

PD ISO/TS 18506:2014



BSI Standards Publication

Procedure to construct injury risk curves for the evaluation of road user protection in crash tests

bsi.

...making excellence a habit.™

National foreword

This Published Document is the UK implementation of ISO/TS 18506:2014.

The UK participation in its preparation was entrusted to Technical Committee AUE/7, Automobile occupant restraint systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2014. Published by BSI Standards Limited 2014

ISBN 978 0 580 83771 5

ICS 43.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2014.

Amendments issued since publication

Date	Text affected
------	---------------

**Procedure to construct injury risk
curves for the evaluation of road user
protection in crash tests**

*Procédure de construction des courbes de risques pour l'évaluation de
la protection des usagers de la route dans les essais de choc*





COPYRIGHT PROTECTED DOCUMENT

© ISO 2014

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword	iv
1 Scope	1
2 Terms and definitions	1
3 Methodology	2
3.1 General.....	2
3.2 Collect the relevant data.....	2
3.3 Assign the censoring status.....	2
3.4 Check for single injury mechanism.....	2
3.5 Estimate the coefficients.....	3
3.6 Identify overly influential observations.....	3
3.7 Check the distribution assumption.....	3
3.8 Choose the best distribution.....	3
3.9 Check the validity of the prediction.....	3
3.10 95 % confidence intervals and its relative size.....	4
3.11 Quality index.....	4
3.12 Recommendation of the injury risk curves.....	4
4 Related electronic documents	5
Bibliography	6

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*.

Procedure to construct injury risk curves for the evaluation of road user protection in crash tests

1 Scope

The aim of this Technical Specification is to provide a procedure to develop injury risk curves for biomechanical samples. These samples are often heavily censored and limited in size, such that specific steps and checks are required when developing injury risk curves. Moreover, several statistical methods were historically used to build injury risk curves. The curves resulting from the different methods could be rather close or fairly different, depending on the biomechanical samples. It is therefore of major importance to recommend a consensual method to be used. Otherwise, injury thresholds candidates to be included into regulations could be highly influenced by the statistical method used. These different methods were compared in a statistical simulation study^[10]. The conclusions of this study were used to recommend the survival analysis.

This Technical Specification identifies steps to be followed to develop injury risk curves. It recommends preliminary checks, statistical method, and recommendation process of the injury risk curve. Guidelines on the type of the samples to be used (cadaver, animal, or dummy), as well as the variables to be used, and the injury severity level are beyond the scope of this Technical Specification.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1

injury risk curve

curve giving the probability, for a defined population and for a given input, to sustain a specified severity of injury

2.2

injury risk function

mathematical function that relates a value of an injury criterion and possible additional factors (variables) to a risk of sustaining an injury of a certain level

2.3

injury criterion

physical parameter which correlates well with a scale of injury severity of the body region under consideration

2.4

injury value

value of an injury criterion

2.5

injury mechanism

mechanical behavior leading to an injury

2.6

abbreviated injury scale

AIS

scale allowing for the classification of injury severity

2.7

variable

parameters which contribute to the prediction of the injury severity

3 Methodology

3.1 General

An injury risk curve corresponds to a statistical modelling of biomechanical data in order to predict the risk of injury. Some general steps are required, as for any statistical model. The modelling includes the choice of the variables to be used in the model. The choice of the model is also of major importance. Once done, the variables of the model are estimated. Essential further steps are to check the assumptions of the model and evaluate the model fit relative to the data used. The prediction is finally made possible when the checks are done.

3.2 Collect the relevant data

The first step is to collect the relevant data, including injury types and severities, and injury values measured during the tests.

There is no specification for the injury severity level (AIS ≥ 2 , AIS ≥ 3) or the type of injuries evaluated (fracture, soft tissue contusion, etc.).

The data could also include variables such as the Post Mortem Human Subject (PHMS) characteristics (age, bone mineral content, gender, etc.).

The choice of the variables to be included in the construction of the injury risk curves is out of the scope of the guidelines. The researcher's expertise should guide this decision and is expected to vary depending on the body region and injury mechanism considered.

3.3 Assign the censoring status

Once the biomechanical data are available, the censoring status must be assigned (left, right, interval censored, exact).

Data are left-censored or right-censored if the measured injury value is greater than or less than the injury threshold, respectively. The injury threshold is the minimum value that is associated with the occurrence of injury for that subject. Data are interval-censored when the injury threshold is bounded within a known range of injury values.

The censoring status can be provided by a coding which might differ from one statistical software to another and should be checked before the user analyses the data. It can also be provided using a mathematical formulation for censoring without coding, giving the interval (e.g. right-censored data are an interval from the injury value to eternity). The correct censoring according to the used software or function is to be used.

After this step, the data set includes the measured injury values, and possibly, the associated coding for the censoring status indicated.

