Moderate Overlap Crashworthiness Evaluation 2.0 Rating Guidelines

Version I

June 2023

Insurance Institute for Highway Safety
988 Dairy Road
Ruckersville, VA 22968
researchpapers@iihs.org
+1 434 985 4600

iihs.org

CONTENTS

OVERVIEW 3
DRIVER 3
Injury rating (front occupant) 3
Restraints and kinematics (front occupant) 5
REAR OCCUPANT 6
Injury rating (rear occupant) 6
Restraints and kinematics (rear occupant) 7
STRUCTURE 8
Overview 8
Measurements of safety cage deformation 8
Evaluating intrusion measurements 8
Qualitative observations leading to downgraded structure rating 9
Fuel and high-voltage system integrity leading to downgraded rating 10
WEIGHTING PRINCIPLES FOR OVERALL RATINGS 11
REFERENCES 12
APPENDIX A: CALCULATING THE DYNAMIC BELT POSITION 13
References (Appendix A) 17
APPENDIX B: CALCULATING THE CAMERA PARALLAX ERROR 18
Formula for calculating the parallax error 19

OVERVIEW

This document provides the rating guidelines for the Insurance Institute for Highway Safety's (IIHS's) moderate overlap 2.0 crash test.

The front-seat occupant is a 50th percentile male Hybrid III dummy.

The rear-seat occupant is a 5th percentile female Hybrid III dummy.

Injury ratings for each occupant are dictated by the worst metric in each body region with downgrades, where applicable. Restraints and kinematics ratings for each occupant are dictated by the sum of the accumulated demerits.

DRIVER

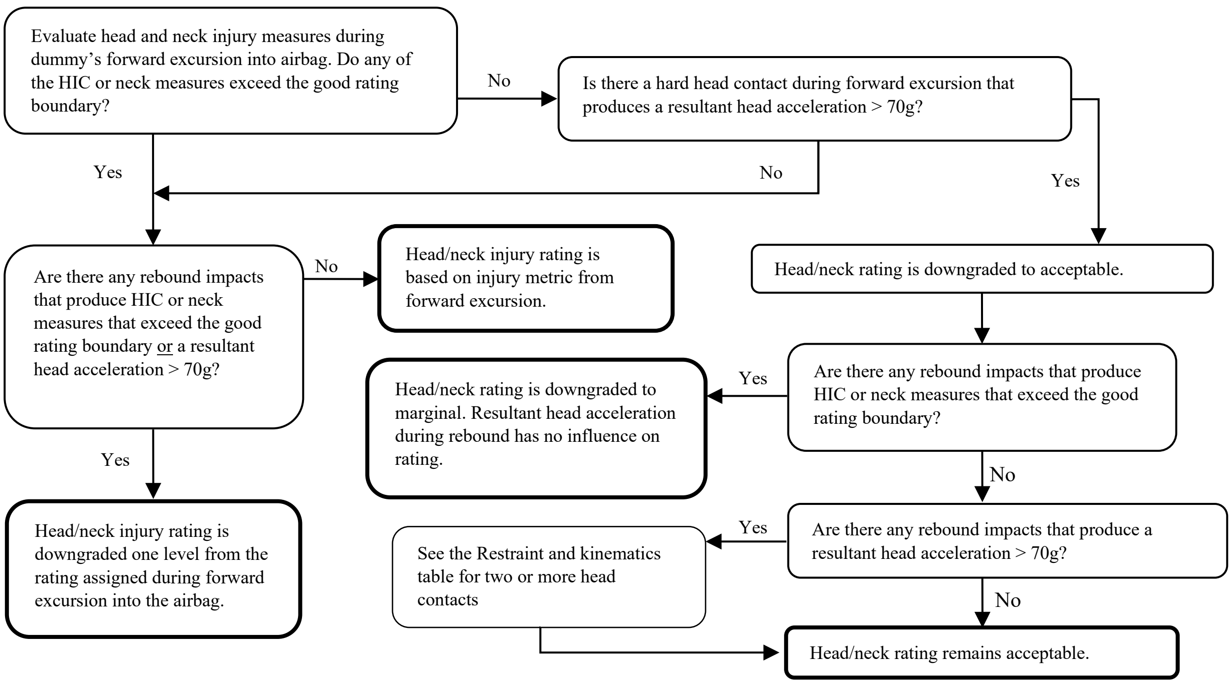
Injury rating (front occupant)

Body region	Parameter	IARV [a]	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC 15	700	560	700	840
	Nij	1.00	0.80	1.00	1.20
	Neck axial tension (kN)	3.3	2.6	3.3	4.0
	Neck compression (kN)	4.0	3.2	4.0	4.8
Chest	Thoracic spine acceleration (3-ms clip, g)	60	60	75	90
	Sternum deflection (mm)	−50	−50	−60	−75
	Sternum deflection rate (m/s)	−8.2	−6.6	−8.2	−9.8
	Viscous criterion (m/s)	1.0	0.8	1.0	1.2
Thigh and hip	Knee-thigh-hip injury risk		5%	15%	25%
Leg and foot	Tibia-femur displacement (mm)	−15	−12	−15	−18
	Tibia index (upper, lower)	1.00	0.80	1.00	1.20
	Tibia axial force (kN)	−8.0	−4.0	−6.0	−8.0
	Foot acceleration (g)	150	150	200	260

Note. HIC = head injury criterion. IARV = injury assessment reference values.

[a] See IIHS's *Moderate Overlap Frontal Crashworthiness Evaluation: Guidelines for Rating Injury Measures* (September 2014).

Figure 1
Flowchart: Influence of rebound impacts on the head/neck injury rating



Note. HIC = head injury criterion.

