TECHNICAL REPORT

ISO/TR 12350

Second edition
2013-10-01

Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

Véhicules routiers — Courbes de risques de blessures pour l'évaluation de la protection des occupants en choc latéral

Reference number
ISO/TR 12350:2013(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems.*

This second edition cancels and replaces the first edition (ISO/TR 12350:2004), which has been technically revised.

Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

1 Scope

This Technical Report provides injury risk curves to assess occupant protection in side impact tests. The curves are given for the WorldSID 50th, a mid-size adult male side impact dummy. Injury risk curves for other side impact dummies could be added as soon as the necessary material is available and processed as described in this Technical Report. These dummies are used during tests carried out according to ISO 10997 or which are under investigation by regulatory bodies and consumer testing organizations.

2 Methodology

2.1 Selection of PMHS sample to be used for the construction of the injury risk curves

An in-depth review of the postmortem human subjects (PMHS) tests available in the literature and in the NHTSA database (http://www-nrd.nhtsa.dot.gov/database/aspx/biodb/querytesttable.aspx) was performed. The listed tests were analysed in order to determine if they could be accurately repeated with dummies and included in the construction of injury risk curves.

This clause summarizes the series of tests that were conducted by body region and type of loading. Reasons for including or excluding each particular test series are detailed. The PMHS characteristics are provided in the form of related electronic documents available through the ISO website and detailed in Clause 4. The detailed descriptions of the PMHS configurations allowing the reproduction of the test with a dummy are presented in Annex A to Annex F, as well as the reasons for inclusion or exclusion.

The rigid and padded head impactor tests conducted by Calspan[18] were included and are detailed in Annex A. The head impactor tests of the Highway Safety Research Institute (HSRI)[51] were excluded because the impact speeds were not known. The head impactor tests of the University of Michigan Transportation Research Institute (UMTRI) (NHTSA database) were excluded because the impactor characteristics were not known.

The whole body drop tests with head impact conducted by Wayne State University (WSU)[22], those conducted by the Association Peugeot-Renault (APR) without helmet, and the head drop tests conducted by Medical College of Wisconsin (MCW)[56] were included and are detailed in Annex A. The whole body drop tests with head impact conducted by APR with helmet were excluded because the helmet properties were unknown.

The shoulder impactor tests performed by APR[2], INRETS[14] [15] [17], and WSU[26] [30] were included. The shoulder impactor tests conducted by Ohio State University (OSU) on a rigid bench were also included[3] [4]. These configurations are detailed in Annex B. The oblique shoulder impactor tests performed by OSU on a 1996 Ford Taurus seat were excluded because the characteristics of the seat were unknown.

All, but one, of the thorax impactor tests conducted by HSRI[43] [44] [45] were included. The single-impact WSU thorax impactor test[54] [55] was also included. The UMTRI[34] [35] and OSU[49] thorax impactor tests were included when the level of load was deemed to be below the threshold of rib fracture (700 N), such that the fractures could be attributed to the final high-speed impact. These test configurations are detailed in Annex C. The 76T038 HSRI test was excluded because the data were questionable. The HSRI tests 77T079 and 77T080 were excluded because it does not seem realistic to have 18 rib fractures for 2 165 N of impact force. All the WSU and INRETS[16] multi-impact tests, as well as some UMTRI tests (83E085, 83E086, 83E106, 83E107, 83E108) and OSU tests (0505OTH25L01, 0505LTH25R01, 0506OTH25R01, 0506LTH25L01, 0601LTH25L01, 0601OTH25R01), were excluded because it was not possible to determine which impact caused each injury.

Only one of the abdomen impactor tests performed by WSU[54] [55] (WSU063-34) was included because all the other subjects were impacted more than once in the abdomen and/or thorax. All the OSU abdomen impactor tests but two (93VRTAB08, 93VRTAB09) were included. These two tests were excluded because the abdomen deflection exceeded the target level of 16 % of the chest breadth. The test configurations are detailed in Annex D.

