ACCURACY, UNCERTAINTY, PROBABILITY OF DETECTION

PD Dr. Ernst Niederleithinger

CONTENT

What is measurement accuracy?

What is measurement uncertainty?

How to quantify it?

What is Probability of Detection?

COPYRIGHT NOTE

ACCURACY

MEASUREMENT AND MEASURAND

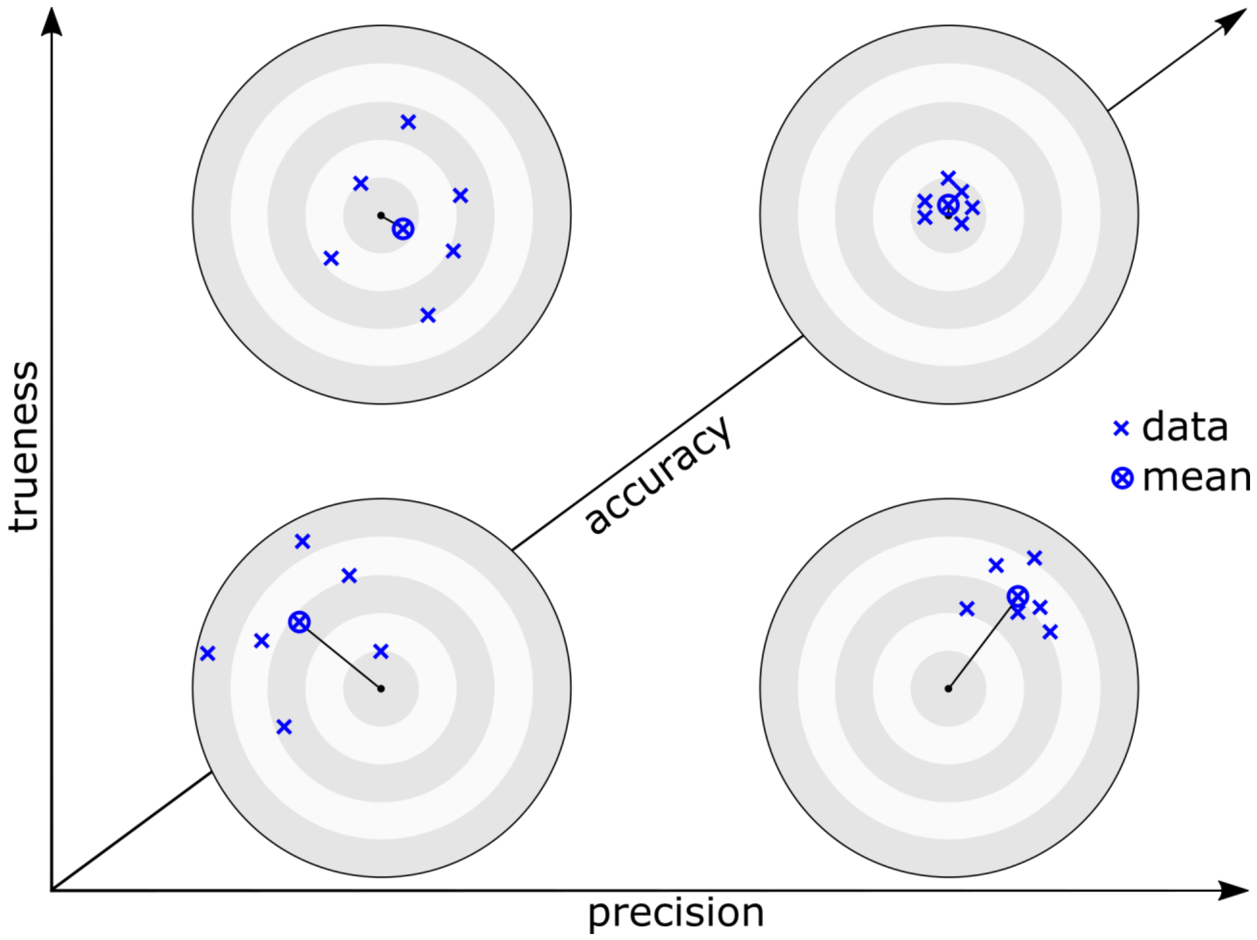
Measurement: An experimental process that produces a value that can reasonably be attributed to a quantitative property

Measurand: Property that is the object of measurement. It has a numerical **magnitude** and a **reference** that gives meaning to that numerical magnitude.

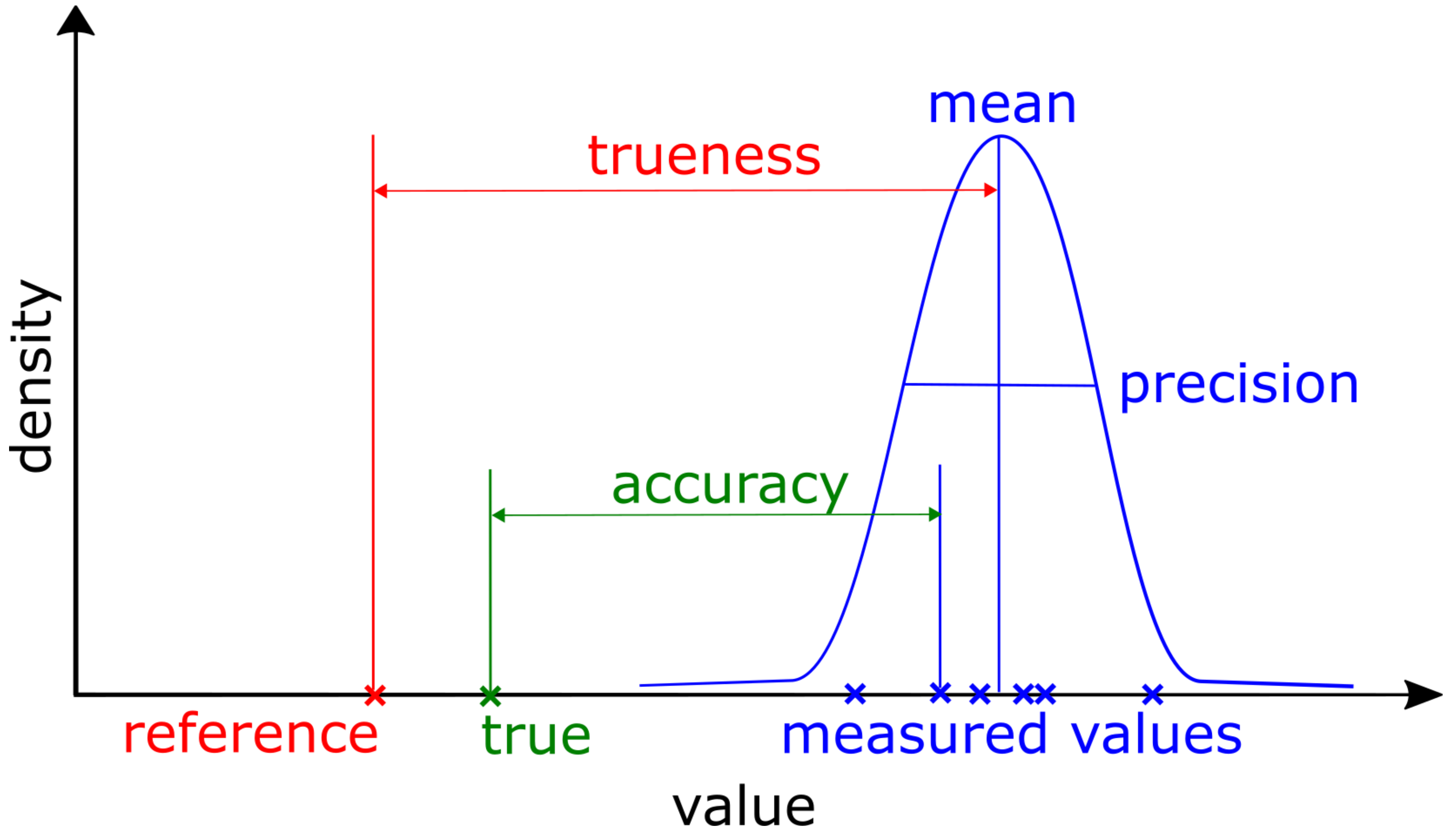
Example:
Measurement: Determining the mass of a sample by putting it on a balance and reading the indicated value from the scale, including all required preparation and calibration procedures.
Measurand: Value read from the scale
Reference: the mass of the *International Prototype Kilogram* is 1 kg (if the scale ist referenced to SI units).

After nist.gov

ACCURACY



ACCURACY


mean
trueness
precision
accuracy
density
reference
true
measured values
value

UNCERTAINTY

UNCERTAINTY

GUM: **measurement uncertainty:** a "parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand‘’.

VIM: a "non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used‘’.

VIM: “International Vocabulary of Metrology”, https://jcgm.bipm.org/vim/en/1.4.html

GUM?

UNCERTAINTY

First edition September 2008

https://www.bipm.org/en/committees/jc/jcgm/publications

Bureau International des Poids et Mesures

GUM: INTRODUCTION

0.1 “When reporting the result of a measurement of a physical quantity, it is obligatory that **some quantitative indication of the quality of the result** be given so that those who use it can **assess its reliability**. Without such an indication, measurement results cannot be compared, either among themselves or with reference values given in a specification or standard. It is therefore necessary that there be a readily implemented, easily understood, and generally accepted procedure for characterizing the quality of a result of a measurement, that is, for evaluating and expressing its ***uncertainty***.”

GUM: INTRODUCTION

0.2 “The concept of uncertainty as a quantifiable attribute is relatively new in the history of measurement, although **error and error analysis** have long been a part of the practice of measurement science or metrology. It is now widely recognized that, when all of the known or suspected components of error have been evaluated and the appropriate corrections have been applied, there **still remains an uncertainty about the correctness of the stated result**, that is, a doubt about how well the result of the measurement represents the value of the quantity being measured.”

GUM: INTRODUCTION

0.3, 0.4

“.. it is imperative that the method for evaluating and expressing uncertaintybe uniform throughout the world so that measurements performed in different countries can be easily compared.“

“The **ideal method** for evaluating and expressing the uncertainty ... should be **universal**: the method should be applicable to all kinds of measurements and to all types of input data ... “
fraction of the distribution of values

GUM: MODELING

A measurand Y is in most cases determined by N other quantities X_i :

$$Y_i = f(X_1, X_2, \ldots, X_N)$$

Note: the X_i may depend themselves of many other quantities

Note: the X_i may be categorized as

- Quantities, whose values and uncertainties are directly determined in the current measurement (single or repeated observations, judgement based on experience, corrections, …)
- Quantities, whose values and uncertainties are brought in from external sources (data from handbooks, certified reference materials, calibrated measurement standards)

GUM: MODELING

An output estimate y of measurand Y is obtained by input estimates x_i :

$$y_i = f(x_1, x_2, \ldots, x_N)$$

The estimated standard deviation associated with the output estimate or measurement result y, termed **combined standard uncertainty** $u_c(y)$, is determined from the estimated standard deviation associated with each input estimate x_i, termed standard uncertainty $u(x_i)$.

GUM: EVALUATION OF UNCERTAINTY

Each input estimate x_i and its standard uncertainty $u(x_i)$ are determined by a distribution of possible values of the input quantity X_i

The probability distribution may be

- frequency based (based on a series of observations $X_{i,k}$ of X_i), requiring a Type A evaluation
- An a priori distribution, requiring a type B evaluation

GUM: TYPE A EVALUATION (SIMPLIFIED)

The best estimate of the experimental variance of the mean is given by:

$$s^2(\overline{X}_i) = \frac{s^2(X_{i,k})}{n}$$

This (or the corresponding experimental standard deviation of the mean) quantify how well the mean estimates the expected value of X_i.
Both can be used as a measure of the uncertainty $u^2(x_i)$ resp. $u(x_i)$ ("Type A variance" resp. "Type A standard uncertainty).

Variance: more fundamental quantity
Standard Deviation: Easier to use as same unit as the variable.