Restraints and kinematics (front occupant)

Kinematic event	Demerits
Side curtain airbag not equipped or did not deploy	1
Frontal airbag deployed late or did not deploy	3
Movement of *most* of the dummy's head through the original plane of the vehicle's side window	3
Two or more distinct head contacts with stiff structures that each generate more than 70 g of maximum acceleration (e.g., contacts with the steering wheel *and* B-pillar)	4
Instability of the seat due to floorpan or seat-riser deformation	3
Excessive rearward, lateral, or upward movement (≥ 100 mm) of the steering column	3
Moderately excessive (100–150 mm), uncontrolled lengthening of the lap belt	3
Burning or melting of dummy body parts or clothing due to the expulsion of hot gases from deflating airbags during impact	3
Dummy movement considerably less controlled (e.g., the head and shoulders pass through the original plane of the side window, or there is sufficient rotation of the upper torso for the head to face upward or nearly upward on rebound from the airbag), regardless of contact with a stiff structure	7
Vehicle door opening	10
Failure of seat attachments	10
Excessive belt slack introduced by belt tearing	10

	Good	Acceptable	Marginal	Poor
Total restraint and kinematic demerits	0–1	2–5	6–9	≥ 10

REAR OCCUPANT

Injury rating (rear occupant)

Peak injury values for the rear occupant are collected and reported for the entire event, unless they exceed a rating boundary. Values that exceed rating boundaries are only reported and rated if they occur during the primary loading phase of the event.

Body region	Parameter	IARV [a]	Pass/fail cutoff	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC 15 (only used with contacts)	779	—	560	700	840
	Nij [b] (only used with contacts)	1.00	—	0.80	1.00	1.20
	Neck axial tension (kN)	2.6	—	2.0	2.4	2.8
	Neck compression (kN)	2.5	—	2.0	2.5	3.0
	Head resultant acceleration from contact (g)		70	Fail → Head and neck rating is downgraded one level		
				Good	**Marginal**	**Poor**
Chest	Sternum deflection (mm)	−41	−30	Fail 0	Fail 1	Fail 2 or 3
	Shoulder belt tension (kN)	—	<6.0			
	Maximum shoulder belt position [c] (mm)	—	110			
				Good – Acceptable	**Acceptable – Marginal**	**Marginal – Poor**
Thigh	Femur axial compression (kN)	6.2	—	4.9	6.2	7.4

Note. HIC = head injury criterion. IARV = injury assessment reference values.

[a] Based on Mertz et al., 2016.

[b] Based on Eppinger et al., 2000.

[c] Belt position is measured at the highest position on the chest. See Appendix A for details on calculating the dynamic belt position.

Restraints and kinematics (rear occupant)

Restraint and kinematic events	Demerits
Head excursion (only one applies) [a]	
50-mm line	2
Front-seatback line at test position	6
Head contact	10
Submarining	10
Rebound head-contact acceleration (3 ms) > 70g	2
Lack of head containment during rebound (only one applies)	
Head is outside of the side curtain airbag, or curtain airbag is not equipped or did not deploy	2
At least half of the head is outside the window plane	6
Instability of the seat due to floorpan or seat-riser deformation	3
Occupant burn risk	3
Vehicle door opening	10
Failure of seat attachments	10

	Good	Acceptable	Marginal	Poor
Total restraint and kinematic demerits	0–1	2–5	6–9	≥ 10

[a] See Appendix B for details on head-excursion measurements.

STRUCTURE

Overview

In the Insurance Institute for Highway Safety's frontal offset crash tests, injury measures recorded on a 50th percentile male Hybrid III driver dummy are used as one indicator of crashworthiness performance. These measures are not the only indicators, however, because although high dummy injury measures recorded in the offset test mean some people in similar real-world crashes would sustain significant injuries, the converse is not true. Low dummy injury measures do not necessarily mean there is no risk of significant injury to people in similar crashes. This is because the forces experienced by people of different sizes from the test dummy, or seated in different positions, can be quite different, especially when there is significant collapse of/intrusion into the occupant compartment. Major deformation or intrusion into the compartment is a good predictor of injury risk for people in similar crashes, even when dummy injury measures are low. For this reason, the Institute evaluates the structural integrity of the occupant compartment, or safety cage, during the offset test and uses this as an important additional indicator of crashworthiness performance. Specific measurements of intrusion into the occupant compartment are used to assess this aspect of performance.