The Laboratory of Accidentology and Biomechanics (LAB) abdomen impactor tests[52] were excluded because a measurement system was positioned at the level of the liver and could have influenced the abdominal injuries.

Most of the reviewed pelvis impactor tests were multi-impact tests. The pelvis impactor tests performed by WSU[54] [55], UMTRI[33] [36], ONSER[11] [12], and INRETS[5] [6] were included when an increase in impactor speed was accompanied by an increase in energy for a given PMHS, as this was assumed to be an indication of no injury. The configurations are detailed in Annex E. Two UMTRI tests (83E087, 83E109) were conducted with an APR pad that is no longer available. The ONSER multi-impact tests C3, C4, D3, E2, F2, F3, H4, H5, I6, J2, J3, N7, S3, S4, X1, X2, Y2, Z1, and Z2 were excluded because there was a possible weakening of the pelvis bone.

APR conducted lateral drop tests with PMHS[2] [53]. A review of the films failed to confirm the position of the subjects' lower extremities and whether or not an impact surface was provided to catch the lower extremities. The test films revealed that some tests were conducted with the subjects' head, some were conducted without the head, and for the others, the film coverage did not reveal if the head was attached or removed. Some subjects were observed to rotate during the free fall. For these reasons, and because the APR padding cannot be reproduced, all of the whole body drop tests were excluded from the construction of injury risk curves for the thorax, abdomen, and pelvis.

Some sled tests performed by Heidelberg[25] [29], MCW/OSU[39] [40] [28] [27], and WSU[7] [8] [9] [10] [23] were included and are detailed in Annex F. Several checks were done to select the PMHS to be included in the construction of the injury risk curves. The checks are detailed in Annex G.

— The position of the PMHS at the time of impact was first checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU tests (SC126, SC105, SC131) were then excluded.

— The consistency between the thorax-pelvis transmissibility and the contact times of the thorax and pelvis plates were also checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU (SC126, SC105) were then excluded.

— The total momentum was checked. Tests for which the total momentum differed from other tests with the same impact wall configuration were excluded (MCW/OSU SC131).

— The absence of shoulder interaction with the wall was checked in the MCW/OSU configuration. Sled tests with PMHS seating height under 826 mm and shoulder interaction with the wall observed on the film were excluded from the shoulder, thorax, and abdomen injury risk curves (MCW/OSU SC137, SC138, SC119, 94LSI32P04, LSI32R08, SC30A102).

— PMHS characteristics were checked. The PMHS having sternotomy wires were excluded because the PMHS response and injuries were questionable (MCW/OSU SC122, SC132, LSI32P11, SC103, SC112, SC30A103, SC20A101).

— PMHS injuries were checked. PMHS from the MCW/OSU SC114 test with a right hemithorax, which could have resulted from secondary impact, was excluded.

— Some of the checks required the analysis of the wall plates loads. Some tests were excluded because the impact wall was not instrumented with load cells or because the data were questionable and then the checks could not be done. This was the case for the HSRI sled tests[31], the first test series conducted by WSU (NHTSA database), some Heidelberg tests (H82009, H80011, H80013, H80014, H80017, H80024, H81002, H81004, H81006, H81016, H81022, H81025, H81027, H82002, H82020, H80018, H80020, H80021, H80023, H81011, H81012, H81015, H81021, H83008, H83016, H83021, H83030, H83031), as well as some MCW/OSU sled tests (98LSI32R17, SC106, SC127, 96LSI32R07, SC123).

— Finally, sled tests for which the impact wall padding or the airbag was no longer available were excluded (Heidelberg tests H82008, H82021, H82022, H83008, H83016, H83021, H83030, H83031, H83011, H83020, H84008, H83010, H83012, HSRI tests 76T029, 76T034, 76T039, 76T042, MCW/OSU tests SAC 101, SAC 103, SAC 104, SAC 105, WSU 2nd test series SIC-09, SIC-10, SIC-11, SIC-12, SIC-13, SIC-14, SIC-15, SIC-16, SIC-17).

