A Fitness Function for Vehicle Front Optimisation for Pedestrian Protection, Accounting for Real-world Collision Configurations

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I. INTRODUCTION

The design of a vehicle front has significant influence on pedestrian injury risk in a vehicle collision [1]. Significant progress has been made in understanding which features of vehicle front design are crucial for mitigating pedestrian injuries. However, real-world accidents show that an optimal vehicle design has not been achieved and current evaluation standards only consider limited impact configurations. The purpose of this study is to develop a fitness function for vehicle front optimisation for pedestrian protection based on a multi-body simulation sample that can represent real-world accident scenarios.

II. METHODS

Pedestrian Accident Scenarios

Vehicle impact speed, pedestrian height, pedestrian gait stance and walking speed are the main factors influencing severity of pedestrian injuries in a vehicle impact [1-2]. The distribution of these four impact parameters was derived from previous studies [2-5] (Table I; Fig. 1) as the inputs of MADYMO multi-body simulations of vehicle pedestrian impacts, with a baseline model from Elliott et al. [6].

TABLE I
IMPACT PARAMETERS

Impact parameter	Source
Vehicle impact speed	IHRA accident data [3]
Pedestrian height	Age groups in IHRA accident data [3] and anthropometric data of British [4]
Pedestrian gait stance	10 gait stances during the walking cycle reported by Untaroiu et al. [2]
Pedestrian speed	Age group in IHRA accident data [3] and walking speed distribution from Huang et al. [5]

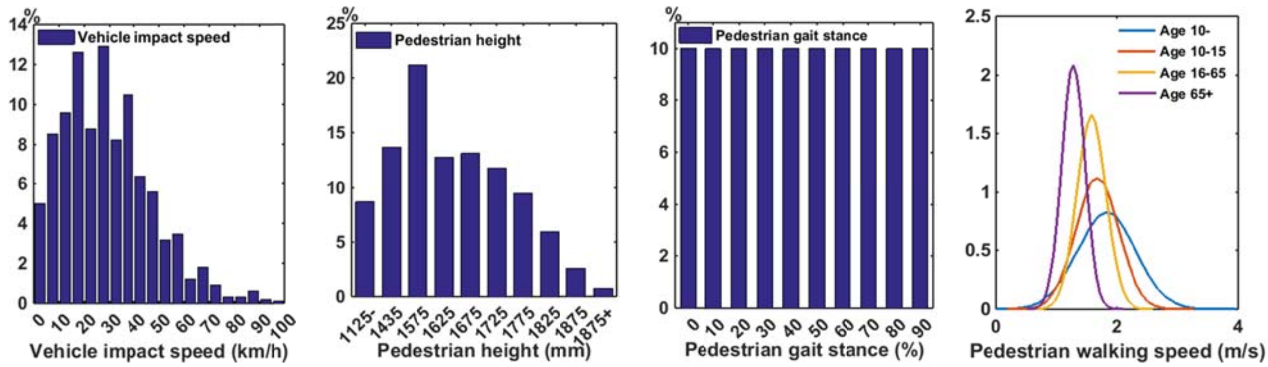

Fig. 1. Distribution of vehicle impact speed and pedestrian height, gait stance and walking speed in accidents.

Injury Cost

As reported in ISO 13232-5 [7], injury cost (including medical and auxiliary costs) can be calculated based on AIS injury levels in the different body regions. These were estimated by the injury criteria extracted from the MADYMO simulations. In the current study, injury criteria of HIC (head), Nij (neck), sternum acceleration (thorax), lateral impact force (pelvis), bending moment (long bones in lower limbs) and bending angle (knee) were used for calculating the overall pedestrian injury cost in a collision. The limits of those injury criteria for AIS were adapted from previous studies [8-12].

