An assessment of a multi-body pedestrian model versus PMHS during ground contact

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I. INTRODUCTION

The MADYMO 50 percentile male pedestrian model, developed by TNO Automotive, is one of the most commonly used multi-body pedestrian models for vulnerable road user crash reconstruction and numerical parametric study. The model was validated for both full model [1] and model segments such like tibia and femur static 3-point bending tests, PMHS side impactor tests for pelvis, thorax and shoulder, PMHS leg impactor tests for bending moment and shear force of lower extremities [2]. However, all models appear to be validated for the vehicle impact only, and model validations for ground contact are so far lacking. As the importance of pedestrian ground contact is growing due to improvements in the primary vehicle contact [3], it is also necessary to assess the performance of pedestrian models after vehicle impact. The staged PMHS impact tests [4] provided a reference including pedestrian kinematics and injury outcomes (skull fracture, HIC and BrIC) for multi-body model assessment.

Accordingly, the aims of this study are to assess

1) the capacity of the MADYMO pedestrian model to reconstruct the PMHS tests for ground contact.
2) which influencing factors have greatest effect on pedestrian ground contact.

II. METHODS

Flow Chart of Assessing the Multi-body Models

The MADYMO pedestrian multi-body model as well as simplified vehicle models were employed to assess the performance in ground contact. Before reconstructing the MB models against the PMHS impact tests presented in previous cadaver tests, it should be noted that uncertainties (loading and unloading functions in vehicle pedestrian contact and pedestrian ground contact, damping inside the MB pedestrian model, pedestrian initial joint angles) exist. Fig.1 illustrates the flowchart of steps to assess the MB models.

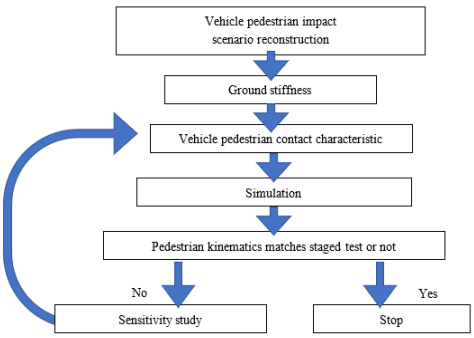

Fig. 1. Flow chart of assessing the multi-body models.

Multibody Models

The Simplified multi-body vehicle models were built using the MADYMO platform based on shape profiles from the blueprints to represent the vehicles tested. Each vehicle model consists of a lower bumper, bumper, bonnet leading edge, bonnet, windshield, wheels and roof. Since the heights and weights of the PMHS pedestrians tested varied, a scaling tool based on a customized Matlab code was applied to obtain scaled pedestrian models based on the input pedestrian height and weight.

Movement input of the MB vehicle models

The time-displacement curves in X (horizontal) direction and Z (vertical) direction, and the time-rotation curve of the vehicle, extracted every 20 ms by using customized Matlab code, were used to define how the MB vehicle model moves. The general steps of selecting the tracking point are as follows:

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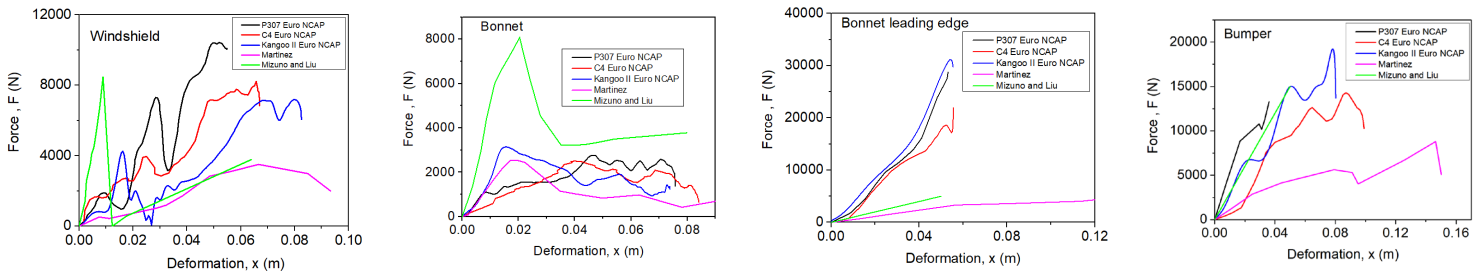
(1) According to the width of the vehicle and the markers on the lab ground, using ginput function in Matlab to pick 2 pair of points (a1 and a2, a3 and a4) which defines 1 m in y=0 and y=0.75, then the expecting scale (b1 and b2) can be found based on the relation, see Fig. 2 (a). The scale in Y direction depends on the coordinates of the points P1 and P2 in Fig. 2 (b).

(2) P1 is a reference point which can be used to find the tracking point P0 based on their relative positional relationship. Pick two points P1 and P2 in a line on the side of the vehicle, then the angular change of the vehicle can be calculated.