— The severity of PMHS injuries were coded according to the Abbreviated Injury Scale 2005[1]. Table 1 summarizes the body regions and injury severity levels for which PMHS data are available to construct injury risk curves. There were no AIS ≥ 3 shoulder injuries from the PMHS tests. Therefore, injury risk curves for the shoulder can only be constructed for the AIS ≥ 2 level of injury. For the thorax, abdomen, and pelvis, injury risk curves were constructed at the AIS ≥ 3 injury level and either the AIS ≥ 2 or AIS ≥ 4 level if the PMHS injury/no injury results were better balanced at these AIS levels. Note that all rib fractures are coded in thoracic skeletal AIS, including those that resulted from abdominal impacts.

Table 1 — Body regions and AIS levels for which injury risk curves are constructed

Body region	AIS levels used in the injury risk curve construction
Head	AIS ≥ 3
Shoulder	AIS ≥ 2
Thorax (skeletal)	AIS ≥ 3 and AIS ≥ 4
Thorax (soft tissue)	AIS ≥ 2 and AIS ≥ 3
Abdomen	AIS ≥ 2 and AIS ≥ 3
Pelvis	AIS ≥ 2 and AIS ≥ 3

2.2 Dummy data

Once the PMHS sample to build the injury risk curves is selected, the dummy results reproducing these PMHS test configurations are collected.

The injury risk curves are proposed in this Technical Report for a 50th percentile male dummy. Only WorldSID 50th percentile results are presented in the current version of this Technical Report. It is intended to add injury risk curves for the WorldSID 5th percentile adult female dummy to a future edition of the ISO/TR 12350. There are no plans to add injury risk curves for the ES-2 or ES-2re, and it is not appropriate to use the WorldSID injury risk curves with measures from either ES-2 or ES-2re.

The dummy test results reproducing the PMHS test configurations selected for the injury risk curve construction are presented in Annex H. The build level of the production version used was not provided with the results. It is to be noted that there was no head result available. Moreover, the shoulder deflection was only available for the impactor test and not for the sled test configurations.

The test results presented in Annex H are filtered data (according to Reference[50] and according to filters indicated in Annex H) that have not been scaled and should not be used directly to construct dummy-specific injury risk curves.

The PMHS used in the biomechanical tests described in Annex A to Annex F were generally not mid-size adult males. Ideally, the test condition for the dummy tests should be scaled such that the test poses an equally severe impact as the individual PMHS test. However, many of the dummy tests used in this Technical Report were conducted at the same velocity and the same impactor mass as the PMHS tests. It is therefore necessary to scale the results of the dummy tests before they are paired with the PMHS injuries. The dummy data from impactor tests, drop tests, and sled tests were scaled using the formulae included in Annex I. The scaled dummy data are included in Annex A to Annex F.

2.3 Age adjustment

The injury risk curves are provided with age adjustment. It is out of the scope of this Technical Report to recommend an age to be used. The injury risk curves can be built for any age using the formulae included in Table 5. However, the quality index cannot be computed from these formulae. As it was not possible to include the quality index for all ages, only two ages were considered. As indicated in Petitjean et al. (2009), the injury risk curves were constructed for a dummy representing a 45-year-old male, as this age has been used previously to represent the average age of an adult male in the field data. The injury risk curves were also constructed for median age of the PMHS included in the samples available for the construction of the WorldSID 50th injury risk curves (67 years old). This latest age was used because it provides the values with the higher confidence because the PMHS data are mostly around that age.

2.4 Statistical analysis

Guidelines for the construction of the injury risk curves were agreed on within ISO/TC 22/SC 12 (Resolution 2, N851).

The guidelines include several steps.