GUM: TYPE A EVALUATION (SIMPLIFIED)

In most cases the best available estimate for a randomly varying quantity X_i is the arithmetic mean (average) of n observations:

$$\bar{X}_i = \frac{1}{n}\sum_{k=1}^{n} X_{i,k}$$

The variance due to random effects is calculated by:

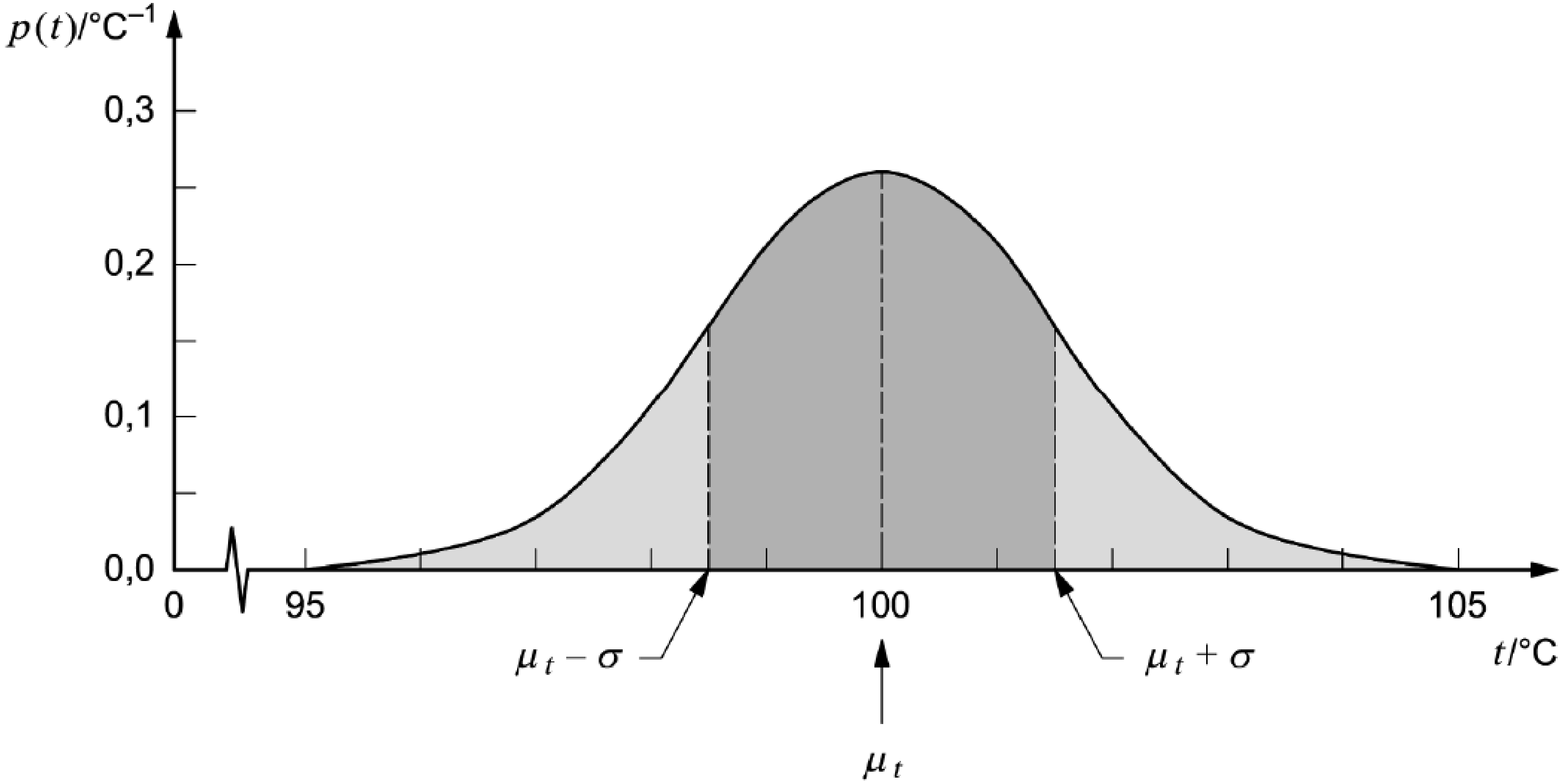
$$s^2(\bar{X}_i) = \frac{1}{n-1}\sum_{k=1}^{n} (X_{i,k} - \bar{X}_i)^2$$

The estimated variance s^2 and its square root, the experimental standard deviation s, characterise the dispersion of values around their mean.

GUM: TYPE A EVALUATION (SIMPLIFIED)

Example:

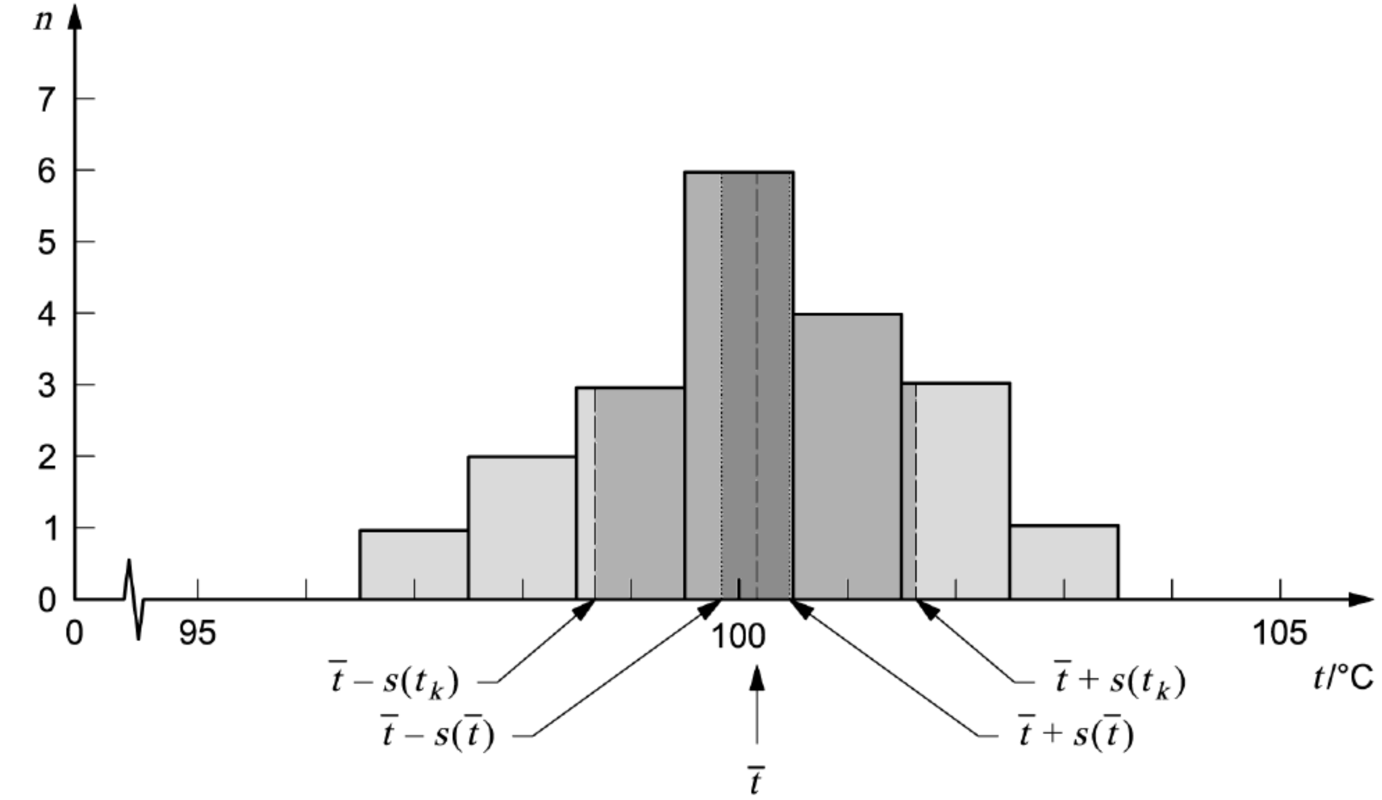
1) Physics/Math: Normal distribution ("the perfect world")



GUM: TYPE A EVALUATION (SIMPLIFIED)

Example:

2) Reality: some discrete values measured



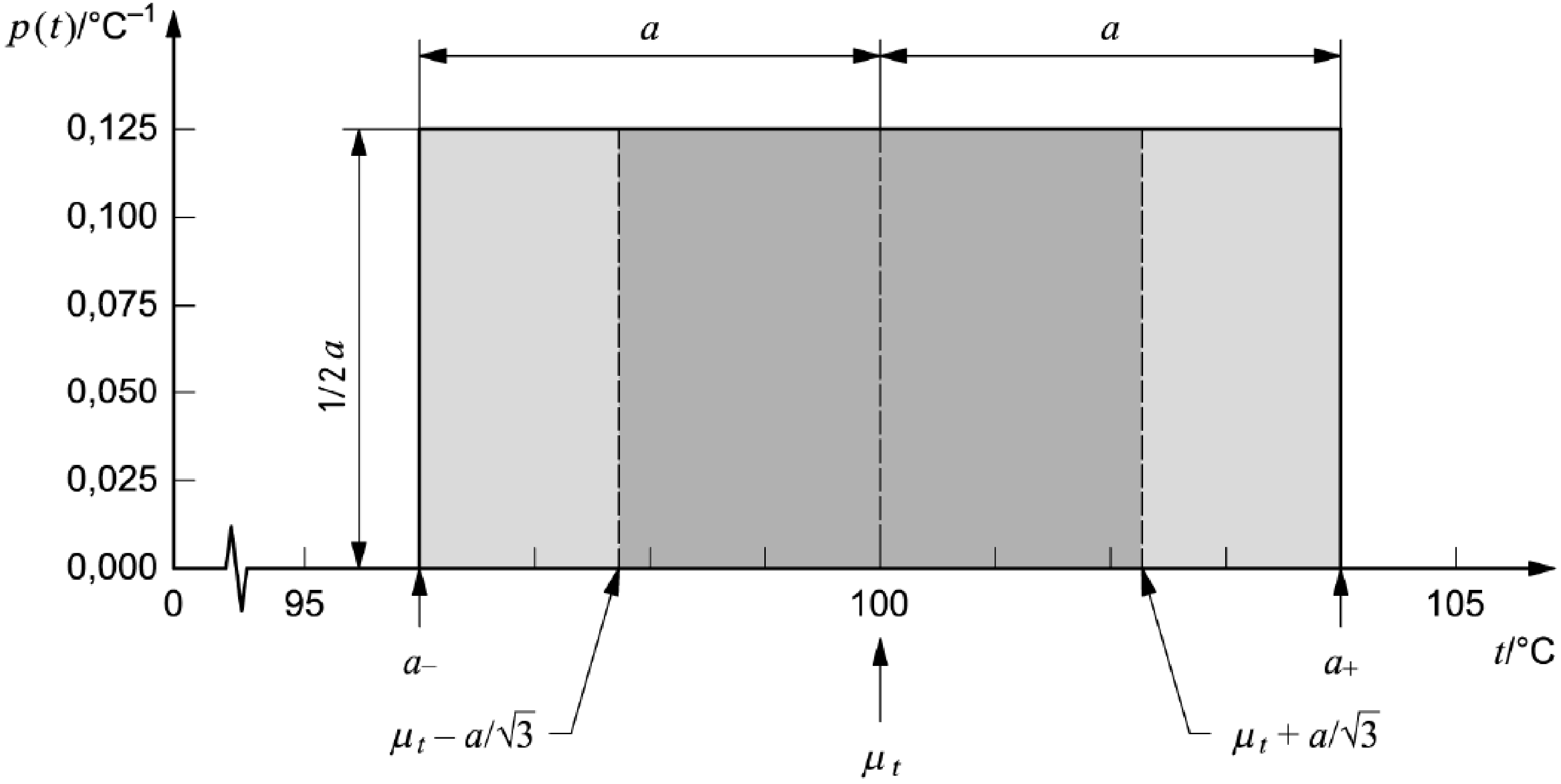
GUM: TYPE B EVALUATION (SIMPLIFIED)

For quantities not obtained by repeated observations,
“Type B variance/standard deviation” (and thus uncertainty)
are evaluated by scientific judgement.
Information may include:

- previous measurement data;
- experience with or general knowledge of the behaviour and properties of relevant materials and instruments;
- manufacturer's specifications;
- data provided in calibration and other certificates;
- uncertainties assigned to reference data taken from handbooks.