Measurements of safety cage deformation

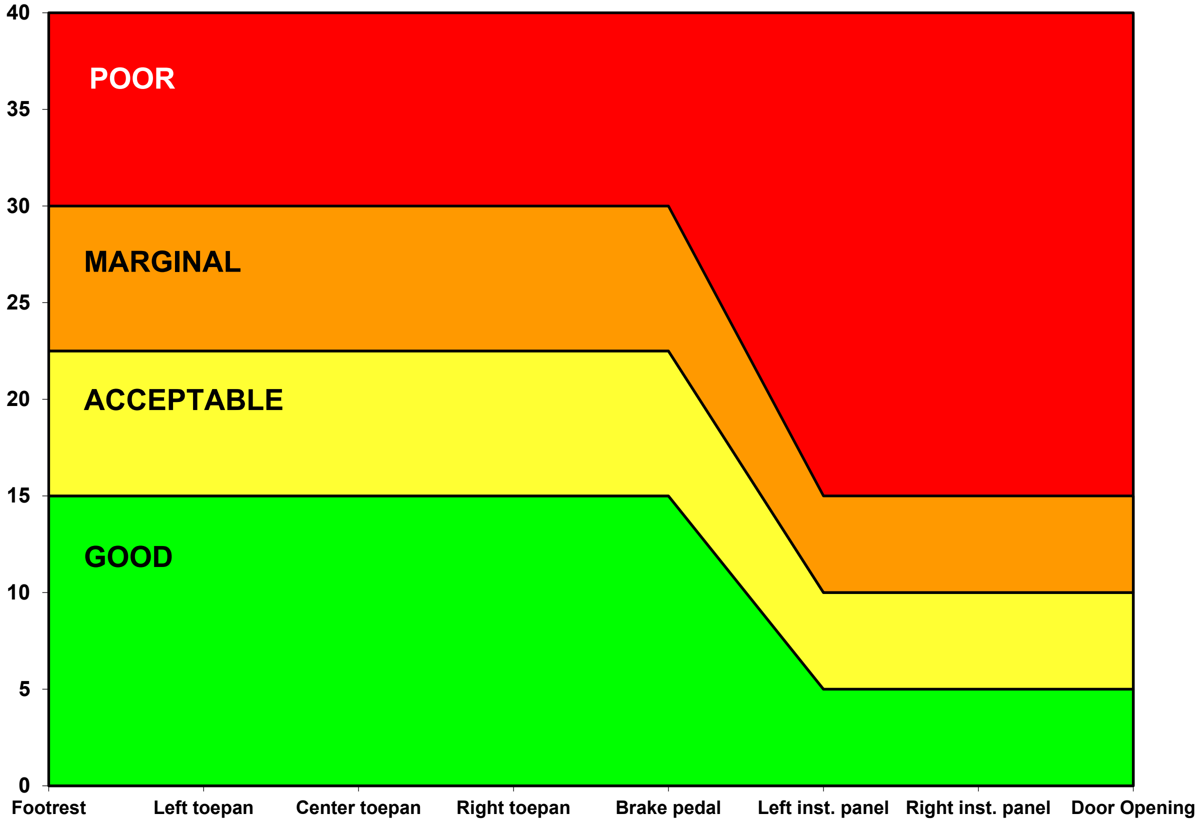
The measurements used by the Institute represent the residual movement (precrash/postcrash difference) of interior structures in front of the driver dummy. The movement of seven points on the vehicle interior plus the closing of the distance between the A- and B-pillars are the foundations of the Institute's structural ratings. Two of the interior measured points are located on the lower instrument panel, in front of the dummy's knees; four points are in the footwell area, three across the toepan and one on the driver's outboard footrest; the last measured point is on the brake pedal. The precrash and postcrash locations of these points are measured with respect to a coordinate system originating on the driver door striker. The measured movement of the interior seven points is adjusted to reflect movement toward the driver seat, which is represented by the locations of its attachment to the vehicle floor. Thus, movement of the driver seat with respect to the reference coordinate system is not reflected in evaluations of vehicle structure (this adjustment is not made for the A-to-B-pillar closure). A further adjustment may be made to the brake pedal intrusion in the event of pedals that "break away" or otherwise deform to limit intrusion. If a brake pedal is constructed so that it dangles loosely after the crash, the brake pedal is pushed straight forward against the toepan and held there to take the postcrash measurement. If the pedal drops away entirely, no postcrash measurement is taken.

Evaluating intrusion measurements

The initial structural rating is based on comparison of intrusion measurements with rating guidelines (Figure 2). This rating may then be modified (downgraded) on the basis of additional observations about the structural integrity of the safety cage.

The X-Y-Z vector resultant movements of the toepan, footrest, and brake pedal points are used for comparison with the rating guidelines. If the X movement is forward (away from the driver seat), then only the Y-Z vector resultant movement is used. Only the rearward movement (X) of the instrument panel is compared with the guidelines. Figure 2 shows the ranges for these measurements and associated structural ratings. Vehicle models with all intrusion measures falling in the area labeled good will receive a good structural rating if no additional observations lead to a downgraded rating. Similarly, vehicle models with all intrusion measures falling into one of the other three zones shown in Figure 2 will receive an acceptable, marginal, or poor rating unless there are modifying observations.

Figure 2
Guidelines for rating occupant compartment intrusion (cm)



When intrusion measurements fall in different rating bands, the final rating generally reflects the band with the most measures. However, the final rating typically will not be more than one rating level better than the worst measurement. For example, a vehicle with a poor measurement for the left instrument panel would not score better than marginal for structure, even if all other measured values were good. Where there are ties, with half the measurements in one band and half in another, the final rating typically will be that of the worst band. Intrusion measurements falling on a boundary value will be considered to fall in the band that represents the better rating.

Qualitative observations leading to downgraded structure rating

Some patterns of deformation are less desirable regardless of intrusion measurements. For example, a footwell that collapses in a way that traps the dummy's feet represents a greater injury risk than a footwell with similar intrusion measurements that does not trap the dummy's feet. Another example of a potentially modifying observation involves intrusion into the safety cage of some component or structure not captured by the ten measurement points (e.g., complete tearing of hinge pillar). If a modifying observation is made, then the overall structural rating will be lowered one level from the rating suggested by the intrusion measurements (e.g., from acceptable to marginal).

If more than one test is conducted of the same make and model with no structural changes in the same model year or consecutive model years, the structure rating will be based on the average measurements from the multiple tests except in the cases of one or more intrusion measurements spanning two or more rating bands. In such cases, the combined structure rating will be based on the worst case. For example, if a vehicle had a marginal toepan measure and a second example of the same vehicle had a good measure at the same point, this could be an indicator of lack of stability or robustness in the vehicle design. In such a case, the average rating of the toepan would be marginal, not acceptable, which in turn could affect the final structure rating.

Fuel and high-voltage system integrity leading to downgraded rating

If a significant fuel leak or compromise of a high-voltage system (i.e., electric drivetrain) is observed during a test, both the structural and overall ratings may be downgraded to poor. Significant fuel leaks are those that exceed the leak rate allowed following tests conducted to assess fuel system integrity under U.S. Federal Motor Vehicle Safety Standard (FMVSS) No. 301 (2017).