2.4.1 Step 1: Collect the relevant data

The first step is to collect the relevant data, including injuries and injury criterion.

According to the methodology developed in this Technical Report, relevant data corresponded to the paired PMHS injuries and scaled dummy measurements from tests performed in similar configurations.

2.4.2 Step 2: Assign the censoring status (left, right, interval censored, exact)

Once the biomechanical data were available, the censoring status was assigned (left, right, interval censored, exact). After this step, the dataset included one column with the injury criteria values associated with the censoring status indicated in a second column.

2.4.3 Step 3: Build the injury risk curve with the Consistent Threshold Estimate (CTE)[37] and check for dual injury mechanism

The step function was visually investigated in order to detect potential change in slope corresponding to different injury mechanisms.

2.4.4 Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

2.4.5 Step 5: Estimate the parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method

2.4.6 Step 6: Identify overly influential observations using the dfbetas statistics

The overly influential observations were identified using the dfbetas statistics.

2.4.7 Step 7: Check the distribution assumption graphically using a qq-plot or the CTE method

2.4.8 Step 8: Choose the distribution with the best fit, based on the Akaike information criterion (AIC)

The distribution with the lowest AIC among the three distributions was selected.

2.4.9 Step 9: Check the validity of the predictions against existing results (such as accidentology outcome), if available

2.4.10 Step 10:

— Step 10.1: The 95 % confidence intervals of the injury risk curve were calculated with the normal approximation of the error.

— Step 10.2: The relative sample size of the confidence interval was defined as the width of the 95 % confidence interval at a given risk relative to the value of the stimulus at this same risk. They were calculated at 5 %, 25 %, and 50 % risk.

2.4.11 Step 11: Provide the injury risk curve associated with the quality index based on the relative sample size of the 95 % confidence interval

A scale of quality indexes based on the relative sample size was defined with four categories ("good" from 0 to 0,5, "fair" from 0,5 to 1, "marginal" from 1 to 1,5, "unacceptable" over 1,5). The injury risk curves associated with the quality indexes were provided. The scale was determined using biomechanical samples in order to distribute injury risk curves in the four categories. Illustrations for one example of each class of quality index are provided in Table 2.

Table 2 — Illustrations of the width of the 95 % confidence interval for an injury risk curve for each of the quality indexes