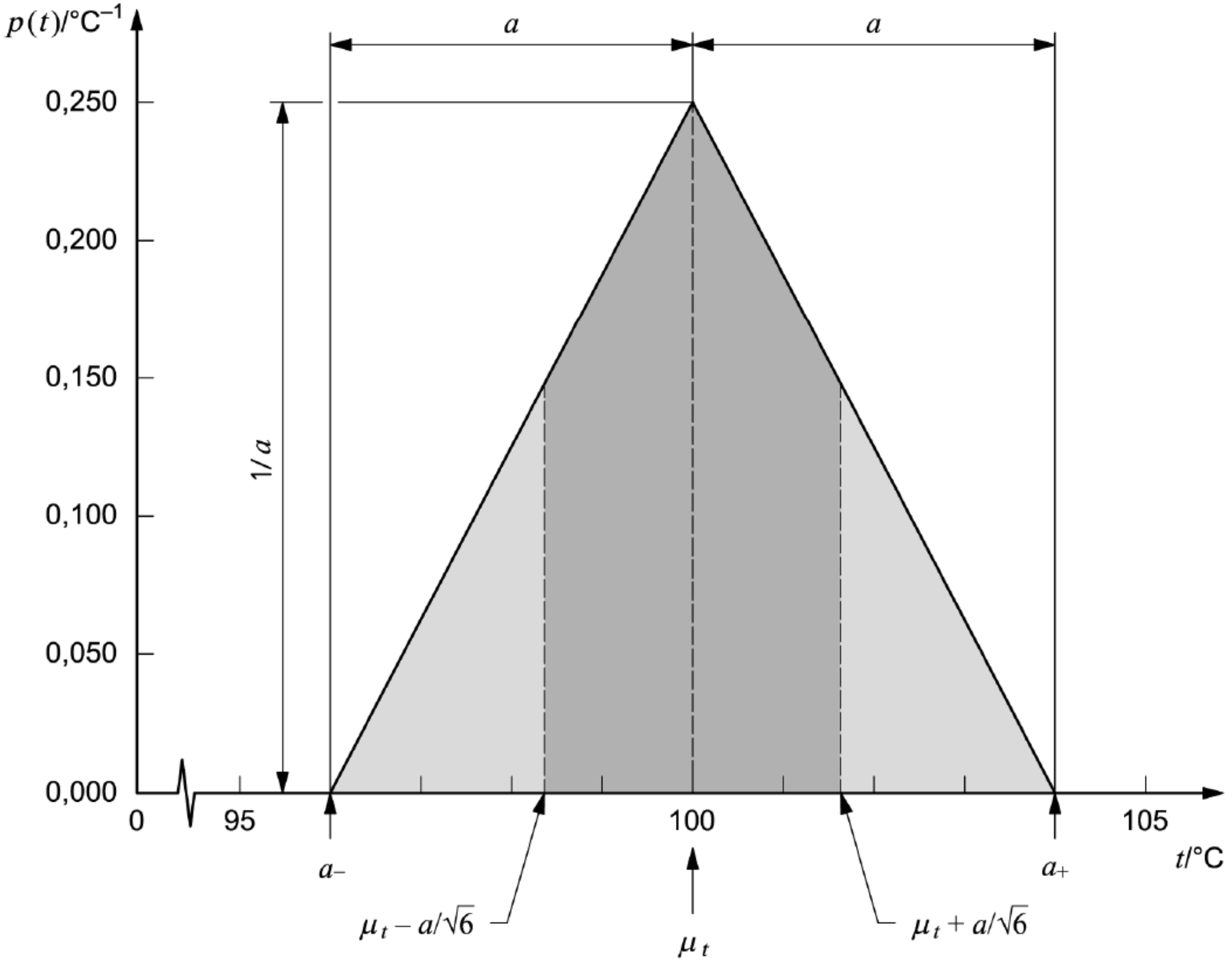
GUM: TYPE B EVALUATION (SIMPLIFIED)

In many cases a rectangular distribution is assumed:



GUM: TYPE B EVALUATION (SIMPLIFIED)

More realistic: triangular or trapezoidal distributions:



GUM: COMBINED STANDARD UNCERTAINTY

Case 1: all input quantities independent (uncorrelated)

Combining all standard uncertainties of the input estimates x_i:

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)$$

Why the derivatives? Sensitivity coefficients!

GUM: COMBINED STANDARD UNCERTAINTY

Case 2: correlated input quantities (interdependent

Combining all standard uncertainties of the input estimates by using the estimated covariance $u(x_i,x_j)$:

$$u_c^2(y) = \sum_{i=1}^{n}\sum_{j=1}^{n}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i,x_j)$$

GUM: SUMMARY (OF PROCEDURE)

1) Express mathematically the relationship between the measurand Y and the input quantities X_i on which Y depends: $Y = f(X_1, X_2, \ldots, X_N)$
   The function f should contain every quantity, including all corrections and correction factors, that can contribute a significant component of uncertainty to the result of the measurement

2) Determine xi, the estimated value of input quantity X_i, either on the basis of the statistical analysis of series of observations or by other means.

GUM: SUMMARY (OF PROCEDURE)

3) Evaluate the standard uncertainty $u(x_i)$ of each input estimate x_i.

- For an input estimate obtained from the statistical analysis of series of observations, the standard uncertainty is evaluated by a type A evaluation
- For an input estimate obtained by other means, the standard uncertainty $u(x_i)$ is evaluated by a type B evaluation.

4) Evaluate the covariances associated with any input estimates that are correlated (see 5.2)

5) Calculate the result of the measurement, that is, the estimate y of the measurand Y, from the functional relationship f using for the input quantities X_i the estimates x_i obtained in step 2.

GUM: SUMMARY (OF PROCEDURE)

6) Determine the combined standard uncertainty $u_c(y)$ of the measurement result y from the standard uncertainties and covariances associated with the input estimates

7) If it is necessary to give an expanded uncertainty U, whose purpose is to provide an interval y – U to y + U, multiply the combined standard uncertainty $u_c(y)$ by a coverage factor k, typically in the range 2 to 3, to obtain $U = ku_c(y)$.

8) Report the result of the measurement y together with its combined standard uncertainty $u_c(y)$ or expanded uncertainty U. Describe how y and u_c (y) or U were obtained.

EXAMPLE FOR UNCERTAINTY EVALUATION

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Sicherheit in Technik und Chemie

ICCRRR2022
03–05 OCT 2022 · CAPE TOWN, SOUTH AFRICA

BAM
Bundesanstalt für Materialforschung und -prüfung

04.10.2022

ON THE ACCURACY OF TENDON LOCALIZATION IN CONCRETE USING ULTRASOUND

S. Küttenbaum [1], S. Maack [1] & A. Taffe [2]

[1] BAM, Division 8.2, Berlin
[2] HTW Berlin – University of Applied Sciences

www.bam.de

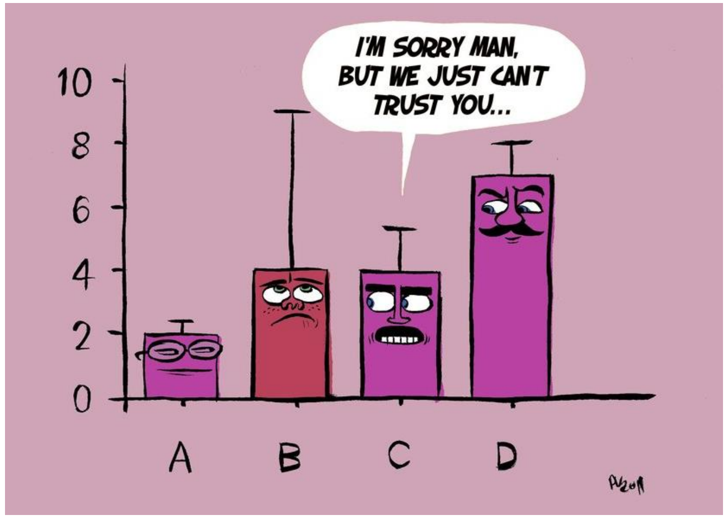
Why bother?

„The basis for decisions are the information available about the considered system."

Information can be

$$\begin{Bmatrix} true \\ biased \end{Bmatrix} + \begin{Bmatrix} precise \\ imprecise \end{Bmatrix} + \begin{Bmatrix} comparable \\ incomparable \end{Bmatrix} + \begin{Bmatrix} relevant \\ irrelevant \end{Bmatrix}.$$

The condition of measured information must be known, especially when it is to be used in safety-relevant calculations!



Source: www.facebook.com/pedromics

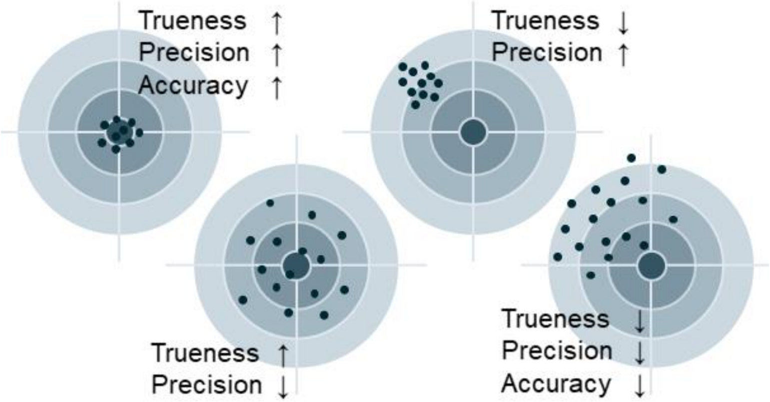
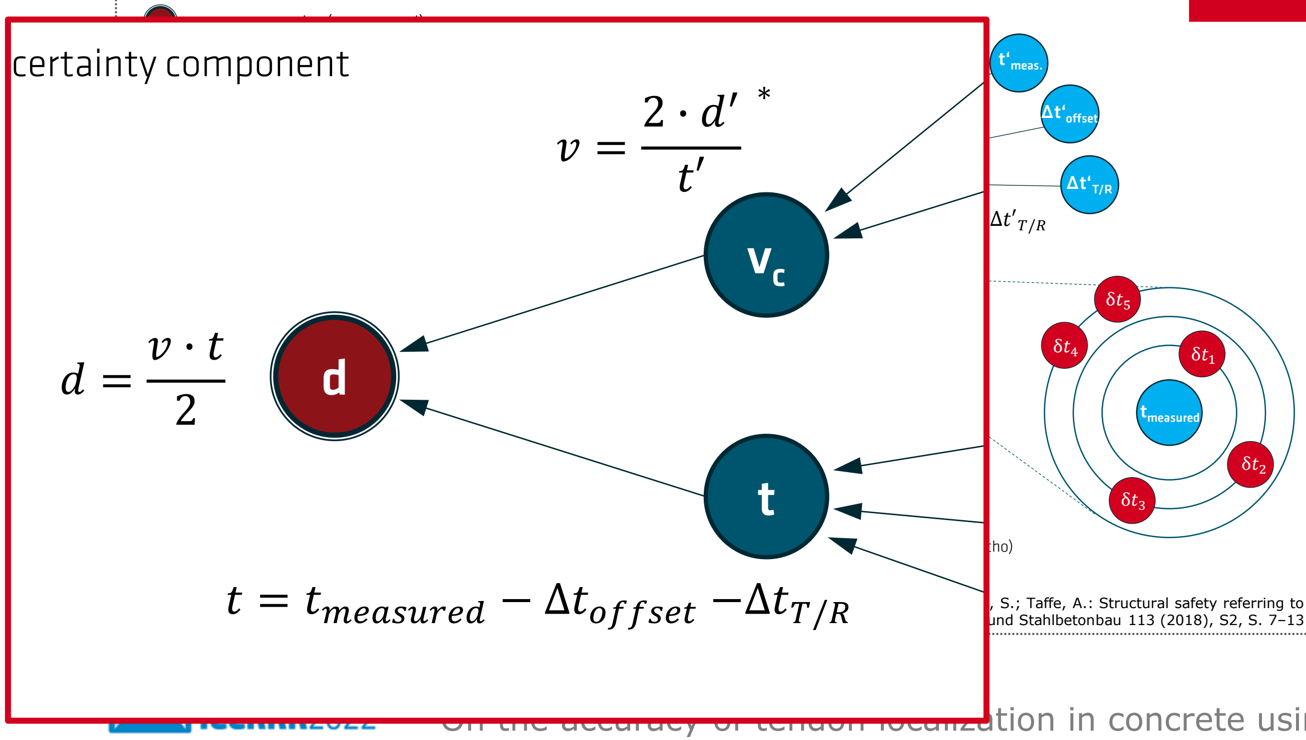


Fig. acc. to e.g. M. Krystek, Calculating measurement uncertainties, Beuth, 2016 & W. Hässelbarth, EUROLAB Technical Report No. 1/2006

