An inverse method to reduce pedestrian-ground contact injuries

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I. INTRODUCTION

The vehicle front shape and Bonnet Leading Edge Height (BLEH) are influential factors for pedestrian-ground contact [1-5] in vehicle-pedestrian impact accidents. Simms *et al*. [2] reported that there was a positive correlation between BLEH and the head injury criteria (HIC) score obtained from ground contact. Based on analysing ground contact mechanisms with multibody models, Yin *et al*. [5] found that the BLEH is the main influencing parameter of vehicle front shape on the severity of pedestrian head injury caused by ground contact. Crocetta *et al*. [1] showed that for a specific category of pedestrian ground impact mechanism, head-ground impact speeds increased with normalised BLEH (BLEH/pedestrian height). Researchers [6, 7] have proposed ideas to eliminate or reduce the secondary ground contact injuries. However, there are limited findings based on real-world collision data. The aims of this study are to

1) assess the relationship between Normalized BLEH (BLEH/hip height) and ground-related head injuries based on a set of real-world collision data;
2) carry out an inverse method based on a virtual test system (VTS) to assess the optimization method to reduce pedestrian-ground contact weighted injury costs (WIC).

II. METHODS

GIDAS Data

The German in-depth Accident Study (GIDAS) data (cases with information of vehicle model/impact speed, pedestrian age/height/gender/suffered injuries with AIS code and source, collected between 2000 and 2015) were used to analyze the effect of vehicle bonnet leading edge height (BLEH) on pedestrian-ground contact injuries. An estimate for the vehicle speed and direction of motion of the pedestrian and the source of each injury (vehicle or ground) was coded following detailed reconstruction of each case by an experienced team (accident investigators and medical staff) using 3-D laser scans of the scene for scaled measurements, assessment of vehicle damage, the pedestrian projection distance and other evidence to produce a PC-crash reconstruction of the event. Based on all available evidence including matching of the vehicle damage pattern to the observed injuries, the team assigned each injury to either vehicle or ground contact [8, 9]. Injuries where the source is doubtful or cannot be assigned are coded as “unknown”.

To evaluate the relationship between ground-related injury and NBLEH, the Blue Prints [10] and the EEVC WG17 [11] protocol were employed to measure the BLEH [12]. Hip heights for pedestrians were estimated from the known pedestrian height in GIDAS using standard anthropometric regression relationships [13].

Statistical Analysis

The Shapiro-Wilk test was used to check the normality of the NBLEH. For non-normal distributions, the Kruskal-Wallis Test was used to test for the differences. Logistic regression and odds ratios (ORs) were used to assess the influence of NBLEH on AIS2+ ground contact head injury outcome (adults only), similar to previous studies [12, 14]. An OR greater than 1 indicated a rising trend. Confidence Intervals (CI) at the 95% level were constructed. The logistic model and injury probabilities are:

$$\text{logit}(p) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 * x_1 + \ldots + \beta_i * x_i \quad (1)$$

$$p = \frac{\exp(\beta_0 + \beta_1 * x_1 + \ldots + \beta_i * x_i)}{1 + \exp(\beta_0 + \beta_1 * x_1 + \ldots + \beta_i * x_i)}. \quad (2)$$

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Virtual Test System

The virtual test system (VTS) has two main parts. The first is a simulation sample of vehicle-pedestrian crash scenarios on the MADYMO platform which are representative of real world crashes with different vehicle speeds, pedestrian heights and pedestrian gaits. The other is an injury weighting system (IWS) based on distributions of impact parameters (vehicle speed, pedestrian height and pedestrian gait) in crashes to weight the predicted injuries in the simulations. The weightings were extracted from GIDAS data. Li *et al*. [15] used VTS to assess the method based on optimizing vehicle front-end to reduce the weighted vehicle related injuries for pedestrian safety. The method of VTS in the current study is based on the results from Li *et al*. [15]. During the processes of optimization, a worst shape (pedestrian suffered highest weighted injury from ground contact) and a best shape (pedestrian suffered lowest weighted injury) for each category (sedan, SUV and van) are produced. The parameters of these six vehicle shapes are employed in current study to test the weighted injuries costs from contact with the ground.

III. INITIAL FINDINGS

Figure 1 shows the relation between NBLEH and AIS2, AIS3 and AIS4-5 head ground-related injuries (GRI). The average NBLEH increased from 0.89 for AIS2 to 0.95 for AIS3 and 1.01 for AIS4-5. Even though the Kruskal-Wallis Test (Table I) shows that these differences are not statistically significant (P=0.366).