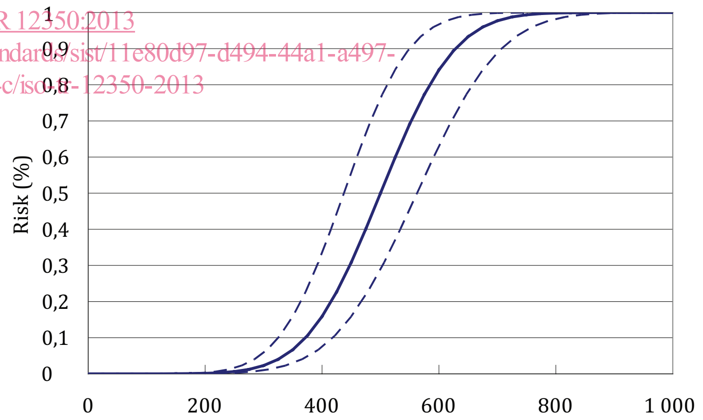
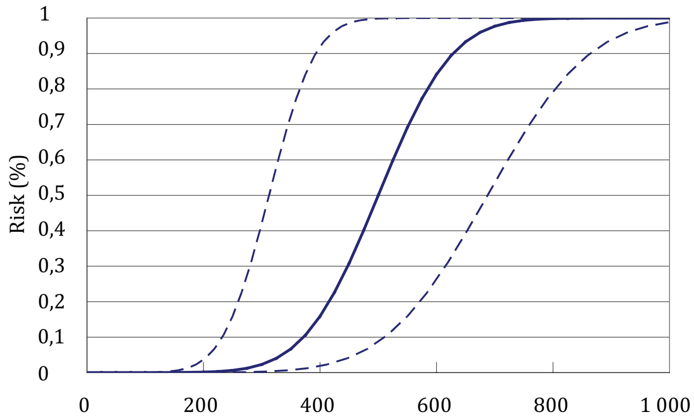
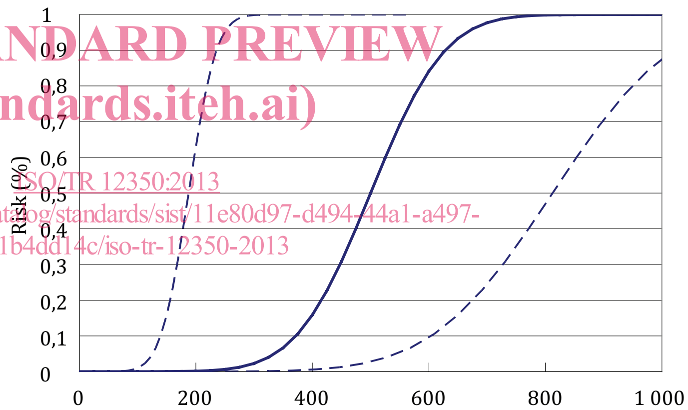
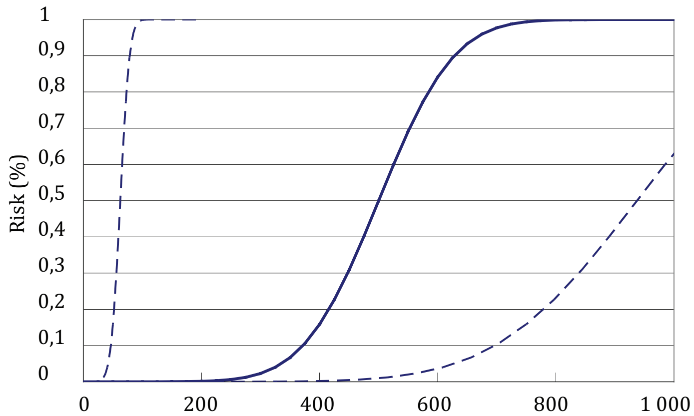
Quality index	Width of the confidence interval at that particular risk divided by the criterion value at that risk	Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)
Good	0-0,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,25

Table 2 *(continued)*

Quality index	Width of the confidence interval at that particular risk divided by the criterion value at that risk	Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)
Fair	0,5-1	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,75
Marginal	1-1,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,25
Unacceptable	>1,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,75

2.4.12 Step 12: Recommend one curve per body region, injury type, and injury level

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

— Step 12.2: If an injury risk curve had an “unacceptable” quality index, it should not be recommended.

— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The recommended injury thresholds should be provided with their associated quality indexes.

3 Injury risk curves for the WorldSID 50th

The injury risk curves were constructed by correlating the dummy responses to the PMHS injuries in the same test configurations.

The injury risk curves were built with the following steps:

Step 1: Paired PMHS injuries and dummy measurements were collected, after having selected the PMHS sample and checking the dummy data.

Step 2: The censoring status was assigned to each pair depending on if it was left, right, interval censored, or exact. The WorldSID 50th injury risk curves were computed with the R software[42]. With the R software, the right, exact, left, and interval censored data are coded 0, 1, 2, and 3 respectively.

Step 3: The injury risk curve should be built with the Consistent Threshold Estimate (CTE)[37] in order to check for dual injury mechanism.

Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into different classes of age before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so dual injury mechanisms were not checked for the WorldSID 50th.

Step 5: The parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method were estimated (see Table J.1).

Step 6: The overly influential observations were identified with the dfbetas test (see Table J.2 to Table J.7). These observations were checked for any specificity. As there was no evidence of difference between these observations and the others included in the sample, these observations were kept in the construction of the injury risk curve.