Measurement uncertainty
Concept

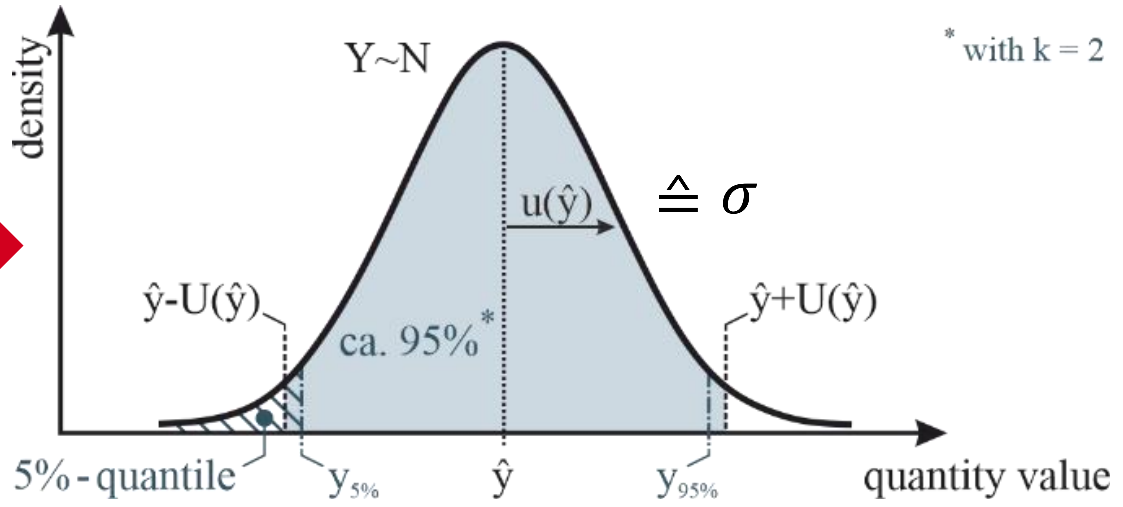
Model of the measurement:

$$Y = f(X_i)$$



…, S.; Taffe, A.: Structural safety referring to … und Stahlbetonbau 113 (2018), S2, S. 7–13

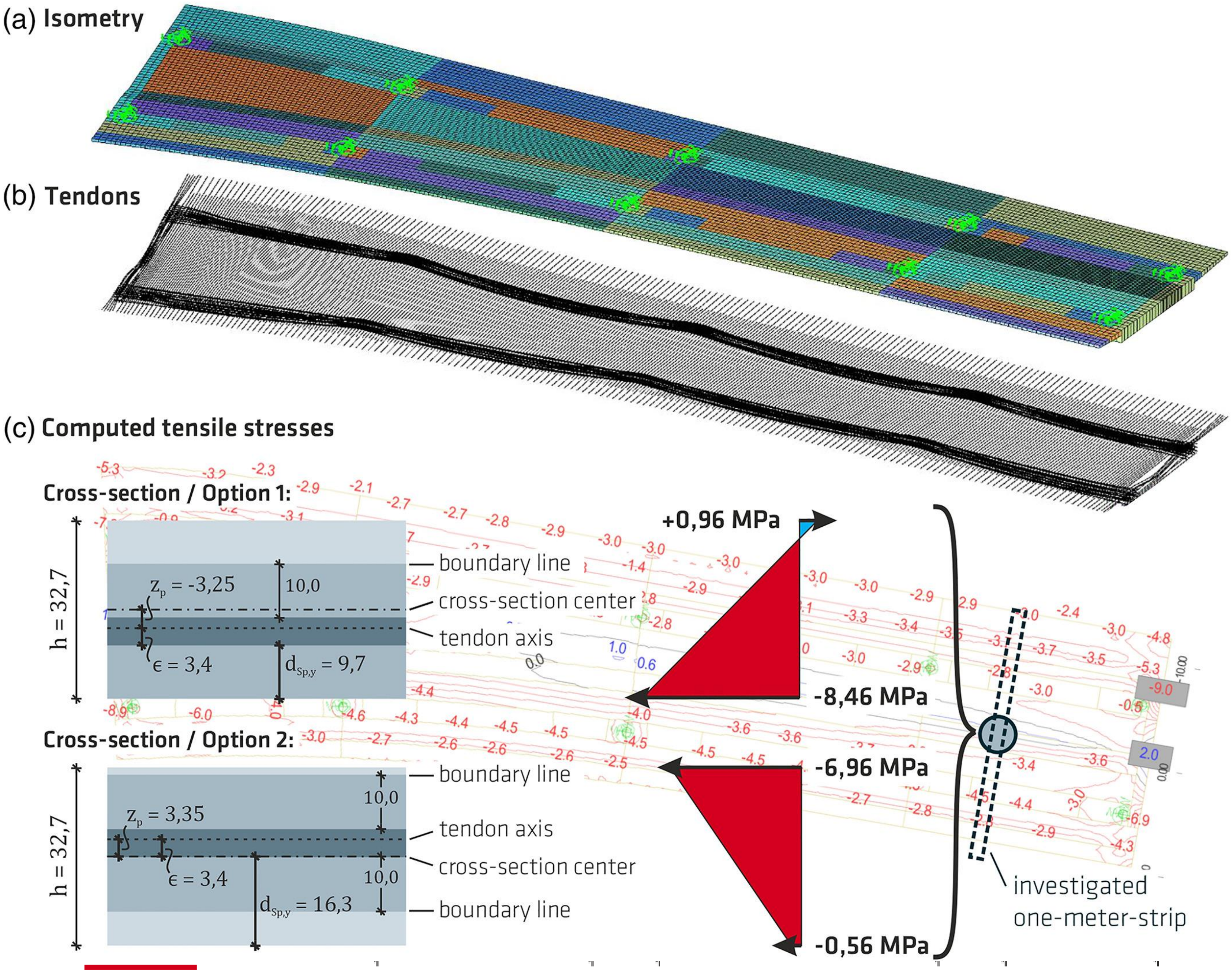
Measurand $Y \sim N$



$\triangleq \sigma$

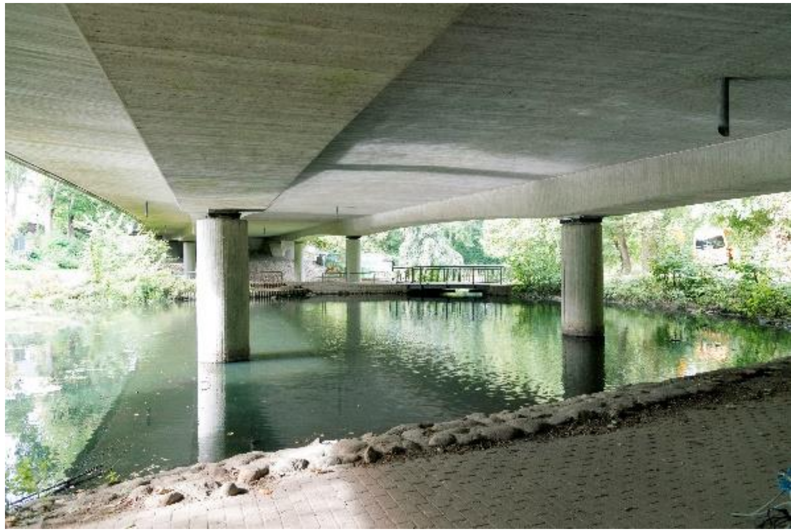
$\mu \triangleq \hat{y}$

Reference: Küttenbaum, S. et al. (2022): Approach to the development of a model to quantify the quality of tendon localization in concrete using ultrasound. ICCRRR2022.

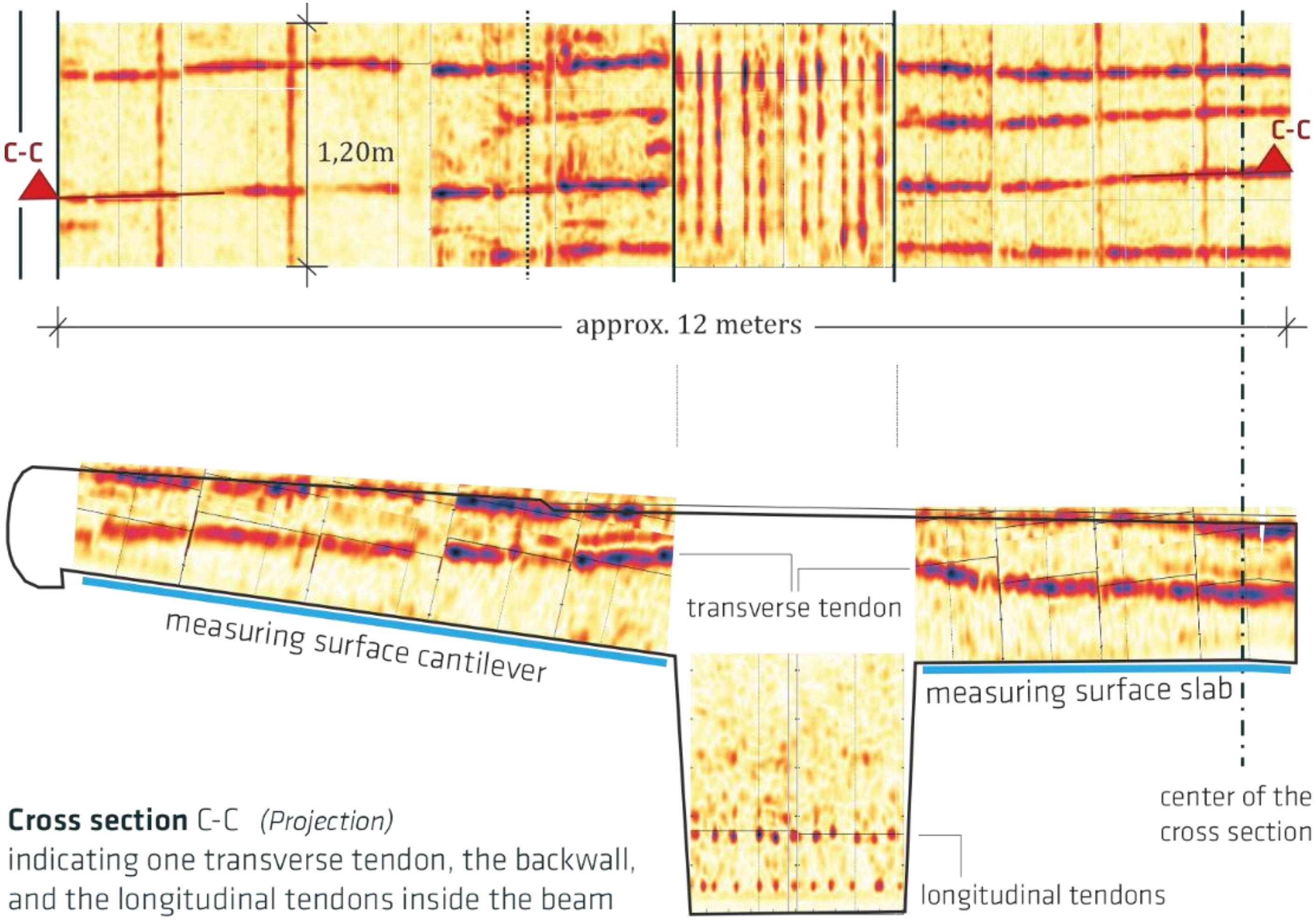


Drawing: Küttenbaum S, Braml T,Taffe A, Keßler S, Maack S. Reliability assessmentof existing structures using results ofnondestructive testing. Structural Concrete. 2021;22:2895–915. https://doi.org/10.1002/suco.202100226

Drawing: Dissertation Küttenbaum (2021), translated

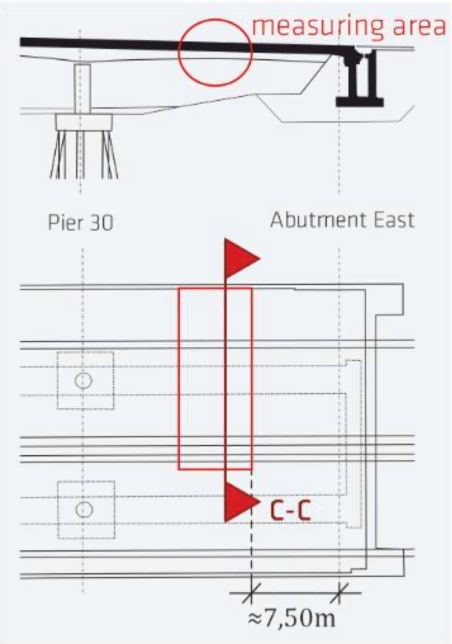


Proposed model
Tendon localization using ultrasonic-echo



Cross section C-C *(Projection)*
indicating one transverse tendon, the backwall, and the longitudinal tendons inside the beam

Aerial perspective
indicating the transverse and longitudinal tendons



Reference: Küttenbaum, S. et al. (2022): Approach to the development of a model to quantify the quality of tendon localization in concrete using ultrasound. ICCRRR2022.