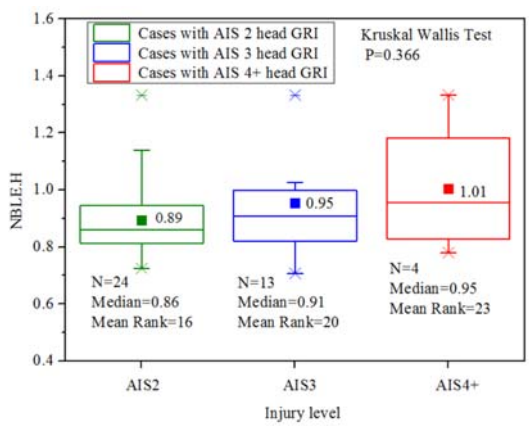


Fig. 1. Distribution of NBLEH for AIS2, AIS3 and AIS4-5 ground-related head injuries.

TABLE I

KRUSKAL-WALLIS TEST RESULT OF NBLEH DISTRIBUTION FOR DIFFERENT GROUND-RELATED AIS LEVEL

Group	N	Median	Mean Rank	*P*-value of Kruskal Wallis Test
AIS2	24	0.86085	16.17	
AIS3	13	0.90855	20.08	0.366
AIS4+	4	0.95478	22.80	

In a further step, logistic regression was used to assess the potential relationship between adult ground-related head injuries and normalised BLEH (24 cases involved). Multicollinearity detection for the parameters of the potential model (speed, age and NBLEH versus AIS2+ adult ground-related head injuries) showed the VIF parameters were all less than 2.5, and the model could therefore be used for logistic regression analysis. ORs were used to assess the effects of NBLEH on AIS2+ ground-related adults head injury risk. TABLE II shows that for adult pedestrian cases the speed, age and NBLEH were all significant predictors of AIS 2+ ground related head injury.

TABLE II
LOGISTIC REGRESSION RESULTS FOR SPEED, AGE AND NBLEH VS ADULT GROUND-RELATED AIS2+ HEAD INJURIES (AGE 18+)

Parameter	Boundary values	β	*P*-value	OR (95% CI)
Constant	/	-9.665	/	/
Speed	3–116 km/h	0.029	**0.019**	1.029 (1.005-1.055)
Age	18–96 year	0.025	**0.030**	1.026 (1.002-1.050)
NBLEH	67–133%	4.693	**0.011**	109.234 (2.910-4100.470)

Based on Eq. (1), Eq. (2) and Table II, the average AIS2+ ground related head injury risk as a function of vehicle speed, pedestrian age and NBLEH can be described as:

$$p = \frac{\exp(-9.665 + 0.029 * \text{speed} + 0.025 * \text{age} + 4.693 * \text{NBLEH})}{1 + \exp(-9.665 + 0.029 * \text{speed} + 0.025 * \text{age} + 4.693 * \text{NBLEH})} \quad (3)$$

The average AIS2+ ground related head injury risks as a function of NBLEH for different speeds and ages are shown in Fig. 2.

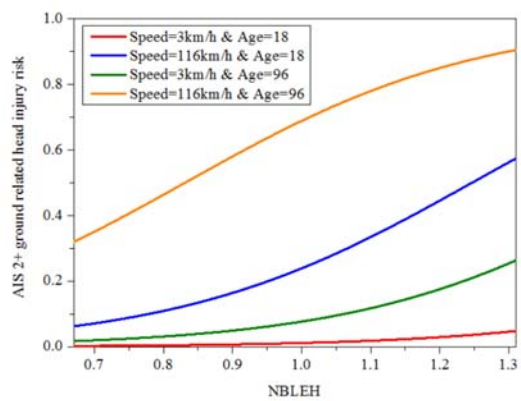
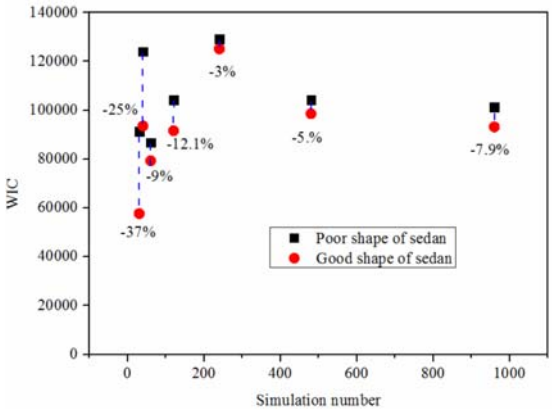
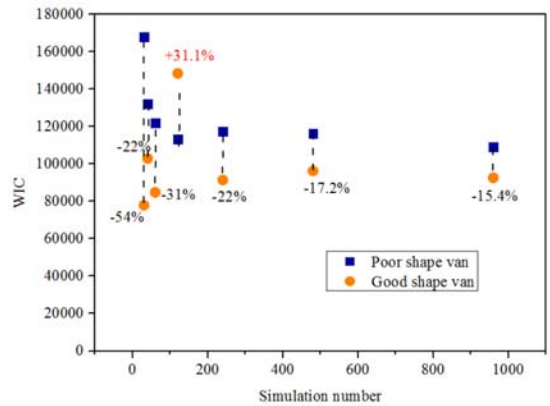


Fig. 2. Average AIS2+ ground related head injury risk as a function of NBLEH for different speed (km/h) and age (years) levels.