(a) Demonstration of choosing the scale (b) Demonstration of choosing the tracking point P0

Fig. 2. The steps of choosing the tracking point

Three sources of vehicle contact characteristic were simulated. One is from [5], one is from the test performed by the European New Car Assessment Programme (EURO-NCAP) [6] and another one is from [7] and [8]. The windshield stiffness and bonnet stiffness from [7] were obtained by impactor tests and the stiffness of bonnet leading edge and bumper were assessed by [8]. [5] summarized 425 Euro NCAP tests then estimated a series of simplified average stiffness curves. The force-deformation curves of each tested vehicle from Euro NCAP test as well as the force-deformation curves from [5] and [7] are shown in Fig. 3. The detailed process of obtaining the vehicle front stiffness by using subsystem impactors can be found in [5].



(a) windshield (b) bonnet (c) bonnet leading edge (b) bumper

Fig. 3. Force-deformation contact characteristics of vehicle front components from different sources

III. INITIAL FINDINGS

The key event timings of the vehicle pedestrian impact from staged test 01 and the reconstructed simulations as well as the ground contact mechanisms are compared, see TABLE I and Fig.6. In Test 01, pedestrian vehicle separation times are generally earlier from MB reconstruction than those observed from the PMHS test. While the head ground contacts occurred more than 100ms earlier for MB simulation.

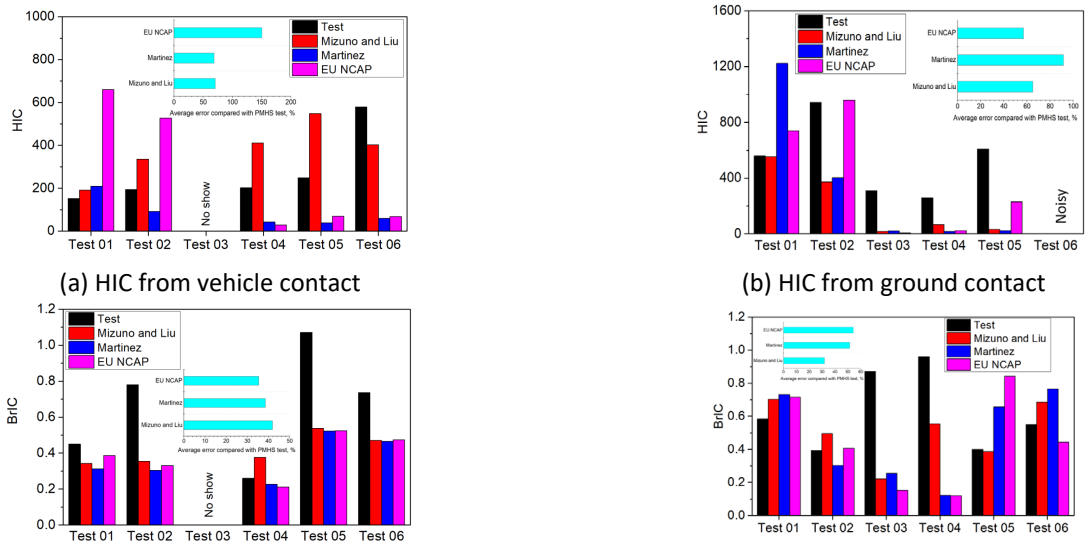
TABLE I

COMPARISON OF KEY EVENTS (S) OF TEST 01

Contact characteristic source	$t_{head\text{-}vehicle\ contact}$	$t_{rebound}$	$t_{separation}$	$t_{head\text{-}ground\ contact}$	Ground contact mechanism, from [9]
Staged test	0.145	0.269	0.770	0.995	M1
Mizuno and Liu[1]	0.140	0.200	0.595	0.845	M3
Martinez	0.140	0.200	0.615	0.875	M3
EU NCAP	0.145	0.205	0.610	0.865	M3

[1] The contact characteristics used in the simulations are from these authors correspondingly.

Pedestrian head injury indices HIC (caused by translational accelerations) and BrIC (caused by rotational angular velocities) were calculated for both vehicle and ground contact for all six cases and were compared with the staged PMHS test results, as shown in Fig. 4.



(a) HIC from vehicle contact (b) HIC from ground contact

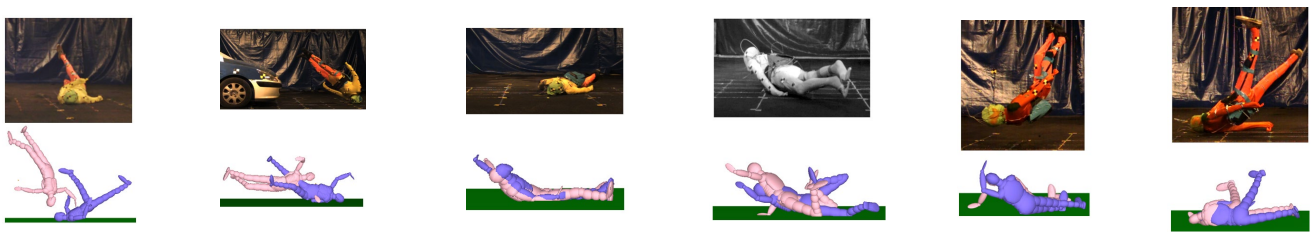
(c) BrIC from vehicle contact (d) BrIC from ground contact