Proposed model

Tendon localization using ultrasonic-echo

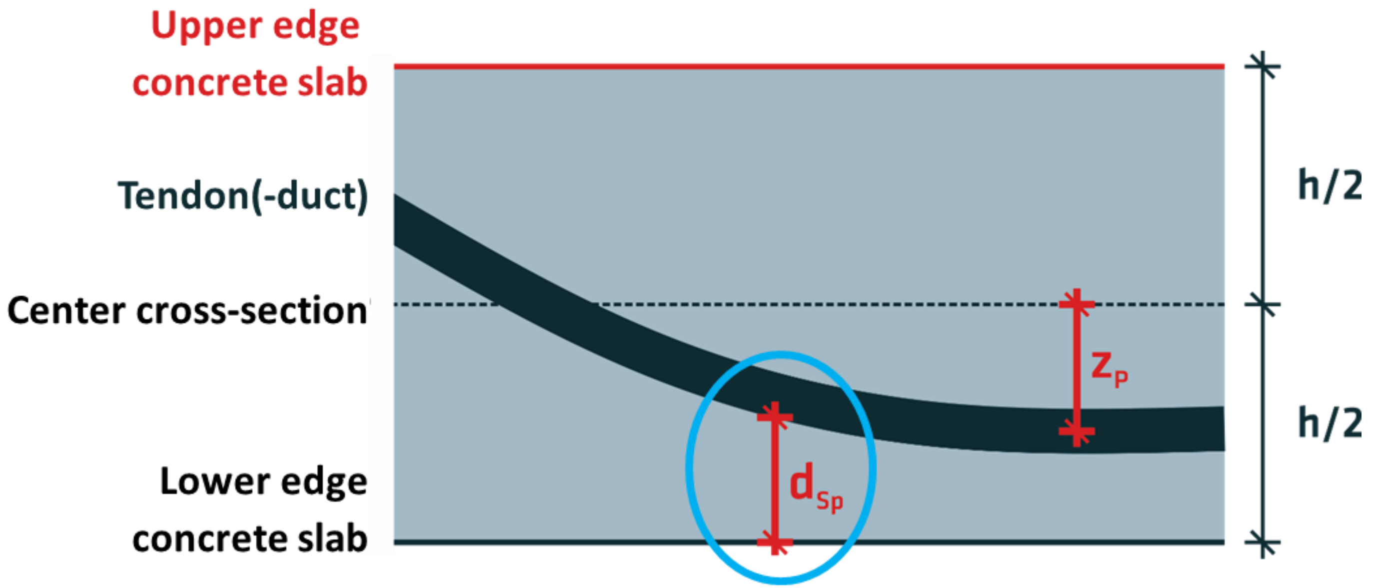
1. Definition of measurand $Y = f(X_i)$

Mounting depth of a tendon duct

$$Y = D_{Sp} = \frac{C_T T}{2} - \cdots$$

with $T = T_A - \cdots - \sum T_i$

and $C_T = \frac{2D_{C_T}}{T_{C_T}} - \cdots - \mathrm{C}_{\mathrm{T,i}} - \cdots$



Proposed model

Tendon localization using ultrasonic-echo

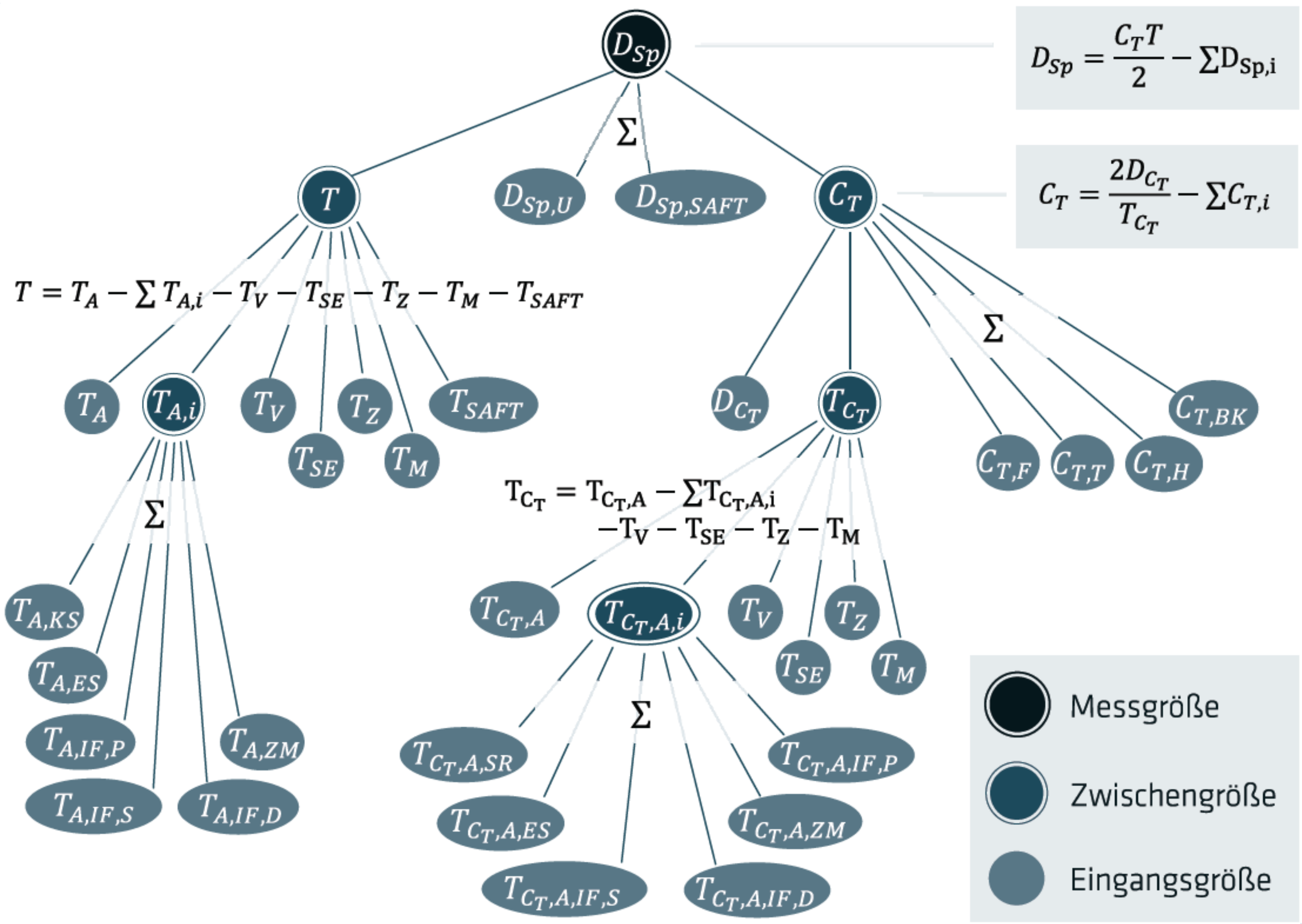
2. Identification of input quantities X_i

Mounting depth of a tendon duct

$$Y = D_{Sp} = \frac{C_T T}{2} - \cdots$$

with $T = T_A - \cdots - \sum T_i$

and $C_T = \frac{2D_{C_T}}{T_{C_T}} - \cdots - C_{T,i} - \cdots$



Reference: Dissertation Küttenbaum, S. (2021)

Proposed model
Tendon localization using ultrasonic-echo

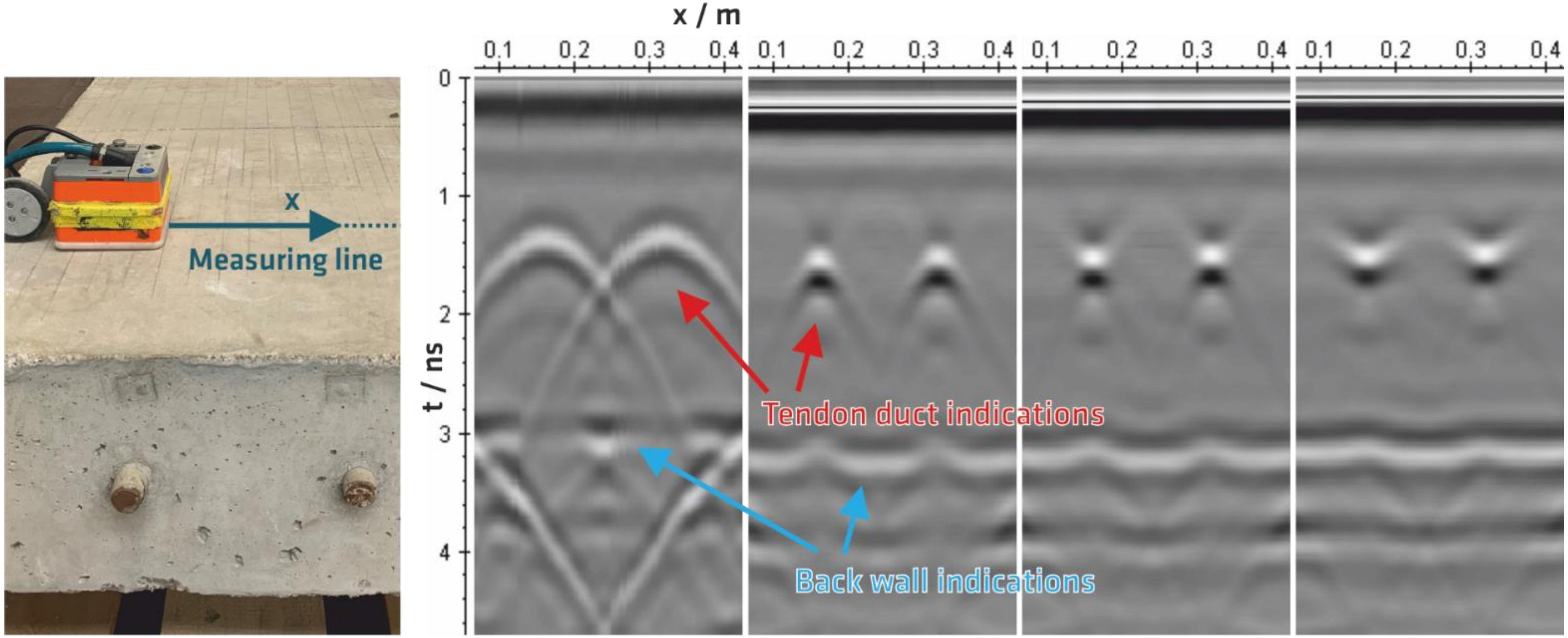
3. Quantification of input quantities X_i

Propagation velocity acc. to Type B

a) Concrete specimen with two tendons

b) Diffraction hyperbola

c) Migrated data using a underestimated (left), overestimated (right) and the unbiased propagation velocity (center)



Reference: XXXXXXXXXXXXXXXXXXX

Proposed model

Tendon localization using ultrasonic-echo

3. Quantification of input quantities X_i

Type B:

1. Definition of a distribution type
2. Calculation of expected value and variance

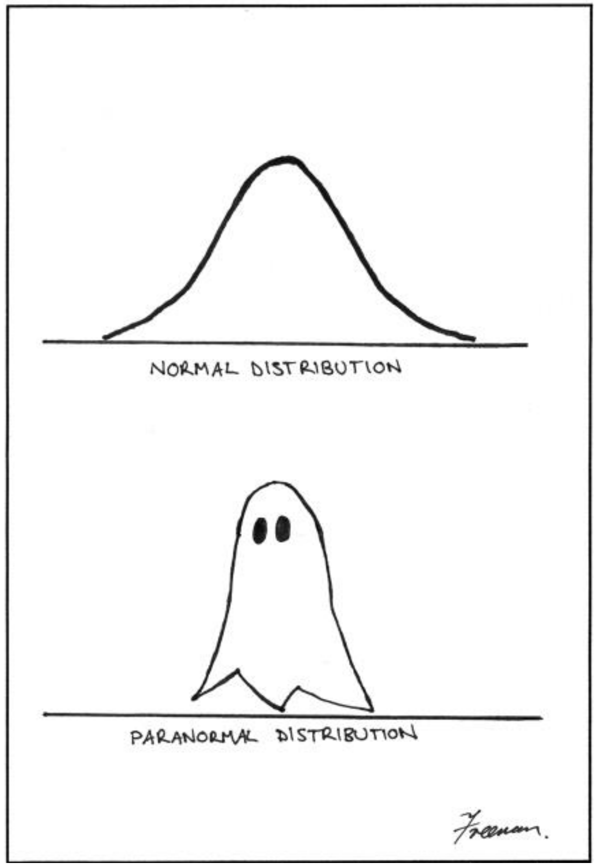


Fig.: ©2006 BMJ Publishing Group Ltd., Matthew Freeman, J Epidemiol Community Health. 2006 Jan; 60(1): 6. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2465539/

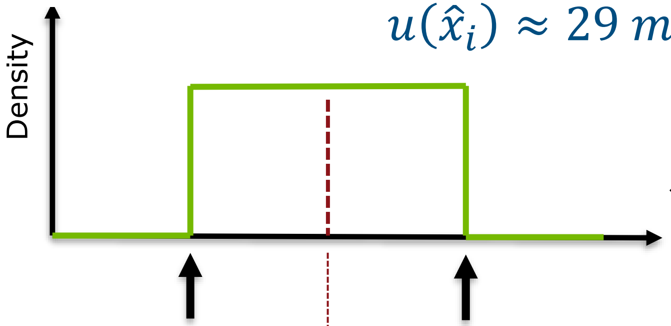
Propagation velocity v

- Expert judgement of two limits: „We individually expect c_T to lie between $2.750 \dots 2.850\ m/s$. That's all we know!."

