Simulation-based investigation of the sensitivity of THOR-50M injury outcomes to testing variability

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I. INTRODUCTION

To evaluate the occupant protection performance in frontal impact, THOR (Test Device for Human Occupant Restraint)-50M dummy is used in the Euro NCAP MPDB impact test [1]. In hardware testing, the outcome is influenced by variations resulting from dummy parts, testing boundary conditions and restraint system used. In previous studies, variations in test results were observed in repeated sled tests with THOR-50M [2]. Assessment results might change due to this variation, which could be even higher than the differences in safety systems (e.g. improved advanced restraint system). To conduct assessment tests under more controlled conditions, it is important to understand the effects of each parameter on injury outcomes. The objective of this study is to investigate the influence of variability, which is assumed to be observed in hardware crash tests, on occupant kinematics and injury outcomes. It is possible to isolate the effects of each parameter through simulation.

II. METHODS

Sled simulations were performed with a THOR-50M Euro NCAP borderline model (V1.8, Humanetics Innovative Solutions [3]) in a rigid seat environment (Fig. 1), developed by Partnership for Dummy Technology and Biomechanics (PDB) [4]. A generic pulse from Euro NCAP knee mapping (Class-B, OLC=25.5 g) [5] was used. A seat-belt retractor model with load limiter and pretensioner, a pre-deployed airbag model and a knee bolster were used. As a baseline model, occupant posture and seat-belt routing were set to closely match conditions measured in previous hardware sled tests. The variation parameters considered in this study are summarised in Table I. The parameters of the dummy and restraint system identified as highly sensitive in previous investigations [6-7] were selected. Thorax stiffness of upper and lower regions was considered as dummy parameters. Stiffness was adjusted by borderline model function, which can change the stiffness based on thorax certification results. Upper and lower thorax stiffness were set within the range of Euro NCAP certification tolerances. Initial dummy postures were adjusted based on accepted tolerances from the Euro NCAP MPDB procedure. Forward and rearward postures were defined by adjusting H-point. The pelvic angle (Y) was changed to maintain the contact between torso and seatback. Neck/T1 angle and heel position were set as closely as possible to baseline posture. The parameter of shoulder-belt routing was defined as relative distance between lower neck bolt and diagonal belt upper edge. This parameter was assumed to have ±10 mm variation as a natural belt routing. A variation of vehicle pulse was set to baseline ±2.5% of the OLC value. Load limiter force and pretensioner deployment timing were selected as restraint system parameters. A total of 100 simulations were conducted, with simulation parameters determined using Design of Experiments (DOE) method using LS-OPT [8]. Regarding the assessment criteria, HIC15 and DAMAGE were calculated for head region, R_{max}, PC Score and TIC-NFR were used for thorax region [9-10].

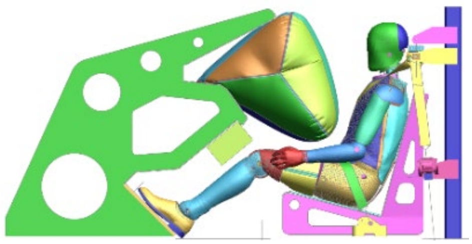

Fig. 1. Overview of simulation model.

TABLE I
VARIABLE PARAMETERS

Parameter		Unit	Minimum	Baseline	Maximum
Dummy	Upper Thorax stiffness	mm	47.5	51.1	54.7
	Lower Thorax stiffness	mm	-52.4	-49	-45.6
Boundary condition	Initial dummy posture (H-point)	mm	390	403	416
	Belt routing	mm	92	102	112
	Vehicle pulse (OLC)	g	24.8	25.5	26.1
Restraint system	Load limiter force	%	92	100	108
	Pretensioner time to fire	ms	9	12	15

III. INITIAL FINDINGS

Probabilities of AIS3+ injury were calculated for each parameter, except DAMAGE (AIS2+). The global sensitivity analysis was conducted using LS-OPT (Sobol method). The global sensitivity indexes are listed in Table II. The two

