Framework on Injury Outcome Estimation using Pedestrian Impact Simulation and Field Data

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I. INTRODUCTION

Multibody pedestrian models are used to predict injury risk of multiple body regions in conjunction with injury risk functions developed from cadaveric tests [1]. Given that multiple body regions are considered during vehicle-pedestrian impact simulations, a more comprehensive metric for assessing a pedestrian's injury risk is often needed to design a vehicle or countermeasure. Although multitrauma metrics, such as the new injury severity score (NISS) [2] and the whole body functional capacity index (WBFCI) [3], exist to estimate loss due to the multiple injuries on physical and economical standpoints, their estimation requires knowledge of specific AIS injury types or severity levels per each body region. There is, therefore, a gap between estimating the probability of injury for each body region, which can be predicted from a simulation, and the estimates of injury loss due to polytrauma, which are functions of more specific injury descriptions. This study presents a framework to estimate multitrauma loss metric values for a given injury risk produced from a multibody pedestrian impact simulation and real-world pedestrian crash injury patterns.

II. METHODS

Preparation of Real-world Pedestrian Data

To describe the real-world prevalence and distribution of injuries sustained by pedestrians struck by motor vehicles in the USA, three data sources were compiled for the calendar year 2012. A census of fatally struck pedestrians was collected through the National Vital Statistics System (NVSS), while the nationally representative databases for hospital-admitted struck pedestrians and treated and released patients were captured through the Healthcare Cost and Utilization Project's (HCUP) nationwide inpatient sample (NIS) and nationwide emergency department sample (NEDS), respectively.

Methods well-described by the Pacific Institute of Research and Evaluation (PIRE) were applied to these data to ascribe loss values in terms of economic costs, and specific to medical, wage work loss, household productivity and monetised quality of life. As struck pedestrians are likely to sustain multiple injuries, quantifying and characterising the long-term consequences and impairment of polytrauma was completed by estimating losses in functional capacity across the 10 dimensions of functionality (eating, excretory, sexual, ambulation, hand/arm mobility, bending and lifting, visual, auditory, speech, and cognition), as described by the whole-body FCI (WFCI).

For each case, injury patterns were described for 17 body regions, including: skull, brain, face, neck, shoulder, upper arm, lower arm, wrist, thorax, abdomen, lumbar, pelvis, femoral neck, femoral shaft, knee, tibia and ankle. This body region classification was selected after considering the capability of a multibody model in predicting injury risk.

MAIS Sampling Per Body Region (Monte Carlo Sampling I)

For each body region, the probability of MAIS1 or less, MAIS2, MAIS3 and MAIS4 or higher was calculated by assuming these are mutually exclusive events, using Equation (1). In some cases, the injury risk functions for different levels of AIS injuries overlap each other. In such instances, the risk for the less severe injury is set to the same value as the risk for the more severe injury.

$$\begin{cases} P(\text{MAIS1 or less}) = 1 - P(\text{AIS2}+), & P(\text{MAIS2}) = P(\text{AIS2}+) - P(\text{AIS3}+), \\ P(\text{MAIS3}) = P(\text{AIS3}+) - P(\text{AIS4}+), & P(\text{MAIS4}+) = P(\text{AIS4}+)) \end{cases} \quad (1)$$

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For each body region, the cumulative probability function was built for the four MAIS level categories. Then, a vector with 17 components was randomly generated following a uniform distribution so that each component has a value from 0 to 1. Based on the value of each component, MAIS levels for each body region were assigned. This Monte Carlo sampling process was repeated *M* times. From this first Monte Carlo sampling, *M* virtual pedestrians with an assigned MAIS level in each body region were generated.

Injury Pattern Mapping Per Body Region (Monte Carlo Sampling II)

For each virtual pedestrian generated in the Monte Carlo Sampling I, a second Monte Carlo sampling was performed to assign specific AIS injury code(s) to each body region. For each body region, an injury pattern was randomly sampled from the real-world pedestrian cases that sustained the same MAIS level for the given body region. After each trial, a second-level virtual pedestrian with specific AIS code(s) per each body region was produced. This task was performed *N* times for each virtual pedestrian modelled from the first Monte Carlo sampling.

Expected Combined Metric Values

The NISS is the sum of the squares of the three highest AIS values, regardless of body region [2]. The functional capacity index describes limitations across 10 dimensions of functionality [4]. Each dimension has scaled values from 60 (complete functional loss) and 100 (no functional loss) and can be used to calculate WFCI due to multiple injuries by considering lowest value for each dimension among injuries.

Equations (2) and (3) show how to calculate expected values of NISS and WFCI for a combined loss metric due to injuries using the two step Monte Carlo sampling results. A combined loss metric due to injuries sustained at the whole-body level can be calculated by using either Equation (2) or Equation (3), depending on the level of detail it requires.

$$\mathrm{E(NISS\ or\ WFCI)} = \frac{1}{M\cdot N}\sum_{i=1}^{M}\sum_{j=1}^{N}(NISS\ or\ WFCI)_{i,j} \quad (2)$$

III. INITIAL FINDINGS

Fig. 1 shows two step Monte Carlo sampling results from a vehicle-pedestrian impact simulation. Note that the risk for AIS+ level injuries was given by a preceding pedestrian impact simulation (Fig. 1, *top left*). Then, the risk of AIS level injuries was calculated using Equation (1) (Fig. 1, *top right*). Lastly, two Monte Carlo samplings were performed to estimate MAIS levels and assign injury patterns to each body region.

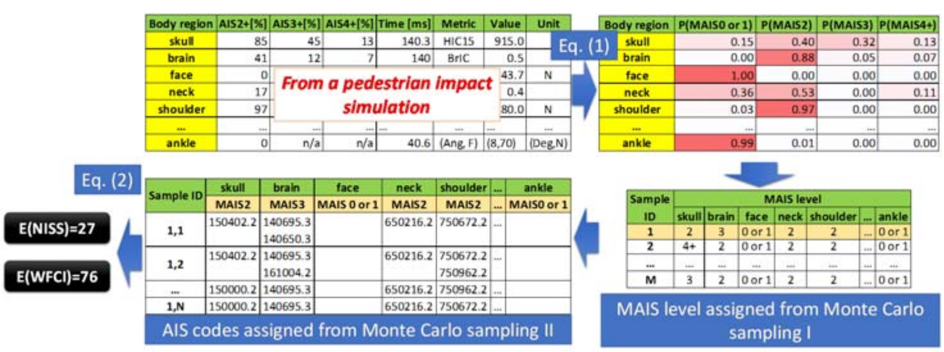

Fig. 1. Example results.

IV. DISCUSSION

This paper presents a method for estimating multitrauma injury loss metrics using injury risk (or probability) information from real-world crash data and two steps of Monte Carlo samplings. Monte Carlo samplings are performed using a pedestrian impact simulation result and they output a combined loss metric. This method can simplify a vehicle design optimisation process by estimating a cost as a scalar value, instead of a matrix quantity consisting of probabilities of MAIS levels.

V. References

[1] Van Hoof, J. *et al*., *Stapp car crash J*, 2003.

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