➔ Uniform distr. with parameters:

$$E(X_i) = \hat{x}_i = \frac{a+b}{2} \quad bzw. \quad u(\hat{x}_i) = \frac{b-a}{2\sqrt{3}}$$

$u(\hat{x}_i) \approx 29\ m/s$



$a = 2.750\ m/s$ $\quad$ $b = 2.850\ m/s$

$E(X_i) = 2.800\ m/s$

Proposed model

Tendon localization using ultrasonic-echo

3. Quantification of input quantities X_i

Component temperature

$$C_T = \frac{2D_{C_T}}{T_{C_T}} - \cdots - \mathrm{C}_{\mathrm{T,T}} - \cdots$$

1) Component temperature varies during the measurements by a maximum of $\Delta T = 20K$.
2) Suitable values for the propagation velocity are determined on average.
3) In the aforementioned temperature range, the change is $\Delta c_T = -0{,}05\%/1K$.
4) Let a frequently suitable value for the S_H- wave velocity in concrete be $c_T \approx 3.000 m/s$.

→ $C_{T,T} \sim U(-15ms^{-1}; +15ms^{-1})$

→ $u(\hat{c}_{T,T}) \approx 9ms^{-1}$

Proposed model

Tendon localization using ultrasonic-echo

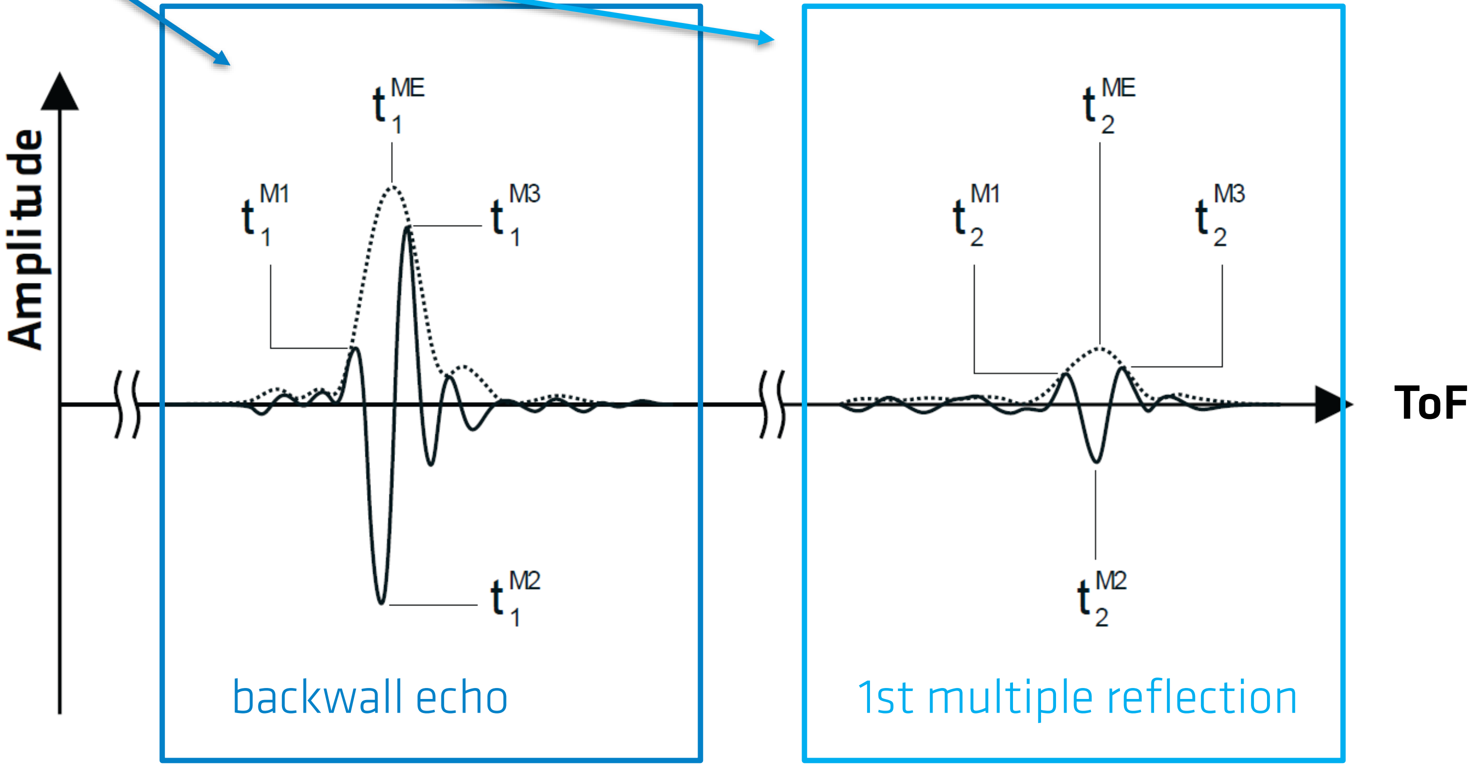
3. Quantification of input quantities X_i

Offset $T_V = -(T_2^{ME} - 2T_1^{ME})$

$$T = T_A - \cdots - T_V - \cdots$$

Displayed ToFs

→ Type A

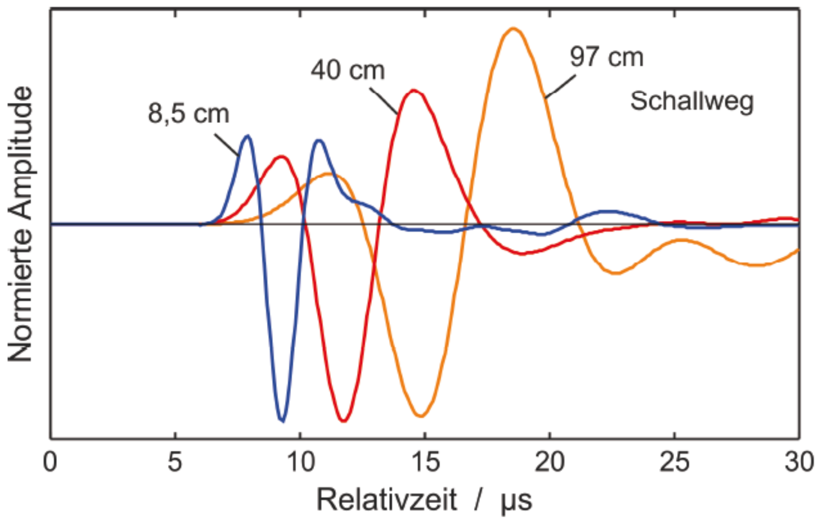


Reference: Dissertation Küttenbaum, S. (2021)

Proposed model

Tendon localization using ultrasonic-echo

Time- & frequency-dependent changes in



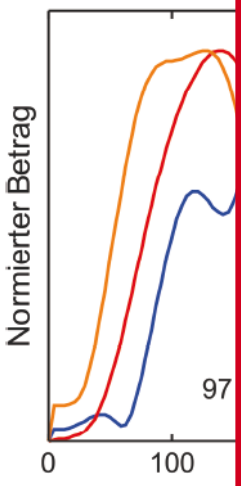


Abb. 2: Einfluss des Schallwegs auf die Signalform (links) und zugehö
jeweils in normierter Darstellung

(Bildquelle: Martin Schickert, Weimar/DGZfP-VNB 124/2018-11-16)

Reference: DGZfP-Merkblatt B04

3. Quantification of input quantities X_i

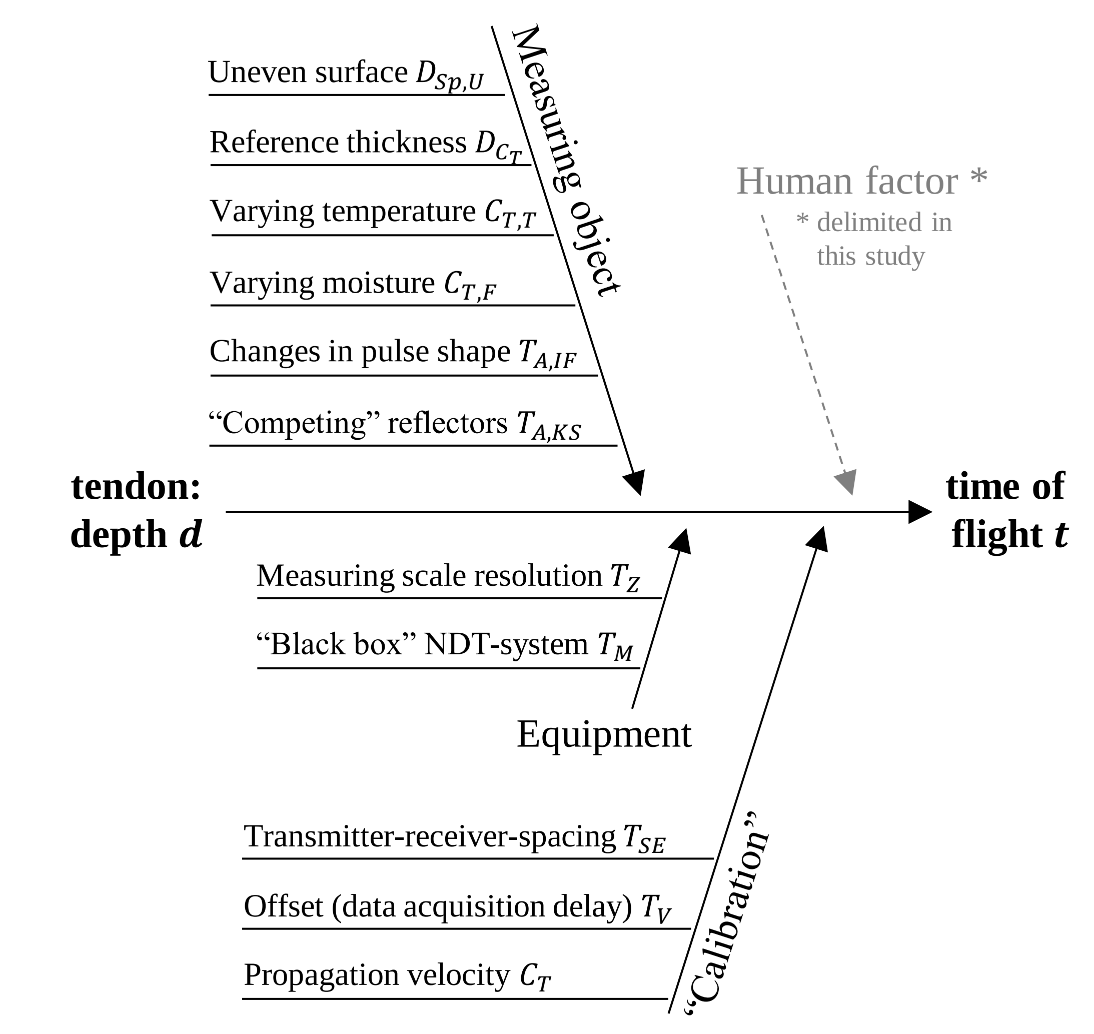


Figure: Küttenbaum, S. et al. (2022): Approach to the development of a model to quantify the quality of tendon localization in concrete using ultrasound. ICCRRR2022.