High-voltage systems must meet the electrolyte spillage, battery retention, and electrical isolation requirements in FMVSS 305 (2019 to avoid downgrade. Additionally, the temperature of the high-voltage battery will be monitored both with a thermocouple and a thermal imaging camera, before and after a crash test. If an increase in temperature is detected, the vehicle will be moved immediately outdoors where continued monitoring will take place. The following summarizes these requirements:

Electrolyte spillage

No more than 5 liters of electrolyte from propulsion batteries shall spill outside the passenger compartment and no visible trace of electrolyte shall spill into the passenger compartment.

Electric energy storage/conversion system retention

Electric energy storage/conversion devices mounted outside the occupant compartment shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure and shall not enter the occupant compartment.

Electrical isolation

After the test, one of the following requirements must be met:

- Electrical isolation between the high-voltage source and vehicle chassis must be greater than or equal to 500 ohms/volt for all high-voltage sources without continuous monitoring of electrical isolation. The isolation must be greater than or equal to 100 ohms/volt for all DC high-voltage sources with continuous monitoring of electrical isolation; or

- The voltages from high-voltage sources measured according to the procedure specified in FMVSS 305 (2019) must be less than or equal to 30 VAC for AC components, or 60 VDC for DC components.

Temperature increase

While postcrash activities commence, the battery temperature will be monitored with the onboard thermocouple for at least 4 hours. An increase in temperature from ambient laboratory temperature (20–22.2 degrees Celsius) will trigger an onboard temperature alarm at 25.5 degrees Celsius, resulting in the immediate evacuation of the vehicle from the facility. If over the next 2 hours of monitoring, both with the thermocouple and thermal imaging camera, the temperature begins to stabilize, and there are no visible signs of fire (i.e., smoke), postcrash activities can continue. A measured temperature above 25.5 degrees Celsius, or visible smoke or fire, will result in a poor overall vehicle rating.

WEIGHTING PRINCIPLES FOR OVERALL RATINGS

	Good	Acceptable	Marginal	Poor
Vehicle structure				
Structure and safety cage	0	4	10	20
Driver dummy				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Leg and foot	0	1	4	6
Restraints and kinematics	0	1	4	6
Rear-passenger dummy				
Head and neck	0	2	10	20
Chest	0	—	10	20
Thigh	0	2	6	10
Restraints and kinematics	0	2	6	10
Total score	**0–5**	**6–10**	**11–24**	**> 24**

REFERENCES

Eppinger, R., Sun, E., Kuppa, S., & Saul, R. (2000, March). *Supplement: Development of improved injury criteria for the assessment of advanced automotive restraint systems - II*. National Highway Traffic Safety Administration.

Insurance Institute for Highway Safety. (2014, September). *Moderate overlap frontal crashworthiness evaluation: Guidelines for rating injury measures*.

Mertz, H. J., Irwin, A. L., & Prasad, P. (2016). Biomechanical and scaling basis for frontal and side impact injury assessment reference values. *Stapp Car Crash Journal*, *60*, 625–657.

U.S. Federal Motor Vehicle Safety Standard No. 301, Fuel system integrity, 49 C.F.R. § 571.301 (2017). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571/subpart-B/section-571.301

U.S. Federal Motor Vehicle Safety Standard No. 305, Electric-powered vehicles: Electrolyte spillage and electrical shock protection. 49 C.F.R. § 571.305 (2019). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571/subpart-B/section-571.305

APPENDIX A: CALCULATING THE DYNAMIC BELT POSITION

The belt pressure impression from the pressure sensor is combined with the pretest data from a coordinate measurement machine (CMM) to locate the dynamic belt position on the rear-passenger dummy's thorax.

The dynamic belt position is defined as the vertical distance from the chest potentiometer to the center of the dynamic belt path. The dynamic belt path is obtained by a regression equation identifying the center of the belt impression.

Dynamic belt position is calculated at two instances: at maximum chest deflection and at the maximum dynamic belt position. The belt position at maximum chest deflection reflects the dynamic belt position approximately at the time of the maximum compression recorded by the chest potentiometer. The maximum dynamic belt position refers to the highest belt position on the dummy's thorax prior to rebound, when a belt impression can be seen in the pressure sensor data. In some cases, these two positions can be identical. Three independent dynamic belt position calculations are performed, and the lowest result of the three is used for ratings. All the measurements are recorded in the dummy-thorax coordinate system (IIHS, 2023; Appendix).

The procedure for calculating belt positions is similar for both instances and is as follows:

1. The output file from the pressure sensor is checked for any loss of data, errors, etc. The appropriate frame for consideration is identified in the pressure sensor software (XSensor HSI or equivalent) (Figure A1).

2. For each sensel (individual 5×5-mm pressure sensor element) that registers pressure, the corresponding Z-axis location (Figure A2) is obtained from the pretest CMM data.