Step 7: The distribution assumption should be checked graphically using a qq-plot or the CTE method. However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into age classes before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so distribution assumption was not checked in this Technical Report.

Step 8: The distribution with the best fit, based on the Akaike information criterion (AIC), was chosen (see Table J.1 and Table 3).

Step 9: Check the validity of the predictions against existing results (such as accidentology), if available. In the case of the WorldSID 50th, there was no prediction to be validated.

Step 10: The 95 % confidence intervals were calculated, as well as the relative sample size of the confidence interval (width of the confidence intervals at 5 %, 25 %, and 50 % relative to the value of the stimulus at 5 %, 25 %, and 50 % of risk, respectively) (see Table J.8).

Step 11: The injury risk curves were provided with their associated quality indexes based on the relative sample size of the confidence interval (see Table 4).

Step 12: Recommend one curve per body region, injury type, and injury level.

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

The samples that could be compared were those with the same PMHS sample and the same level and type of injury. The AIC were then compared between:

— the skeletal risk AIS3+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the skeletal risk AIS4+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the abdomen risk AIS2+ as a function of the maximum abdomen rib deflection and viscous criterion, as well as of the lower spine Y acceleration 3 ms;

— the abdomen risk AIS3+ as a function of the maximum abdomen rib deflection and viscous criterion.

There was no comparison possible for the shoulder and pelvis injury risk curves.

Table 3 — AIC values for the WorldSID 50th injury risk curves

Injury risk	WorldSID measurement	AIC
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	24,883 7
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	29,691 1
Skeletal thoracic AIS4+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	29,735 4
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	30,650 7
Abdomen AIS2+	Maximum abdomen rib deflection (measured by 1D IR TRACC) (mm)	14,988 9
	Maximum abdomen rib VC (measured by 1D IR-TRACC)(m/s)	14,977 7
	Lower spine Y acceleration 3 ms (m/s^2)	27,576 8
Abdomen AIS3+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	11,959 1
	Maximum abdomen rib VC (measured by 1D IR-TRACC) (m/s)	11,869 6

Based on the comparison of the AIC values (see Table 3), the skeletal thoracic risks AIS3+ and AIS4+ were recommended to be predicted as a function of the maximum thoracic rib deflection rather than as a function of the maximum thoracic rib vital capacity (VC). The abdomen risks AIS2+ and AIS3+ were recommended to be predicted as a function of the maximum abdomen rib deflection or VC rather than as a function of the lower spine Y acceleration 3 ms.

— Step 12.2: If an injury risk curve had an "unacceptable" quality index, it should not be recommended.

There was no "unacceptable" quality index for the shoulder, abdomen, and pelvis injury risk curves AIS2+ (see Table J.8). For the skeletal thoracic risk as a function of the maximum thoracic deflection, the 50 % AIS4+ risk for a 45-year-old occupant was "unacceptable". All the thoracic soft tissue injury risk curves were "unacceptable" at 5 % risk. All the abdomen injury risk curves AIS3+ were "unacceptable". This was probably due to the very limited number (only one) of AIS3+ cases. Among the pelvis injury risk curves AIS3+, the curve as a function of the pelvis Y acceleration 3 ms for a 45-year-old occupant was "unacceptable".

— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The shoulder injury risk AIS2+ could still be predicted by the maximum shoulder rib deflection or by the maximum shoulder **Y** force. The available sample for the construction of the injury risk curve as a function of the maximum shoulder deflection was composed of impactor tests only. On the other side, the available sample for the construction of the injury risk curve as a function of the maximum shoulder **Y** force was composed of impactor tests, as well as sled tests. The injury risk curve as a function of the maximum shoulder **Y** force was recommended because the sample was composed of impactor tests, as well as sled tests.

The abdomen soft tissue injury risk AIS2+ could be predicted by the maximum abdomen rib deflection or by the maximum abdomen rib VC. The injury risk curve as a function of the maximum abdomen rib deflection was recommended as the quality indexes associated with this curve were better.