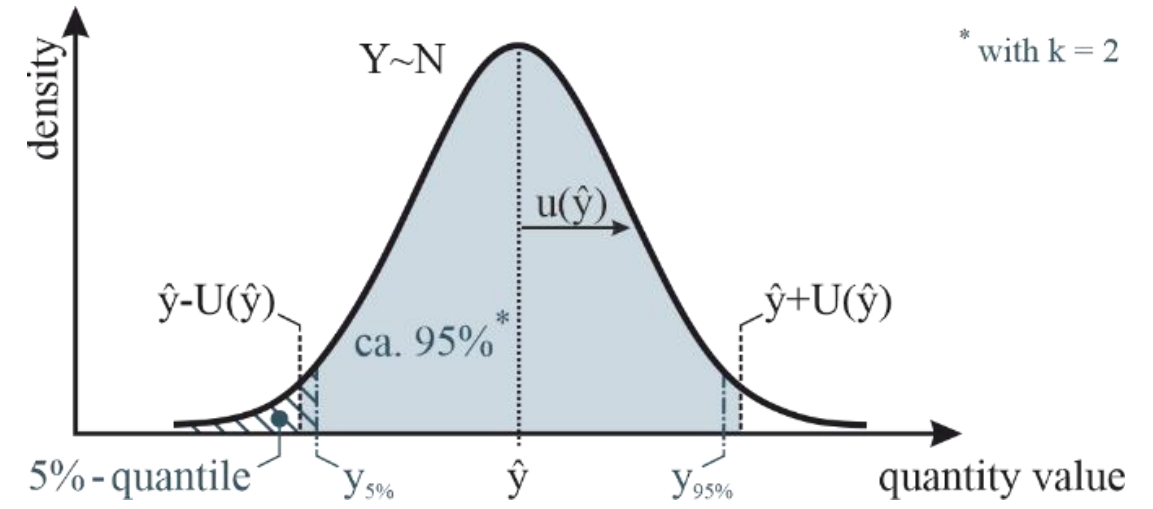
Proposed model

Tendon localization using ultrasonic-echo

4. Measurement result $\hat{y}; u(\hat{y})$; distr. type

Measured quantity value

$$\hat{y} = f(\hat{x}_1, \dots, \hat{x}_n).$$



Combined standard meas. uncertainty

$$u(\hat{y}) = \sqrt{\sum_{i=1}^{n} c_i^2 u^2(\hat{x}_i) + 2\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} c_i c_j u(\hat{x}_i, \hat{x}_j)}.$$

$\hat{y} \pm U(\hat{y}) \equiv$ *Interval containing the value of the measurand (e.g. mean) with a defined probability (of e.g. 95%) based on the available info*

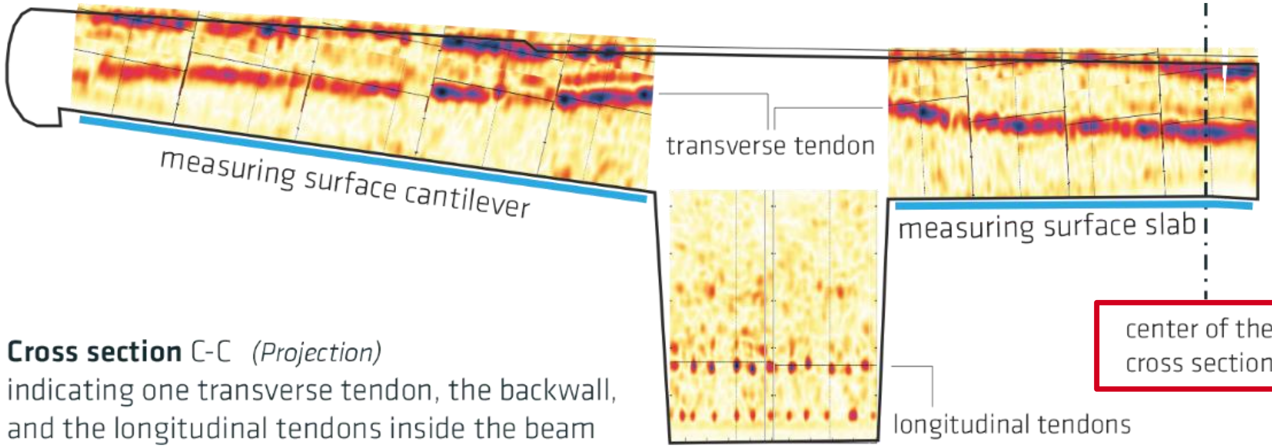
Proposed model

Tendon localization using ultrasonic-echo

4. Measurement result $\hat{y}; u(\hat{y})$; distr. type

Measurement result:

$$d'_{Sp,y} \sim N(\mu = 14{,}9\ cm; \sigma = 0{,}6\ cm)$$



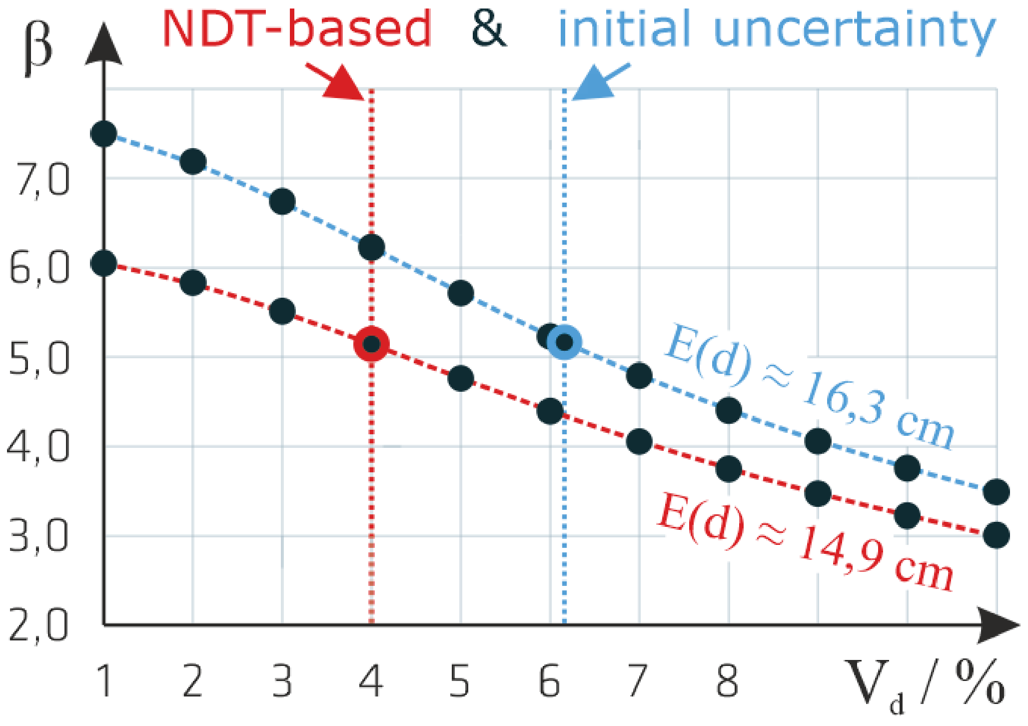
Cross section C-C *(Projection)*
indicating one transverse tendon, the backwall, and the longitudinal tendons inside the beam

Basis-variable	Initial model			NDT-supported model		
	Distr. type	$E(X)$	$\sigma_X\ (V_X)$	Distr. type	$E(X'')$	$\sigma_{X''}$
$d_{Sp,y}$ / cm	N	16,3	1,0 (6,1 %)	N	14,9	$u = 0{,}6$ (ultrasound; 4 %)

Reference: Dissertation Küttenbaum, S. (2021)

Outlook

NDT-results in structural assessment



- increased level of approximation
- improved life time prediction
- targeted planning of measures
- optimized resource consumption

More details:

Küttenbaum S. et al.: *Reliability assessment of existing structures using results of nondestructive testing. Structural Concrete*. (2021) https://doi.org/10.1002/suco.202100226

Reference: Küttenbaum, S. et al. (2022): Approach to the development of a model to quantify the quality of tendon localization in concrete using ultrasound. ICCRRR2022.

PROBABILITY OF DETECTION

SOURCES

NOT MEASUREMENT SENSITIVE

MIL-HDBK-1823A
7 April 2009

SUPERSEDING
MIL-HDBK-1823
14 April 2004

DEPARTMENT OF DEFENSE
HANDBOOK

NONDESTRUCTIVE EVALUATION SYSTEM
RELIABILITY ASSESSMENT

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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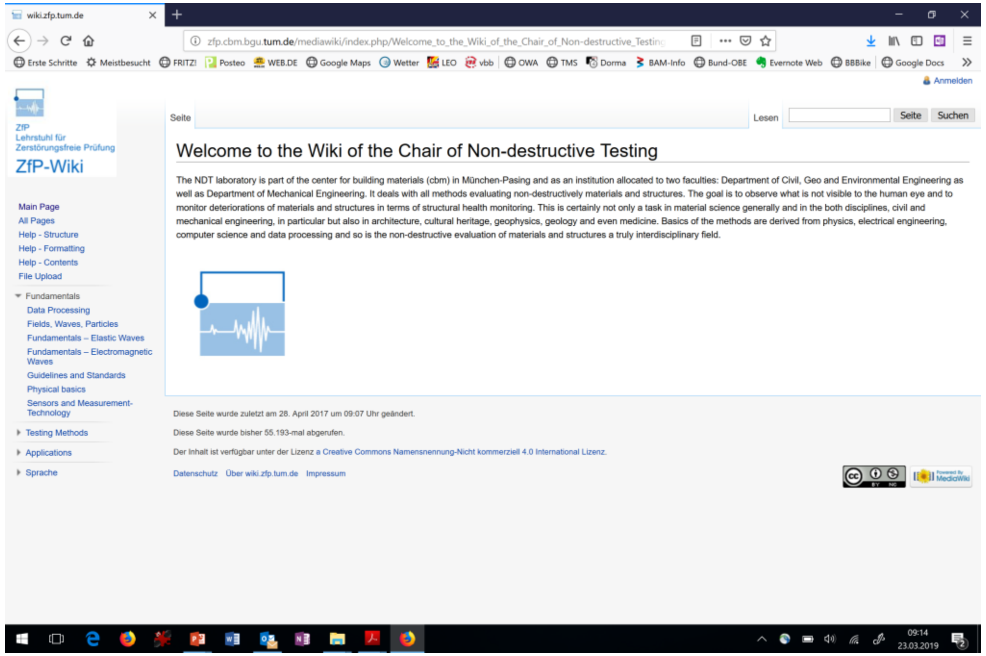
MIL-HDBK-1823A

DEPARTMENT OF DEFENSE HANDBOOK

NONDESTRUCTIVE EVALUATION SYSTEM
RELIABILITY ASSESSMENT

http://www.statisticalengineering.com/mh1823/MIL-HDBK-1823A(2009).pdf

SOURCES



ZfP(NDT)-Wiki

TU Munich (Chair for NDT, Prof. Christian Große)

http://zfp.cbm.bgu.tum.de/mediawiki/index.php

POD

Purpose:

Characterize the reliability of NDT to

- Find a specific flaw/feature: (Hit/Miss) with a desired reliability
  (e. g. “is there a crack?”)

Or

- Measure a specific quantity $\hat{a}$ with a required accuracy
  (e. g. depth of crack)

Source: MIL-HDBK-1823A

POD

Hit/ miss method

The hit/ miss method gives a binary analysis of a testing signal, whether a defect is detected (hit) or missed (miss). Consequently, the testing results can be scaled in four possible configurations depending if a (non-) existing defect is (not) detected:

Table 1: The four possible diagnosis results of testing

defect	detected	not detected	probability
Existing	True positive (TP) The existing defect is detected (hit)	False negative (FN) The existing defect is not detected (miss)	TP + FN = 100 %
non-existing	False positive (FP) A defect is detected even though it is not existing	True negative (TN) No defect is detected, where no defect exists	FP + TN = 100 %

The POD is equal to the probability of TP and can be calculated in the following way:[2]

$$POD = P(TP) = \frac{TP}{(TP + FN)}$$

For one specific flaw size a, this equation can also be represented by the number of positive tests divided by the total amount of tests:[3]

$$POD(a) = \frac{n_{pos}(a)}{n_{tot}(a)}$$

The hit/ miss method requires a clearly defined hit/ miss criterion, e.g. a defined threshold.