Simulation Test Sample

In order to reduce the computing time of the optimisation process, a simulation test sample with a reasonable size was developed for predicting pedestrian injury risk in real-word accidents. Preliminary investigation indicated that collisions of impact speed less than 20 km/h only account for about 2% of the total injury cost and pedestrian

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walking speed has no significant influence on injury cost when impact speeds are higher than 20 km/h. So the impact speed range of the test sample is from 20 km/h to 70 km/h (only 2.4% pedestrian accidents occurred at impact speeds above 70 km/h), and only the mean walking speed of the corresponding age group was applied for the pedestrian models. The impact speed was divided into 10 groups with an interval of 5 km/h (Table II). The pedestrians' heights were modelled by scaled MADYMO pedestrian models [12] (Table II). All the pedestrian models were configured into 10 gait stances [2]. In total, 800 (10*8*10=800) impact scenarios were set as the simulation test sample for assessing the safety performance of a vehicle front design in real-world pedestrian accidents (Table II). As shown in Eq. (1), the proportion of each impact scenario (p_i) in the sample was calculated based on the normalised proportion of impact parameters (p_{vi}-impact speed, p_{hi}-pedestrian height and p_{gi}-pedestrian gait stance). The weighted injury cost (WIC) of the simulation test sample (fitness function for vehicle front optimisation) is the sum of the product of injury cost (IC_i) and proportion of each impact scenario.

$$WIC = \sum_{i=1}^{800} IC_i * p_i = \sum_{i=1}^{800} IC_i * p_{vi} * p_{hi} * p_{gi} \tag{1}$$

To assess the representativeness of the simulation test sample, comparison was made with benchmark simulation samples of 10,000 randomly selected impact scenarios (minimum size for repeatable outputs) based on distributions of impact parameters in the accident data (Fig. 1) for a sedan model.

TABLE II
TEST SIMULATION SAMPLE

Vehicle impact speed /simulation speed (km/h)	Pedestrian height/model height (mm)	Gait stance
(20-24)/22, (25-29)/27, (30-34)/32, (35-39)/37, (40-44)/42, (45-49)/47, (50-54)/52, (55-59)/57, (60-64)/62, (65-69)/67	(-1125)/970, (1125-1435)/1170, (1435-1575)/1530, (1575-1625)/1600, (1625-1675)/1650, (1675-1725)/1700, (1725-1775)/1750, (1775+)/1850	0%-90% (10 discrete cases)

III. INITIAL FINDINGS

Figure 2 shows proportion of injury cost associated with vehicle speed, pedestrian height and pedestrian gait and pedestrian body region for the simulation test sample (N=800) compared to the benchmark samples (N=10,000). The results show very similar distributions of injury cost, with relative errors always within 5%.

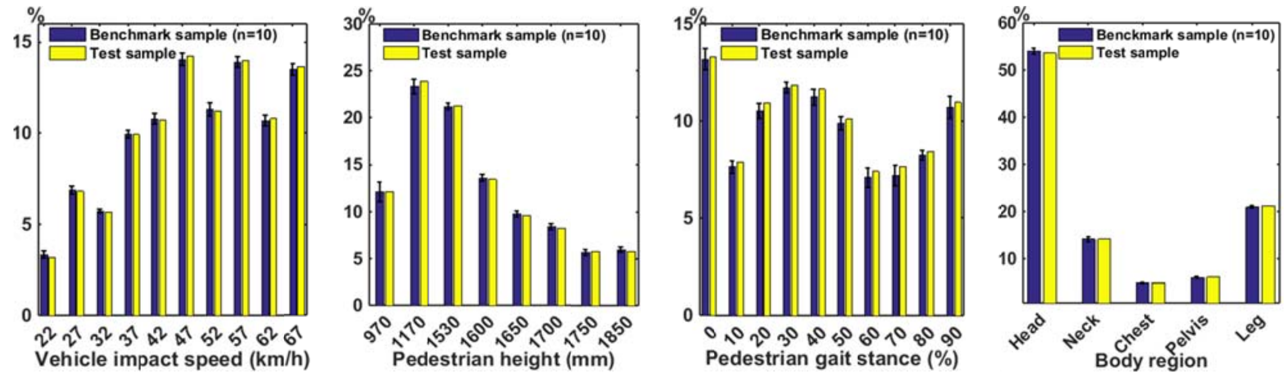

Fig. 2. Injury cost distributions as impact parameters and body region in the test sample and benchmark samples.

IV. DISCUSSION

The comparison results show that the simulation test sample can represent the prediction ability of the benchmark samples where the impact parameters were randomly selected according to their distributions in the accident data. The weighted injury cost from the simulation test sample (N=800) could therefore be a potential fitness function for vehicle front optimisation for pedestrian injury mitigation.

V. REFERENCES

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