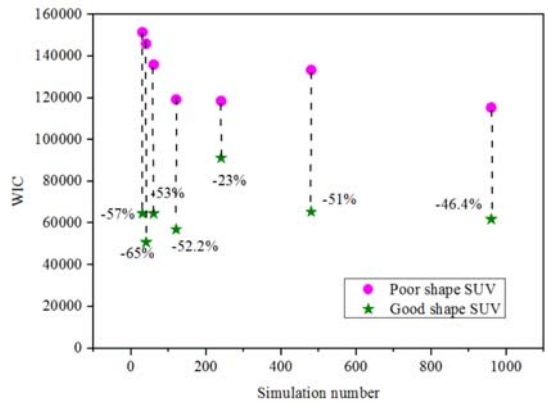
Fig. 3(a), (b) and (c) show the preliminary WIC comparisons between previously proposed “poor shapes” and “good shapes” for sedan, van and SUV, respectively as the simulation number of 30 (3 vehicle speeds × 5 pedestrian heights × 2 pedestrian gaits), 40 (4 vehicle speeds × 5 pedestrian heights × 2 pedestrian gaits), 60 (6 vehicle speeds × 5 pedestrian heights × 2 pedestrian gaits), 120 (12 vehicle speeds × 5 pedestrian heights × 2 pedestrian gaits), 240 (24 vehicle speeds × 5 pedestrian heights × 2 pedestrian gaits), 480 (24 vehicle speeds × 5 pedestrian heights × 4 pedestrian gaits), and 960 (24 vehicle speeds × 5 pedestrian heights × 8 pedestrian gaits) included in the VTS. The percentages shown in the graphs mean pedestrians obtain higher (+) or lower (-) WIC for good shape vehicle compared to the poor shape ones. It can be observed that in most cases, the weighted ground related injury costs pedestrian obtained from good shape vehicles are less than those from poor shape vehicles. The differences in the group of SUV are much more obvious.



(a) sedan



(b) van



(c) SUV

Fig. 3. WIC comparison between poor shape vehicles and good shape vehicles

IV. DISCUSSION

As Table I shows, although the median NBLEH does increase with increasing AIS level, this was not statistically significant. It is unclear whether a larger number of more severe cases would change this result (N=4 for AIS4-5). However, the logistic regression analysis shows for the first time a statistically significant influence of normalised bonnet leading-edge height (NBLEH) on adult pedestrian head injury outcome from ground contact (Table II). It points to the feasibility of changing the parameters of vehicle front end shape to reduce the risk of pedestrian head injuries caused by ground contact. Furthermore, in terms of pedestrian ground contact, the VTS can be also used to assess the pedestrian safety performance of vehicle front-end designs (especially obviously in SUV category), but this needs further development. Only ground related injuries are considered in the current study, so the future work would consider the injuries both from vehicle contact and from ground contact, i.e. in a complete process of crash to find the safest front-end design of the vehicles. A basic outline of the vehicle front end will be set and then the method of Genetic Algorithm (GA) will be applied to optimize the shape in order to achieve the optimum solution in which the sum of pedestrian vehicle related and ground related injuries are the lightest.

V. REFERENCES

[1] Crocetta G et al, Accident Analysis & Prevention, 2015.
[2] Simms C K et al. in *Proceedings of IRCOBI conference, Poland*. 2011.
[3] Gupta V et al, Stapp car crash journal, 2013.
[4] Roudsari B S et al, Traffic Injury Prevention, 2005.
[5] Yin S et al, Accident Analysis & Prevention, 2017.
[6] Shang S et al, Accident Analysis & Prevention, 2018.
[7] Gupta A et al. in *IRCOBI Conference Proceedings*. 2017.
[8] Otte D et al. in *Proceedings: International Technical Conference on the Enhanced Safety of Vehicles*. 2003. National Highway Traffic Safety Administration.

[9] Otte D. in *Proceedings of the International Research Council on the Biomechanics of Injury conference*. 2005. International Research Council on Biomechanics of Injury.
[10]The-Blueprints. 2015; Available from: http://www.the-blueprints.com/.
[11]EEVC, Eevc Working Group Report (December 1998 with September 2002 updates), 2002.
[12]Li G et al, Accident Analysis & Prevention, 2017.
[13]Pheasant S et al. 2016: CRC Press.
[14]Yao J et al, Safety science, 2008.
[15]Li G et al, Traffic Injury Prevention, 2016.