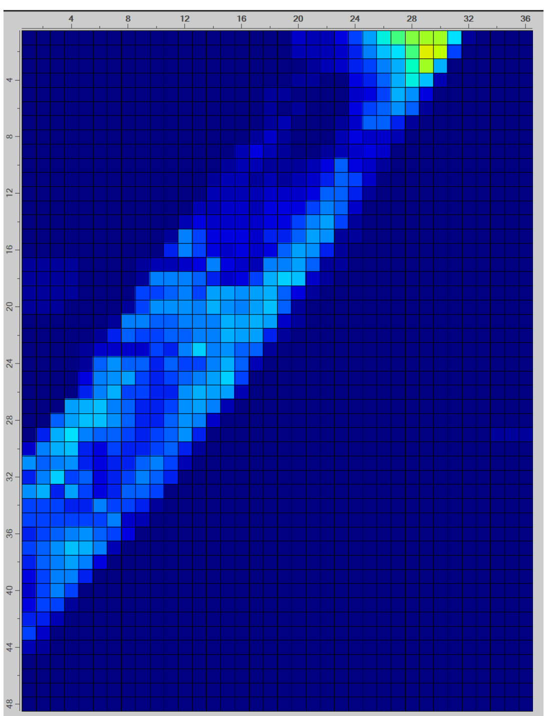


Figure A1. Belt pressure impression output from pressure mat at the frame in consideration

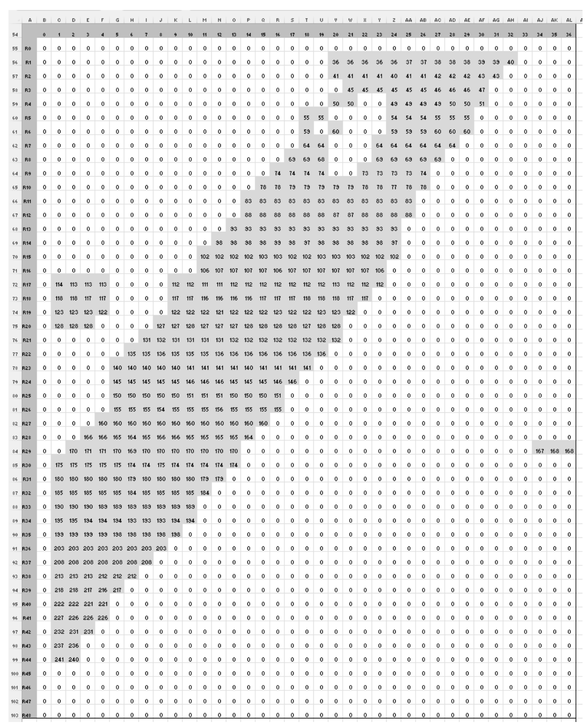


Figure A2. Corresponding Z-axis location of each sensel registering pressure (highlighted in grey)

3. The belt path is calculated by identifying the center of the belt impression for each column at this frame. The following guidelines are used to accurately calculate belt path:

   3.1 To avoid errors in calculation, the belt path center is calculated only in the columns where the complete width of the belt is visible (Figure A3).

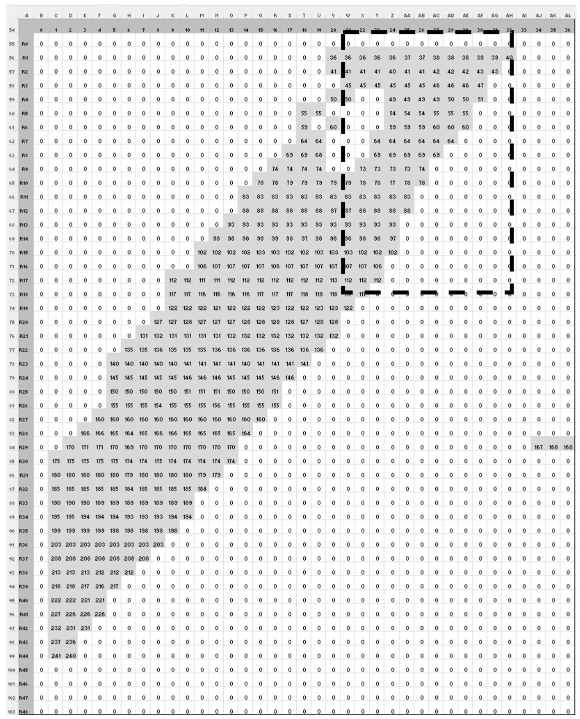


Figure A3. Belt path center is not calculated in highlighted columns because of missing top edge of belt

3.2 In columns where the midpoint of the belt is being calculated, pressure registered by contacts other than belt loading (Figures A4, A6) is removed by either increasing the pressure threshold (in the HSI software, Figure A5) or by manually editing the respective sensel values to zero (Figure A7). If the external contacts cannot be distinguished from the belt path in the identified frame, the nearest time frame where the external contacts can be distinguished is considered.