The pelvis injury risk AIS2+ could be predicted by the maximum pubic force or by the pelvis Y acceleration 3 ms. Most of the injuries observed in the PMHS tests used to build the injury risk curves were related to ilio-ischio rami and pubic symphysis. It was then recommended to predict the risk as a function of the pubic force, as this dummy measurement was the more closely related to these injuries.

The recommended injury thresholds should be provided with their associated quality indexes.

It is out of the scope of this Technical Report to recommend a probability of risk as a limit to be respected. However, the dummy measurement values corresponding to all the probabilities cannot be provided in a table. As a consequence, the dummy measurement values are given for a few levels of risk. The values at 5 % risk are provided because the risk is close to the Injury Assessment Reference Values (IARV). It was also decided to provide the injury thresholds for the 25 % and 50 % risk because values used in regulations can reach those levels (as for example, the limit for the thorax compression criterion in the regulation ECE/R94). These injury thresholds associated with their quality indexes are provided in Table 4 for the WorldSID 50th. Other injury thresholds could be calculated using the estimated parameters of the survival analysis of the recommended injury risk curves given in Table 5.

Table 4 — WorldSID 50th recommended injury thresholds with its quality index

	5 % risk (quality index)	**25 % risk (quality index)**	**50 % risk (quality index)**
shoulder AIS ≥ 2	Maximum shoulder force **Y** adjusted to 67 year old (N)		
	1 594 (good)	2 011 (good)	2 265 (good)
	Maximum shoulder force Y adjusted to 45 year old (N)		
	1 799 (fair)	2 270 (fair)	2 556 (fair)
Skeletal thoracic AIS ≥ 3	Maximum thoracic rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	28,0 (fair)	35,1 (good)	40,2 (good)
	Maximum thoracic rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	38,5 (fair)	48,4 (good)	55,4 (good)
Abdomen AIS ≥ 2	Maximum abdomen rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	37,1 (fair)	45,3 (good)	50,2 (good)
	Maximum abdomen rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	58,9 (fair)	72,0 (fair)	79,8 (fair)

Table 4 *(continued)*

	5 % risk (quality index)	25 % risk (quality index)	50 % risk (quality index)
Pelvis AIS ≥ 2	Maximum pubic force adjusted to 67 year old (N)		
	1 340 (fair)	1 950 (good)	2 361 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	1 818 (fair)	2 645 (marginal)	3 202 (marginal)
Pelvis AIS ≥ 3	Maximum pubic force adjusted to 67 year old (N)		
	1 714 (good)	2 262 (good)	2 605 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	2 214 (marginal)	2 922 (marginal)	3 365 (marginal)

The formulae of the injury risk curves are presented in Table 5.

The risk according to the Weibull distribution is

$$Risk(\%) = 1 - \exp\left[-\left(\frac{Dummy\_measurement}{\exp(\text{int} + PMHS\_age \times coef\_age} \right)^{\frac{1}{\exp(\log\_scale)}} \right] \tag{1}$$

The risk according to the log-normal distribution is

$$Risk(\%) = \log\_normal\_distribution\left[mean = \text{int} + age \times coef\_age, std = \exp(\log\_scale)\right] \tag{2}$$

The risk according to the log-logistic distribution is

$$Risk(\%) = \frac{1}{1 + \exp\left\{ -\left[\ln(Dummy\_measurement) - (\text{int} + age \times coef\_age) \right] / \exp(\log\_scale) \right\}} \tag{3}$$

where

Dummy_measurement corresponds to the dummy measurement;