3.4 Check for single injury mechanism

The complexity of the human body might lead to different injury mechanisms^[3]. This could lead to injury risk curves with changes of slope and discontinuities. The next step, before applying a parametric method to build an injury risk curve, is to check that the biomechanical sample only included a single injury mechanism.

This is achieved by building the injury risk curve with the Consistent Threshold Estimate (CTE)^[3] for doubly censored data and extended CTE for a mix of actual and censored data^[4]. Visually inspect the resulting step function for changes in slope which can be indicative of different injury mechanisms.

If there is evidence of multiple injury mechanisms, separate the biomechanical sample into samples with single injury mechanism before starting again the guidelines given at [3.2](#). If there is no evidence of

multiple injury mechanisms, use the survival analysis to build the injury risk curve^{[6][7][8][10]} according to the following steps.

3.5 Estimate the coefficients

The coefficients should be estimated with the survival analysis method. Substantially different results can be obtained when extrapolating outside the range of observed data.

Several distributions should be evaluated in order to recommend the one that best predicts the injury risk function. Consider Weibull, log-normal and log-logistic distributions prior to using a more complicated spline formulation in case one of the other distributions is not confirmed in [3.7](#).

3.6 Identify overly influential observations

Overly influential observations can be identified using the dfbetas statistics. The dfbetas statistic gives an indication of the change of each parameter estimate when deleting one observation of the sample at a time.

The dfbetas corresponds to the difference between the regression coefficient when all the data is included and the regression coefficient calculated with one observation is deleted, scaled by the standard error calculated with the observation deleted. The dfbetas is calculated for each coefficient and for each observation.

Choose a cut-off value close to the cut-off value recommended in Reference [\[1\]](#) given the size of the biomechanical samples [$2/\sqrt{\text{sample size}}$]. For the biomechanical sample generally available in the biomechanical field, an absolute value of the dfbetas statistic higher than 0,3 give an indication that the associated observation might be overly influential.

These observations are checked for any specificity. If there is no evidence of difference between these observations and the others included in the sample, keep these observations in the construction of the injury risk curve.

3.7 Check the distribution assumption

Check the assumed distribution. One way is to check graphically using a Q-Q plot (“Q” stands for quantile)^{[5][11]}. The plot of the percentiles of the distribution against the corresponding percentiles of the biomechanical sample is presented in the Q-Q plot. If the plot follows a line through the origin with slope equal to one, then the chosen distribution is appropriate.

Another way to check is to graphically plot the cumulated risk calculated with the survival analysis, with a given distribution against the cumulated risk calculated with the CTE method. If the cumulated risks lie close one to the other, then the chosen distribution is appropriate.

Note that this is not possible if survival analysis is performed with more than one variable.

3.8 Choose the best distribution

Choose the distribution with the best fit based on the Akaike information criterion (AIC).

The AIC criterion assesses the likelihood that the model takes into account the number of variables used in the model ($\text{AIC} = -2 \cdot \log \text{likelihood} + 2 \cdot \text{number of variables}$).

The lowest AIC indicates the best fit of the model with the test data. Of the three distributions, select the one with the lowest AIC.

3.9 Check the validity of the prediction

Check the validity of the injury risk curve predictions against existing results (such as accidentology outcome), if available.

3.10 95 % confidence intervals and its relative size

Calculate the 95 % confidence interval of the injury risk curve with the normal approximation of the error.

The relative size of the confidence interval is defined as the width of the 95 % confidence interval (upper limit minus lower limit of 95 % confidence interval) at a given injury risk, relative to the value of the stimulus at this same injury risk. Perform the calculation at the 5 %, 25 %, and 50 % risks of injury.

3.11 Quality index

Four categories of the quality index are defined, based on the relative size of the 95 % confidence interval ("good" from 0 to 0,5, "fair" from 0,5 to 1, "marginal" from 1 to 1,5, "unacceptable" over 1,5).

The ranges of the quality indices were established to distribute injury risk curves from biomechanical samples into four categories. Provide the quality index along with each injury risk curve.

3.12 Recommendation of the injury risk curves

3.12.1 Principle

It is recommended to select only one injury risk curve per body region, injury type, and injury level.

The injury risk curve recommended should be a function of the more relevant injury measure associated with the single injury mechanism of the sample.

This recommendation is intended to avoid inconsistent injury risk predictions due to contradictory criteria. However, there is no problem to recommend several injury risk curves for a given body region if they address different injury mechanisms (as for example, rib deflection can be the best predictor of thoracic skeletal fractures, while viscous criterion from the ribs can be the best predictor of thoracic soft tissue injuries).

3.12.2 Selection of one injury risk curve

If several injury risk curves can be compared with AIC and if the difference of AIC is greater than two, then the curve with the lowest AIC is selected among the others.