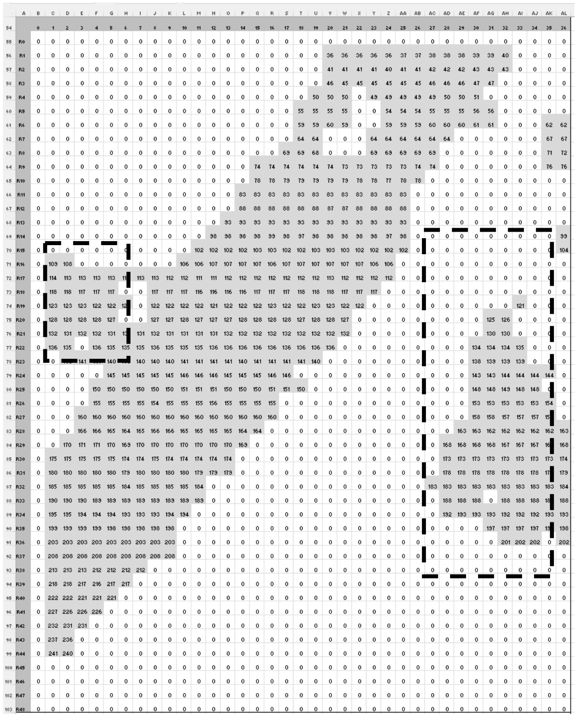


Figure A4. Pressure registered by contacts other than belt loading

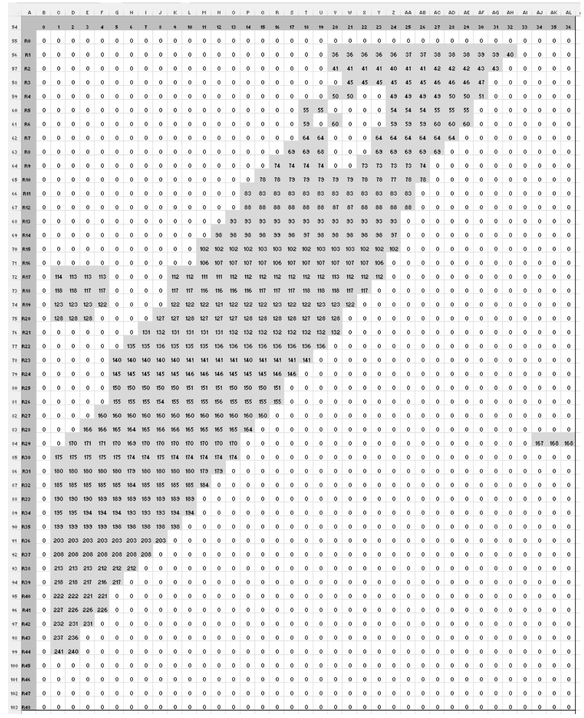


Figure A5. Increasing the pressure threshold to remove pressure registered by other contacts

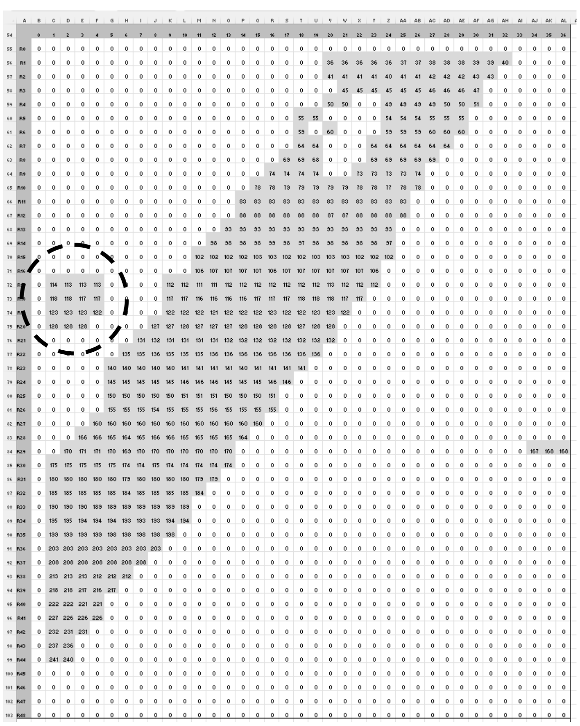


Figure A6. Pressure registered by sensels other than belt loading

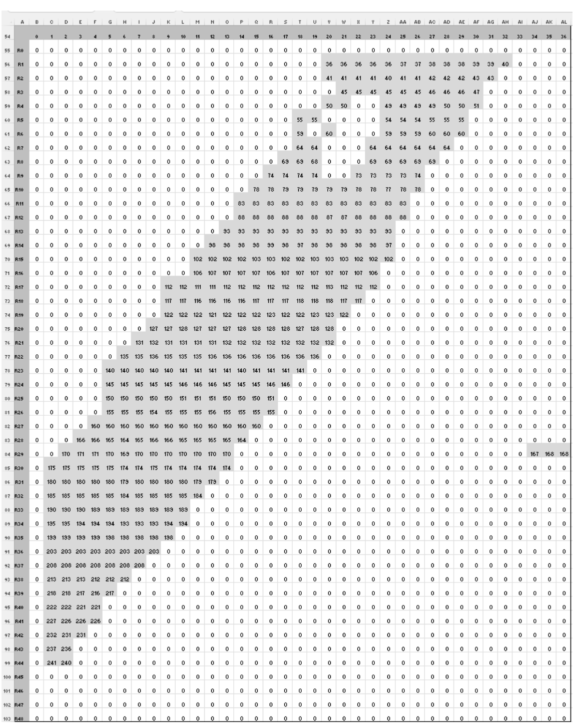


Figure A7. Manually removing the pressure registered by sensels

3.3 In some cases, there can be sensels along the belt path that register zero pressure (Figure A8). These sensels are manually edited to calculate the accurate belt path (Figure A9).

