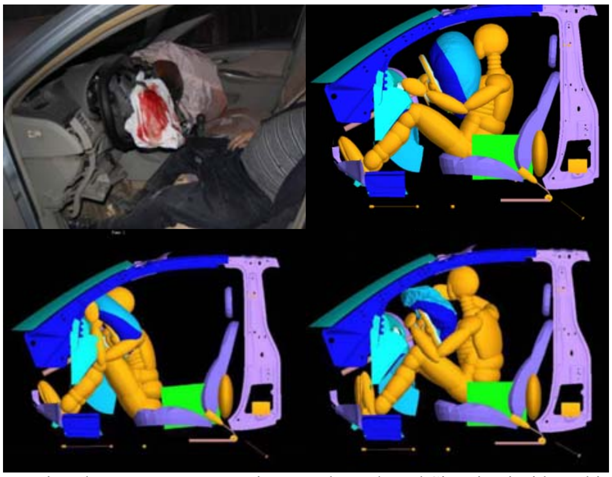
Figure 5 Comparison between Reconstruction Results and Real Situation inside Vehicle of Case 2

Case 2: In a simulation, the driver does not wear a safety belt; at the stage of airbag inflation, the driver's head and chest have started to make contact with the airbag; then the head and chest come into contact with the steering wheel, and finally the body rebounds. In an actual accident, the driver's body hits the steering wheel, causing it to bend inward, and staining the airbag with a substantial amount of blood, which indicates that the driver's head and chest make contact with the steering wheel, and finally the driver is found in a leaning backward position. All of this proves that the driver's motion process during a simulation coincides with that in a real accident.

Case 6: In a simulation, the driver does not wear a safety belt; at the stage of airbag inflation, the driver's head and chest have started to make contact with the airbag; then the head and chest come into contact with the steering wheel; the head does not make contact with the windshield during the whole process. In an actual accident, the driver's body hits the steering wheel, causing it to bend inward, the column of the steering wheel is broken, and there is no blood on the surface of the airbag, all of which indicates that the driver's chest makes contact the steering wheel; moreover, according to the in-depth investigation results, the cobweb-like crack in the upper left corner of the windshield is most likely formed by the driver's head making contact with the windshield during impact. All of this demonstrates that there is some difference between the driver's motion process during a simulation and in a real accident.

Figure 6 Comparison between Reconstruction Results and Real Situation inside Vehicle of Case 6

Table 3 Comparison Between Reconstruction Results and In-depth Investigation Results

Case	Simulation Results		In-depth Investigation Results		Simulation Situation Consistent with Real Situation or Not
	Head and Chest Contacting Steering Wheel or Not	Stage of Airbag When Head Contacts Airbag	Steering Wheel Deformed or Not	With Presence of Blood on Airbag or Steering Wheel or Not	
1	No	Deflation	No	No	Yes
2	Yes	Inflation	Yes	Yes	Yes
3	No	Deflation	No	No	Yes
4	No	-	No	No	Yes
5	Yes	-	Yes	Yes	Yes
6	Yes	Inflation	Yes	No	No
7	No	Deflation	No	No	Yes
8	No	Deflation	No	No	Yes

4.2 Injury Prediction

Driver injury can be predicted by following the head and chest injury criterion, with the force, acceleration, velocity and other indicators extracted from the responses of the multi-body dummy, based on the reconstruction results of the driver's injury process. In this section, the head injury criteria are HIC_{36} and HIC_{15}, tolerance values of which are 1000 and 700 respectively; the chest injury criteria include viscous criterion (VC) and combined thoracic index (CTI), and their tolerance values are 1m/s and 1 respectively.

See Table 3 for driver head injury indicators and results of prediction evaluation, and Table 3 for driver chest injury indicators and results of prediction evaluation. It can be found from the comparison between prediction results and actual injuries, all other injury prediction results are consistent with actual injuries, with exception of the head injury prediction results in Case 6.

Table 4 Evaluation of Driver Head Injury Prediction

Case	HIC_{36}	HIC_{15}	Predicted Injury	Real Injury	Consistent or Not
1	23.530	10.877	AIS＜2	AIS 0	Yes
2	3814.2	3421.3	AIS≥2 Probability: 90%	AIS 3	Yes
3	25.005	11.693	AIS＜2	AIS 1	Yes
4	69.167	46.910	AIS＜2	AIS 1	Yes
5	876.55	686.86	AIS≥2 Probability: 40%	AIS 3	Yes
6	2663.7	2346.9	AIS≥2 Probability: 80%	AIS 1	No
7	4.4488	2.7283	AIS＜2	AIS 0	Yes
8	29.074	14.216	AIS＜2	AIS 1	Yes

Table 5 Evaluation of Driver Chest Injury Prediction

Case	VC(m/s)	CTI	Predicted Injury	Real Injury	Consistent or Not
1	0.06212	0.37419	AIS＜3	AIS 0	Yes
2	1.7851	2.1546	AIS≥3	AIS 5	Yes
3	0.05827	0.39298	AIS＜3	AIS 0	Yes
4	0.04238	0.25398	AIS＜3	AIS 0	Yes
5	0.44988	0.97522	AIS≥3 Probability: 50%	AIS 4	Yes
6	1.0970	1.4521	AIS≥3 Probability: 95%	AIS 4	Yes
7	0.05478	0.23385	AIS＜3	AIS 0	Yes
8	0.05615	0.37969	AIS＜3	AIS 0	Yes