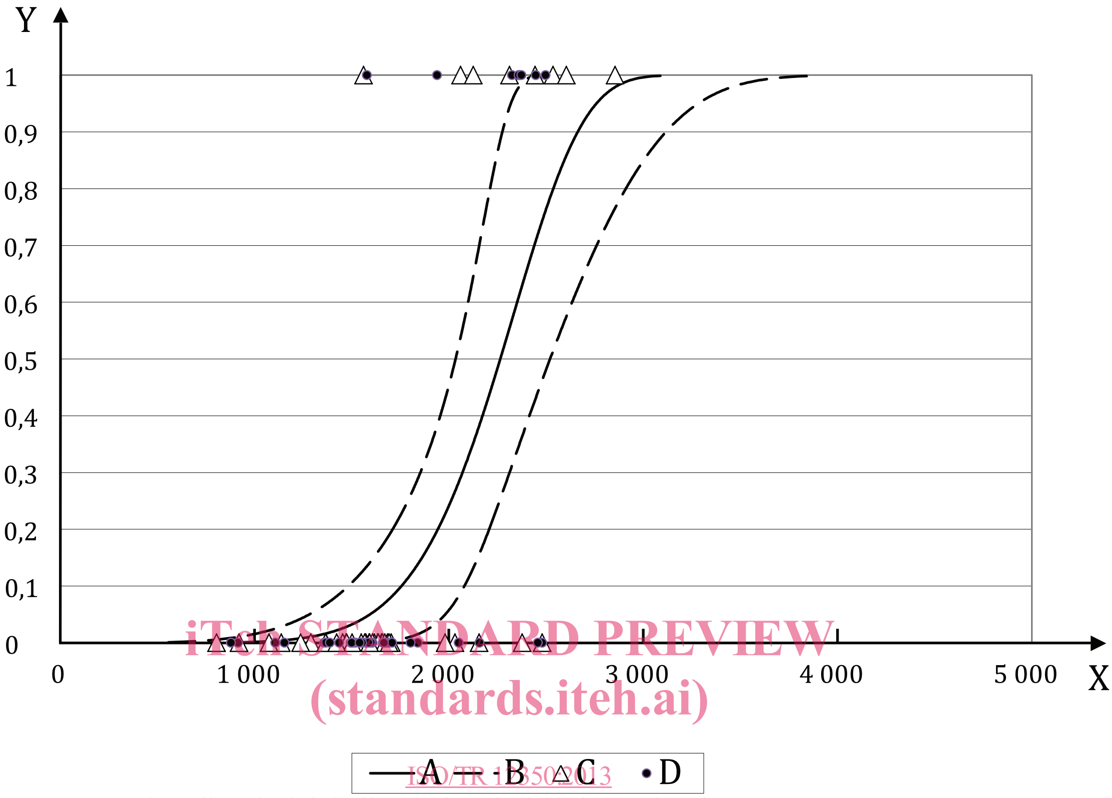
PMHS_age corresponds to the PMHS age.

Table 5 — Formulae of the recommended WorldSID 50th injury risk curves built with the survival analysis

Injury risk	Dummy measurement	Distribution	int	Coef_age	Log_scale
Shoulder AIS2+	Maximum shoulder rib **Y** force (N)	Weibull	8,143 5	−0,005 5	−2,002 8
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) mm)	Log-logistic	4,669 9	−0,014 6	−2,094 5
Abdomen soft tissue AIS2+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	Weibull	5,367 8	−0,021 0	−2,153 1
Pelvis AIS2+	Maximum pubic force (N)	Weibull	8,774 8	−0,013 9	−1,525 9
Pelvis AIS3+	Maximum pubic force (N)	Weibull	8,704 1	−0,011 6	−1,827 4

Injury risk curves for the WorldSID 50th percentile are given in Figures 1 to 10.

Figures 1 and 2 present the shoulder injury risk curves AIS ≥ 2 as a function of the maximum shoulder **Y** force for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum shoulder **Y** force (N)

Y shoulder injury risk AIS2+

A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 1 — Shoulder injury risk curve AIS ≥ 2 as a function of the maximum shoulder Y force adjusted to 67 year old for the WorldSID 50th