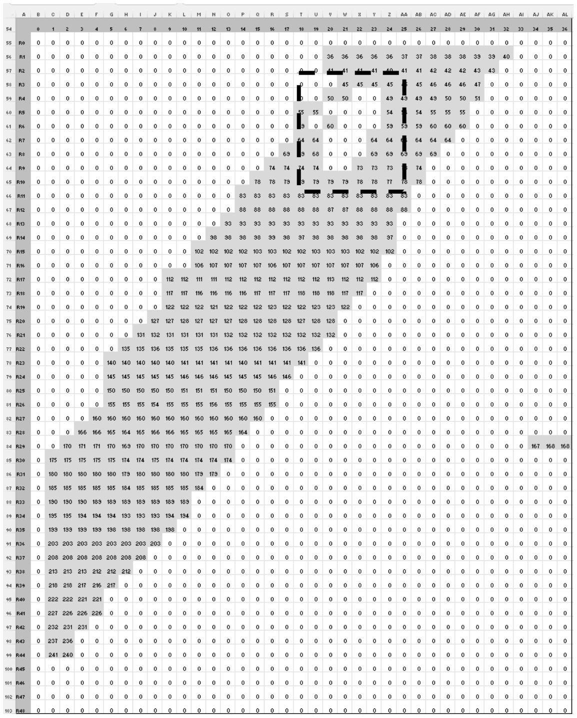


Figure A8. Sensels along the belt path that register zero pressure

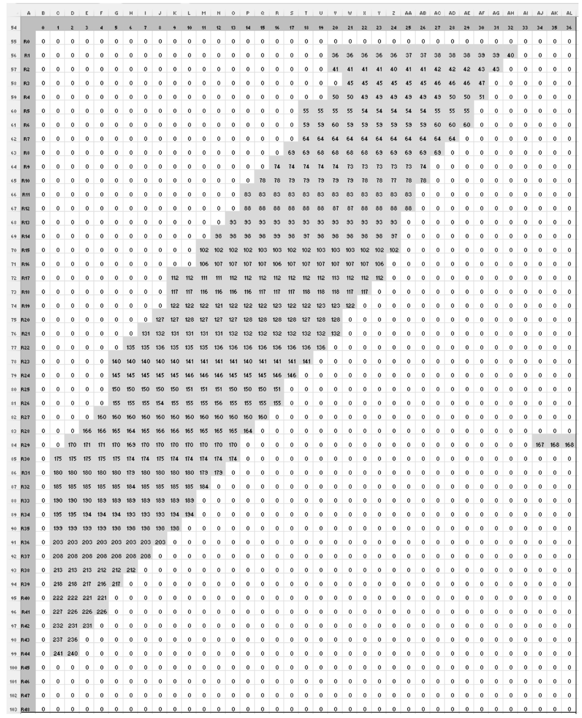


Figure A9. Manually editing sensels to calculate the accurate belt path

3.4 The center of each column is calculated to identify the centerline of the dynamic belt path (Figure A10).

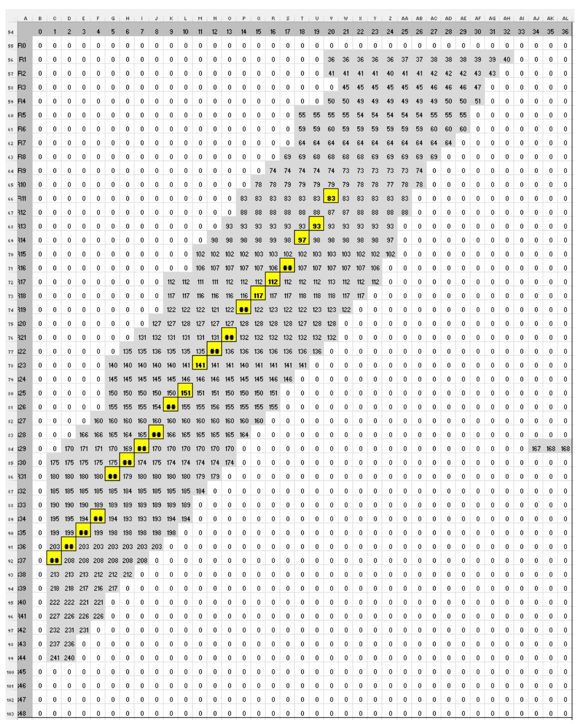


Figure A10. The centerline of the dynamic belt path (indicated by the highlighted [yellow] sensels)

4. A regression equation is created by using the belt path points identified in step 3. This regression equation is then used to calculate the dynamic belt position by interpolation.

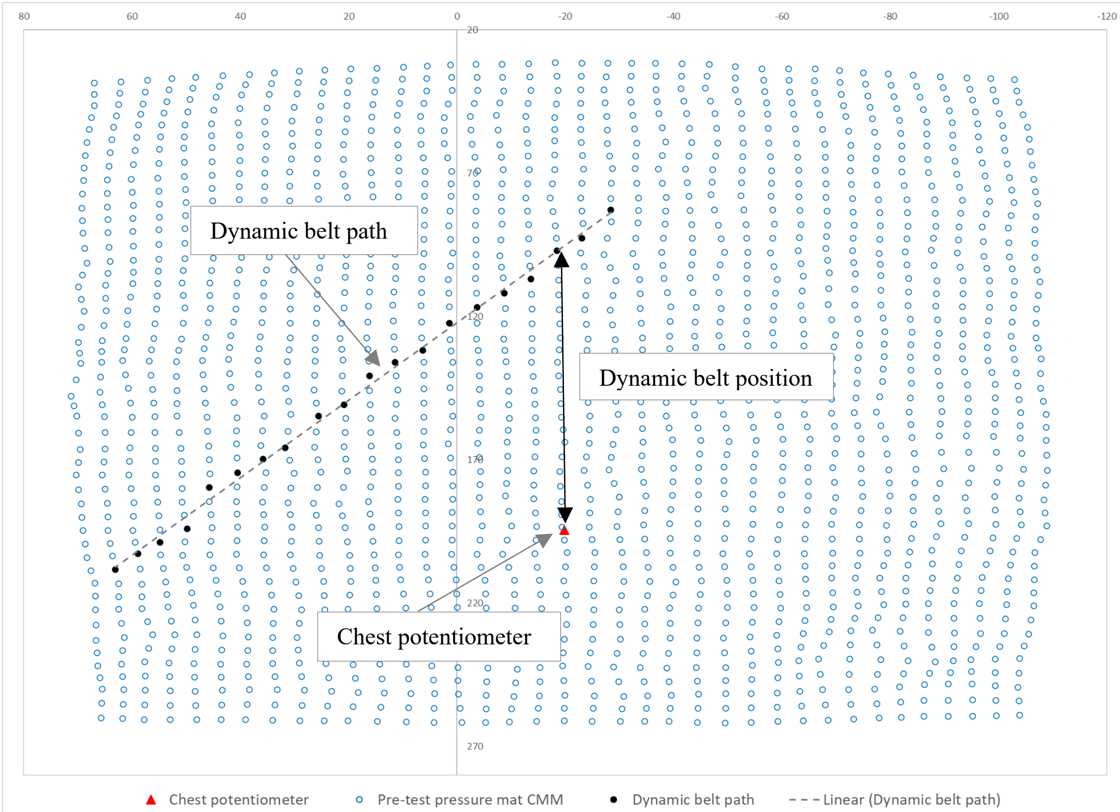


Figure A11. Calculating the dynamic belt position

References (Appendix A)

Insurance Institute for Highway Safety. (2023). *Moderate overlap frontal crashworthiness evaluation 2.0 crash test protocol (Version I)*.