5 Discussion

The kinematical responses of drivers under different initial and boundary conditions are obtained through reconstruction of the driver injury process in eight cases on the basis of EDR data. Except in Case 6, the kinematical responses of the drivers in all the other cases are identical to the in-depth investigation and analysis results. Then the force, acceleration, velocity and other indicators are extracted from the head and chest responses of the multi-body dummy, to calculate the head HIC_{36} and HIC_{15} and chest VC and CTI. The driver's head and chest injuries are predicted by using these indicators as well as human head and chest tolerance limit and injury risk curve. Judging from the comparison between predicted and actual injuries, the injury prediction matches actual injuries in all cases, except for driver head injury prediction in Case 6.

The findings of this in-depth investigation indicate that, in Case 6, the driver's head makes contact with the windshield, which causes the formation of cobweb-like cracks on the windshield. These findings are different from the kinematical responses of the driver obtained through reconstruction. To determine the causes of the discrepancy, the accident process is reconstructed on the basis of impact velocity (from EDR data) and in-depth investigation results, as shown in Figure 6. According to the results of accident reconstruction in Figure 7, the rear of the vehicle up warps when the vehicle runs into the tree, which means that the vehicle contains a vertical acceleration component, causing the driver, who is not wearing a safety belt, to move forward and upward, and finally making contact with the windshield. At present, no content about vertical acceleration is contained in EDR data; therefore, there exists a significant difference between real motion responses and injuries of the human body and results of driver injury reconstruction when only EDR data is used. In other cases, though, vertical acceleration does not make a significant difference in drivers' motion responses. The study results indicate: it can accurately predict the kinematical responses and a driver's head and chest injuries through the EDR data-based reconstruction of the driver injury process, which, however, is inaccurate for prediction of accidents with large vertical acceleration.

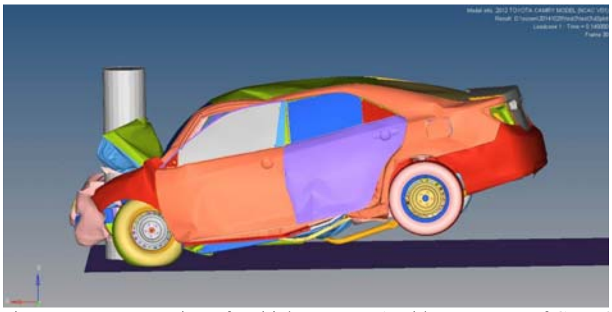

Figure 7 Reconstruction of Vehicle-to-Tree Accident Process of Case 6

The maximum longitudinal ΔV is significantly related to the driver MAIS[25]. In this paper, maximum longitudinal ΔV is 74.5km/h and 69.2km/h in Case 2 and Case 6, which are among the largest of the eight cases. The driver's head and chest are most seriously injured in these two cases. Apart from large impact intensity, one important cause for this is that the drivers in these two cases don't wear their safety belts properly. In Case 5, the driver's head and chest are severely injured, at the maximum longitudinal ΔV of 48.1km/h, because the passive safety equipment is ineffective. In Case 1, 3, 7, and 8, the driers all properly wear their safety belts and airbags deployment normally; therefore, drivers are only slightly injured at the maximum longitudinal ΔV of 17.1km/h -33.4km/h. All of this proves that safety belts and airbags play a significant role in protecting drivers during frontal impact.

6 Conclusions

In this paper, the head and chest injury tolerance limit and injury criteria were first introduced; then the kinematical responses of drivers under different initial and boundary conditions were obtained by reconstruction of the driver injury process, with the EDR data in eight accident cases, including airbag deployment time, pretensioner deployment time, impact velocity, drivers' use of safety belts, and longitudinal ΔV (longitudinal acceleration after derivation) as the boundary input conditions of the driver restraint system; the head HIC_{36} and HIC_{15} and chest VC and CTI were determined from the head and chest responses of the multi-body dummy, before the drivers' head and chest injuries were predicted with the human head and chest tolerance limit and injury risk curve. The following conclusions can be reached:

(1) For a frontal impact accident, the kinematical response of a driver can be obtained easily through reconstruction of the driver injury process with EDR data as initial and boundary conditions, which basically coincides with the findings of in-depth investigations.

(2) The multi-body dummy head HIC_{36} and HIC_{15} and chest VC and CTI obtained from the reconstruction of the driver injury process, can be used to accurately predict the severity of injury to a driver's head and chest, which basically coincides with the severity of drivers' injuries in actual accidents.

(3) It is inaccurate to reconstruct the driver injury process by directly using EDR data, for vehicle frontal impact accidents, during which, a vehicle vertically makes impact.

(4) Safety belts and airbags play a significant role in protecting drivers during frontal impact.

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