The cut-off values shown in [Table 1](#) were proposed by Burnham and Anderson[2]. The absolute AIC value was not used, but the relative AIC values over a set of injury risk curves were considered to recommend the more appropriate one.

Note that AIC values can only be compared for injury risk curves developed from different injury measures for the same biomechanical samples (the same sample size and the same coding of censoring status).

Table 1 — Difference of one model compared to the model with the lowest AIC

Difference of AIC between a model and the model with the lowest AIC	Difference between the two models
From 0 to 2	Essentially none
From 4 to 7	Slightly more
Higher than 10	Substantial

3.12.3 Non-recommendation based on the quality index

If an injury risk curve had an "unacceptable" quality index (>1,5), it should not be recommended.

3.12.4 Engineering judgment

If after evaluating the AIC differences and the quality indices several injury risk curves are still available for a given injury type and severity level, then engineering judgment should be used to recommend one curve over the others.

3.12.5 Presentation

Finally, the recommended injury risk curves should be provided with their associated quality indices.

If the non-parametric maximum likelihood estimate of the survival analysis shows large steps in some levels of risk, cautions should be considered when using the parametric survival analysis in this area. An estimate of an injury risk below the lowest injury value observed should be used with caution.

4 Related electronic documents

The files providing the R scripts to be used for the construction of the injury risk curves are gathered in related electronic documents posted on the ISO website at the following link:

<http://standards.iso.org/iso/18506>

- RED1: R scripts to build curves as a function of one variable;
- RED2: R scripts to build curves as a function of one variable and of age.

The Bureau de Normalization de l'Automobile (BNA) has been appointed by the ISO technical management board (TMB) as the maintenance agency responsible for regularly updating all electronic documents related to ISO/TS 18506.

Bibliography

- [1] BELSLEY D. A., KUH E., WELSCH R.E. (1980) Regression diagnostics: identifying influential data and sources of collinearity, New York Wiley 1980
- [2] BURNHAM K.P., & ANDERSON D. *Model Selection and Multi-Model Inference*. Springer, 2010
- [3] DI DOMENICO L., & NUSHOLTZ G. *Comparison of Parametric and Non-Parametric Methods for Determining Injury Risk*. SAE Paper N°2003-01-1362. Society of Automotive Engineers, Warrendale, PA, 2003
- [4] DI DOMENICO L., & NUSHOLTZ G. Risk Curve Boundaries. *Traffic Inj. Prev.* 2005, **6** pp. 86–94
- [5] DOKSUM K.A., & SIEVERS G.L. Plotting with confidence: graphical comparisons of two populations. *Biometrika*. 1976, **63** pp. 421–434
- [6] FUNK J.R., SRINIVASAN S.C.M., CRANDALL J.R., KHAEWPOONG N., EPPINGER R.H., JAFFREDO A.S. et al. The Effects of Axial Preload and Dorsiflexion on the Tolerance of the Ankle/Subtalar Joint to Dynamic Inversion and Eversion. *Stapp Car Crash J.* 2002, **46** pp. 245–265
- [7] KENNEDY E.A., HURST W.J., STITZEL J.D., CORMIER J.M., HANSEN G.A., SMITH E.P. et al. Lateral and Posterior Dynamic Bending of the Mid-Shaft Femur: Fracture Risk Curves for the Adult Population. *Stapp Car Crash J.* 2004, **48** pp. 27–51
- [8] KENT R.W., & FUNK J.R. *Data censoring and parametric distribution assignment in the development of injury risk functions from biomechanical data*. SAE Paper N°2004-01-0317. Society of Automotive Engineers, Warrendale, PA, 2004
- [9] NUSHOLTZ G., & MOSIER R. Consistent Threshold Estimate for Doubly Censored Biomechanical Data”, SAE1999-01-0714
- [10] PETITJEAN A., & TROSSEILLE X. Statistical simulations to evaluate the methods of the construction of injury risk curves. *Stapp Car Crash J.* 2011 Nov, **55** pp. 411–440
- [11] WILK M.B., & GNANADESIKAN R. (1968) Probability plotting methods for the analysis of data. *Biometrika*, 55-1-17

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards-based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

All the data, software and documentation set out in all British Standards and other BSI publications are the property of and copyrighted by BSI, or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI. Details and advice can be obtained from the Copyright & Licensing Department.

Useful Contacts:

Customer Services

Tel: +44 845 086 9001

Email (orders): orders@bsigroup.com

Email (enquiries): cservices@bsigroup.com

Subscriptions

Tel: +44 845 086 9001

Email: subscriptions@bsigroup.com

Knowledge Centre

Tel: +44 20 8996 7004

Email: knowledgecentre@bsigroup.com

Copyright & Licensing

Tel: +44 20 8996 7070

Email: copyright@bsigroup.com



...making excellence a habit.™