APPENDIX B: CALCULATING THE CAMERA PARALLAX ERROR

The leading edge of two vertical excursion lines placed on the interior rear left door and on the camera located at the rear-passenger door (camera K, Figure B2) are used for judging head excursion (Figure B1).

Camera K is aligned 50 ± 5 mm longitudinally behind the front-seatback line. In this standard position, any camera parallax error would be approximately constant between tests and is not considered when judging head excursion. In cases where it is not possible to align the camera K 50 ± 5 mm behind the seatback line, the camera parallax error is calculated using the formula below and the guidelines in Table B1 are followed while judging head excursion.

Figure B1

Vertical excursion lines used for judging head excursion

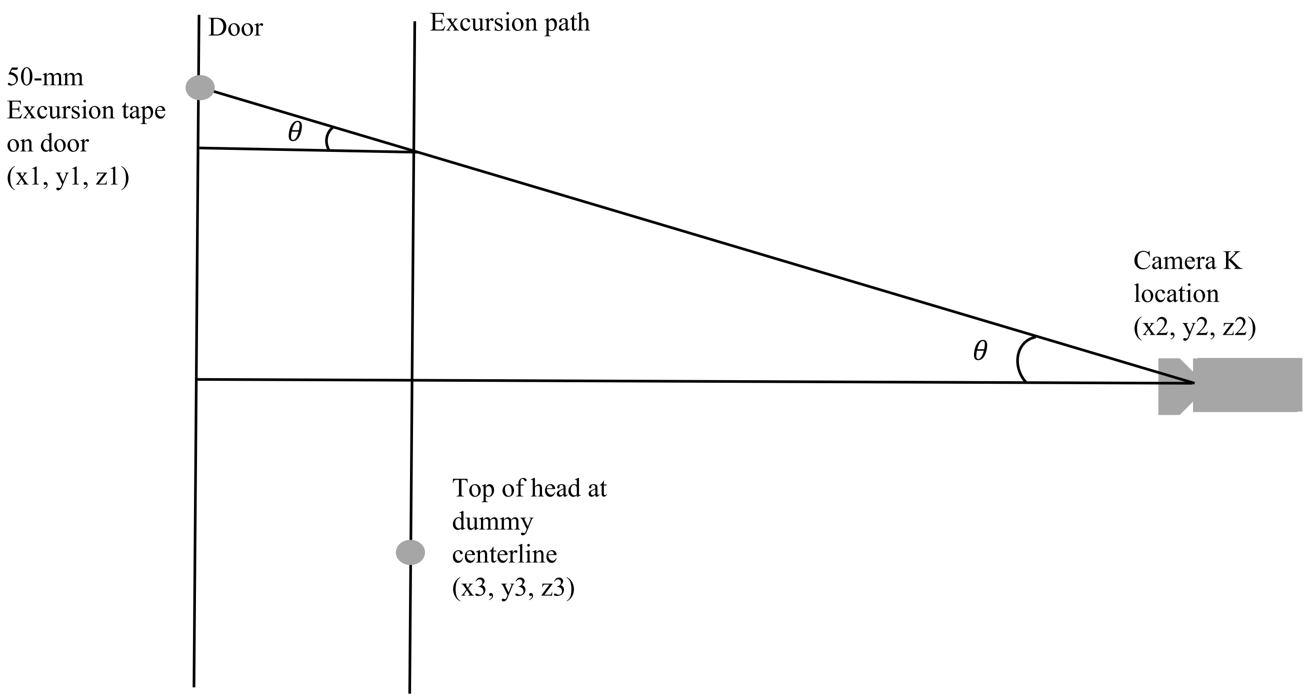
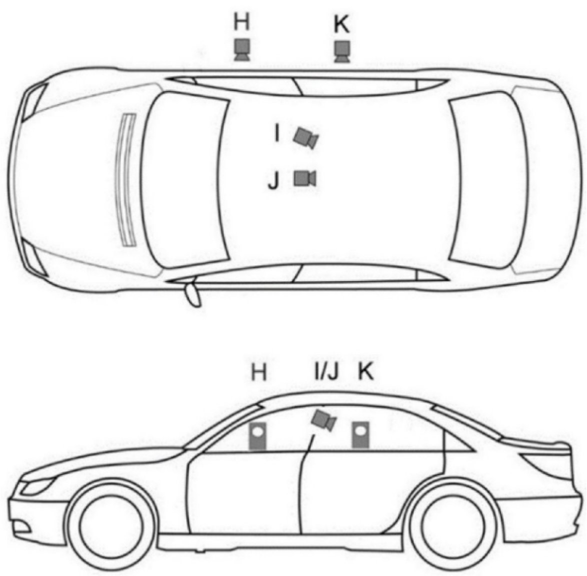


Figure B2
Onboard high-speed camera positions



Formula for calculating the parallax error

$$Error = (y_3 - y_1) \times tan\,\theta$$

$$where\ \theta = tan^{-1}\left(\frac{x_2 - x_1}{y_2 - y_1}\right)$$

Table B1
Parallax error while judging excursion

Calculated camera parallax error (mm)	Error considered while judging excursion mm (inch)
<= 5	0
6–20	12.7 (0.5 inch)
21–30	25.4 (1 inch)