Fig. 4. Comparison of head injury indices from PMHS tests and 1st round simulations

The results of first round simulations showed that the pedestrian kinematics could not be represented well for some of the tests. It is proved that contact characteristics, initial angle of pedestrian hip and knee joints, bending of MB pedestrian model all affect the head injury indices during ground contact. Then a second round of reconstructed simulation were performed by changing the windshield/bonnet/bonnet leading/bumper contact characteristics (the changed stiffness curves used are shown in Fig. 5) what aimed to obtain a better kinematics matching of pedestrian models to the cadavers. The ground impact mechanisms are shown in Fig. 6. Both of the ground impact mechanisms of MB pedestrian models from first round and second round were compared with the cadaver tests. Pedestrian rotation in Test 01 and 02 was reduced. Test 05 is ignored because the cadaver could not represent the practical pedestrian posture due to the hard stiffness of the joints.

(a) bonnet leading edge (b) bumper

Fig. 5. Force-deformation contact characteristics of vehicle front components used in 2nd round simulation

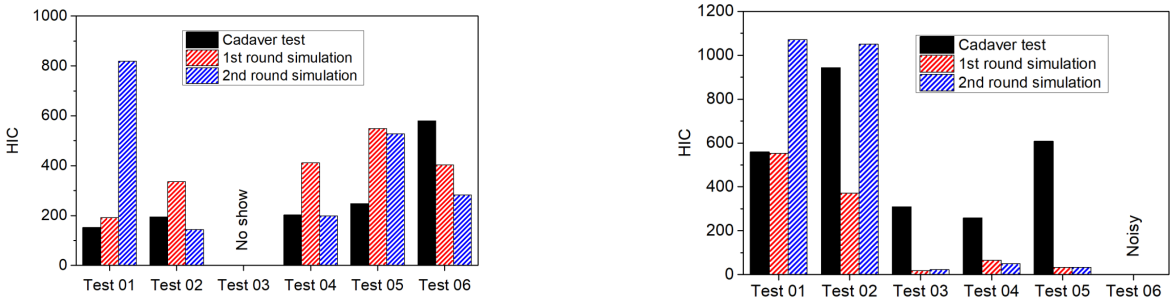


(a) Test 01 (b) Test 02 (c) Test 03 (d) Test 04 (e) Test 05 (f) Test 06

Fig. 6. Comparison of pedestrian landing mechanisms between PMHS tests and MB reconstructions (Pink model: First round; Blue model: Second round)

The injury indices of the second round of simulations are compared with the results from the first round of

simulations and the cadaver tests, as shown in Fig. 7. For Test 01, HIC scores from both the vehicle contact and ground contact are significantly higher in the 2nd round simulations than HIC obtained from 1st round simulations and the cadaver tests. For Test 02, HIC obtained from ground contact in the 2nd round is more than twice as that in the 1st round, but it close to the cadaver test result.



(a) HIC from vehicle contact (b) HIC from ground contact

Fig. 7. Comparison of head injury indices from PMHS tests, 1st round and 2nd round simulations

IV. DISCUSSION

This study presents the first kinematics assessment of a MB pedestrian model for the phases after vehicle impact by comparison with staged test data. In Test 01 and Test 02 reconstructions, the pedestrian models bounced off the vehicle after head windshield impact, but the bounces did not occur in the cadaver tests. Then the vehicle stiffnesses were changed to try making the pedestrian kinematics close to the experiments. For Test 01 and Test 02, pedestrian rotations can be increased or reduced by harden or soften the contact characteristics of bumper and bonnet leading edge, see Fig. 6, based on the references of pedestrian ground impact mechanisms summarized by [9], the ground impact mechanisms from the second round of simulations showed the MB pedestrian performed better to represent the experiments.

Even though the pedestrian kinematics improved in the 2nd round simulations, the injury indices (HIC from vehicle contact and ground contact) were not generally close to that from cadaver tests compared with 1st round simulations. Moreover, the mechanisms of pedestrian impacting with bumper/bonnet leading edge in 2nd round simulations were unreal (unexpected deep penetration) when softening the bumper/bonnet leading edge to match the ground impact mechanisms close to the cadaver tests.

There are also several limitations in this study. Firstly, the MB pedestrian models were scaled basing on the MADYMO 50th percentile pedestrian male model, but the segments of each body parts were not scaled as the actual sizes of the PMHS. Secondly, the contact characteristics of PMHS should be individually different, but we did not change the stiffness of the pedestrian model because lacking related information.

Future work will focus on improving the post impact kinematic performance of MADYMO pedestrian model by changing the contact characteristic and the joint stiffness.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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