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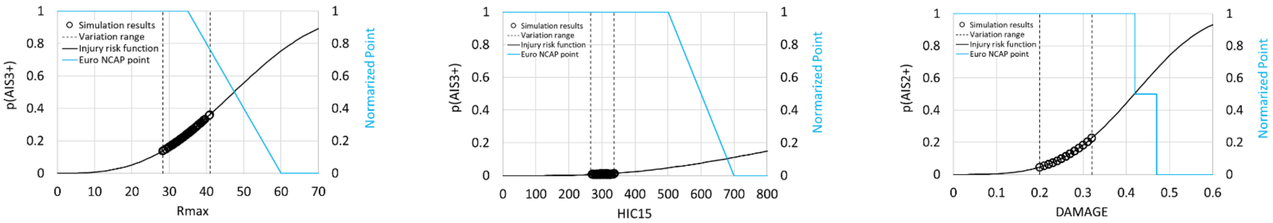
most influential parameters for each injury outcome are shown in bold. Regarding the thorax injury criteria, all criteria were more sensitive to upper thorax stiffness than other parameters. The second most sensitive parameter was different depending on the criteria; R_{max} and PC Score were influenced by LL force, TIC-NFR was sensitive to the belt routing. For head and brain injury criteria, vehicle pulse had a higher influence on the HIC15, and DAMAGE was sensitive to initial dummy posture and pretensioner time to fire. Figure 2 shows the comparison between the variation of injury outcomes and the current Euro NCAP rating point [11]. The variation range of the criteria was 28–41mm (R_{max}), 265–338 (HIC15), and 0.20–0.32 (DAMAGE), respectively. The highest value of R_{max} variation was larger than the upper limit of rating scheme (35 mm), however the maximum values of head region were smaller than the upper limit (500 for HIC15) or modifier value (0.42 for DAMAGE).

TABLE II

GLOBAL SENSITIVITY INDEX OF EACH PARAMETER (UNIT: %)

	Parameter	Rmax	PC Score	TIC-NFR	HIC15	DAMAGE
Dummy	Upper Thorax stiffness	**80.9**	**63.6**	**54.6**	1.3	1.0
	Lower Thorax stiffness	0.3	3.6	1.6	0.3	1.0
Boundary condition	Initial posture	4.3	11.0	5.8	10.1	**45.1**
	Belt routing	1.0	0.3	**20.0**	0.6	4.0
	Vehicle pulse	0.5	0.6	2.0	**66.7**	3.4
Restraint system	Load limiter force	**11.8**	**20.0**	5.9	0.7	9.0
	Pretensioner TTF	1.3	0.8	10.0	**20.3**	**36.6**



(a) Rmax. (b) HIC15. (c) DAMAGE.

Fig. 2. Comparison between variation of injury outcomes and current Euro NCAP rating point.

IV. DISCUSSION

Regarding the thorax injury criteria, differences of global sensitivity index were observed. PC Score is calculated by sum of upper/lower maximum thorax deflection and difference (left and right) of upper/lower deflection. TIC-NFR is defined using R_{max} and upper deflection difference. In this study, the contribution of the upper deflection term for TIC-NFR was larger than PC Score, and it is considered that the upper deflection difference was influenced by shoulder-belt routing. Thus, TIC-NFR was sensitive to upper thorax stiffness and shoulder-belt routing. In the previous study [2], the maximum R_{max} variation range of the hardware testing with different THOR-50M dummies was approximately 16 mm. Similar variation of R_{max} (13 mm) was observed in this study. The sensitivity of upper thorax stiffness was higher than that of other parameters and this variation effect could be larger than the differences resulting from different restraint systems. Regarding the variation of injury criteria currently assessed by Euro NCAP, R_{max} was scattering within the sliding scale range of rating point scheme, i.e. the rating result of thorax region could be affected by the variation considered in this study. A variation of R_{max} of 13mm in the assessment could change the scoring of the chest by two levels (e.g. green to orange). This study shows the importance of limiting the variation influence of the THOR-50M upper thorax for assessment testing under more controlled conditions. Sensitivity analysis under conditions that are closer to actual vehicles and research of methods to control thorax characteristics (e.g. dummy qualification procedure) are planned in future steps.

V. REFERENCES

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