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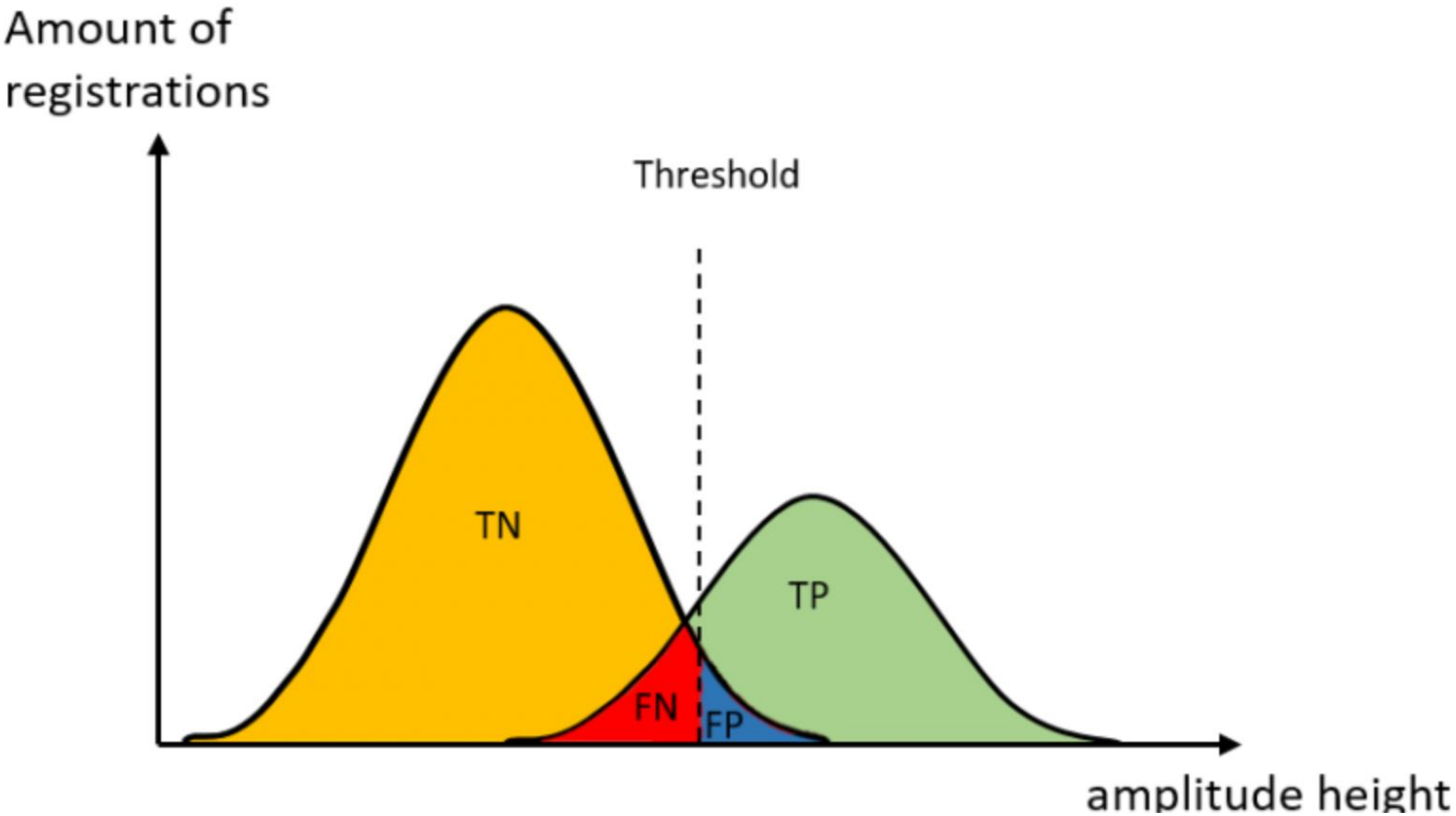
POD



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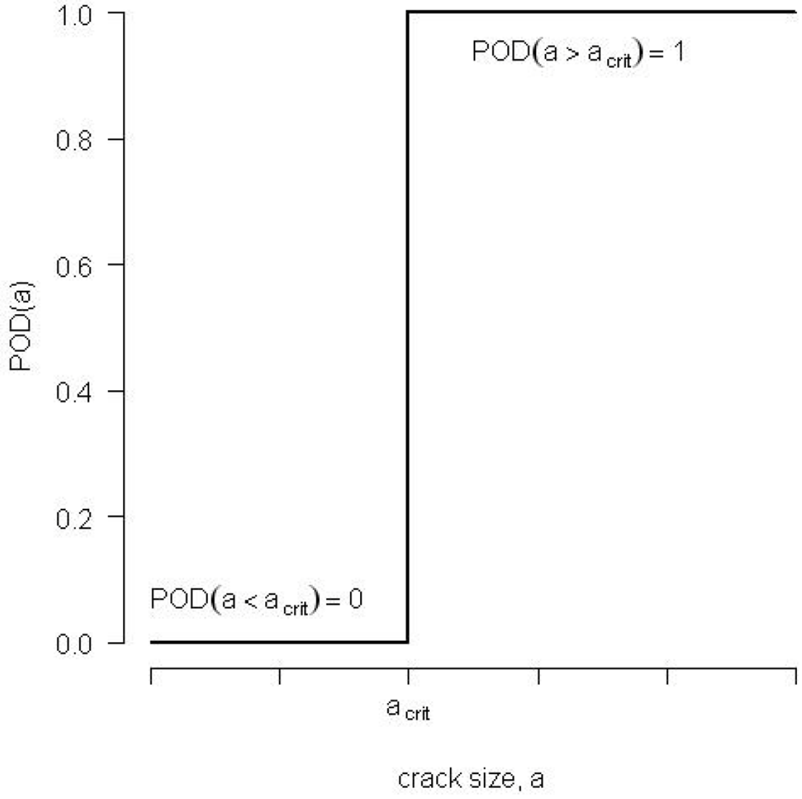
POD

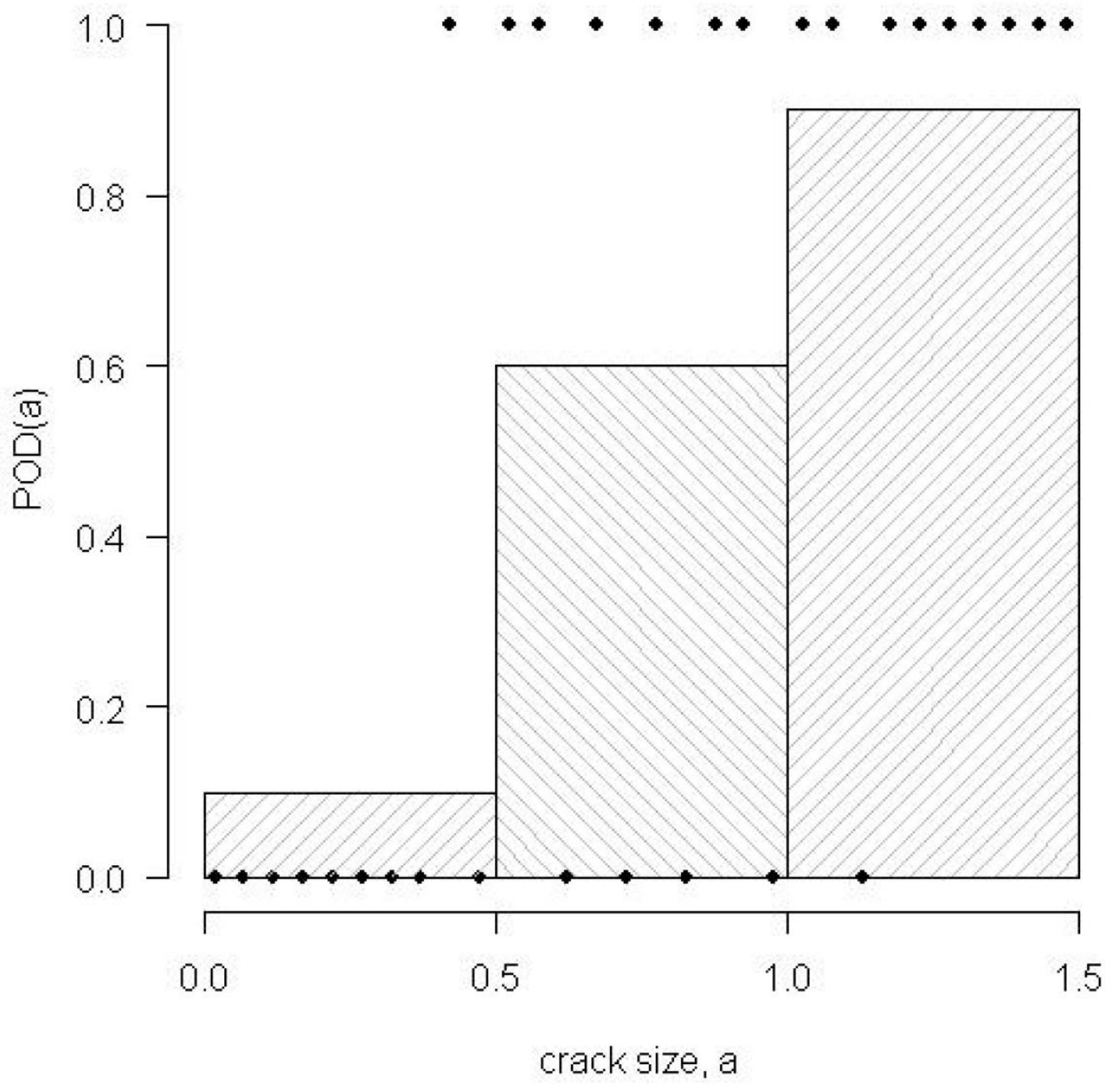
Perfect inspection situation:



Source: MIL-HDBK-1823A

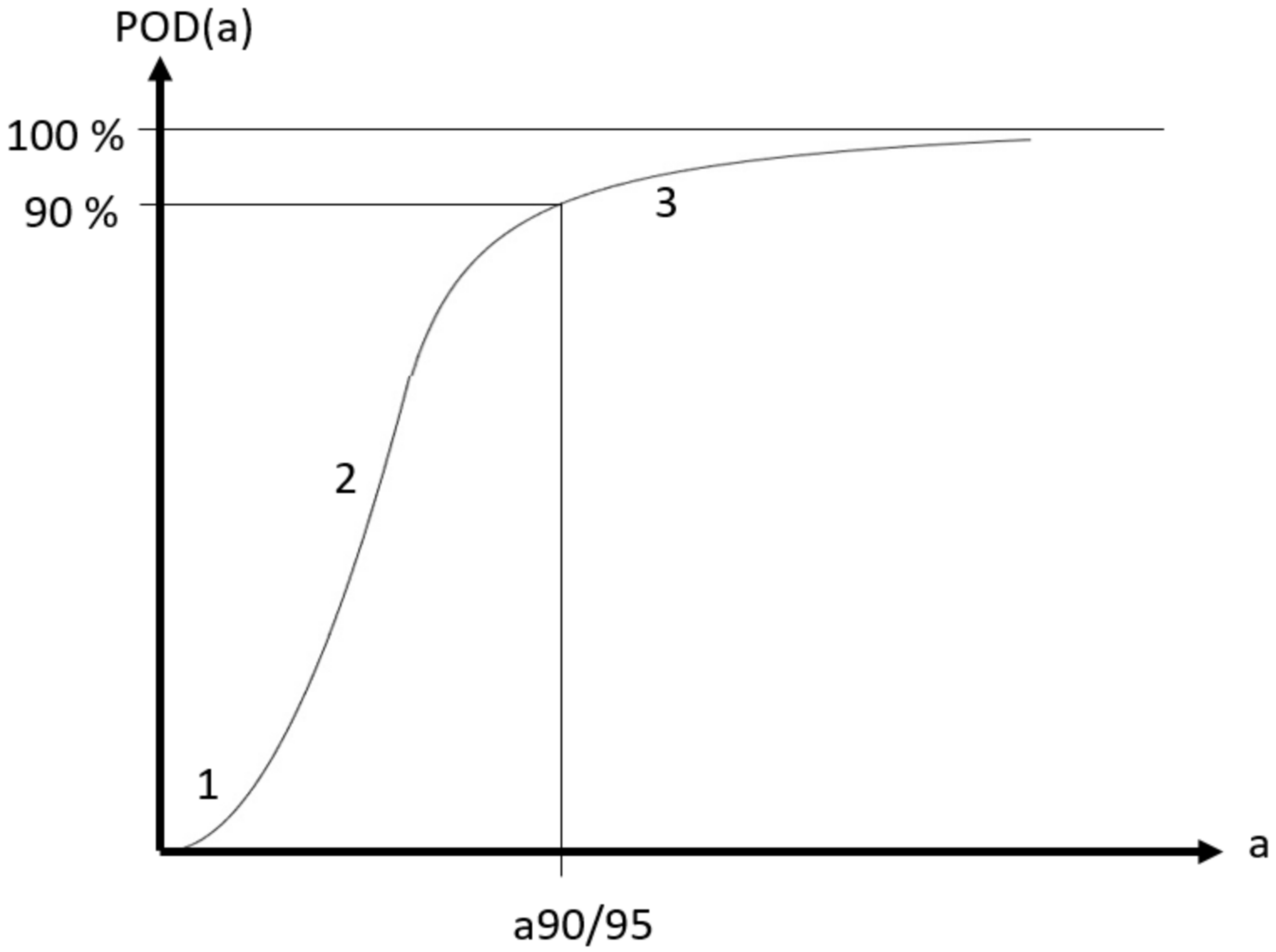
POD

More realistic:



Source: MIL-HDBK-1823A

POD



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POD DETERMINATION

Experimental design – objectives (shortened):

- not to determine the smallest crack the system can find
- to determine the largest crack the system can miss.
- to establish the relationship between POD and target size (or other variables)
- to determine the potential for false positives (false calls) at each set of conditions,,
- To do this use representative specimens with targets of known size (and other characteristics to be evaluated)
  - Real
  - numerical

Source: MIL-HDBK-1823A

POD DETERMINATION

Account for:

- Specimen preprocessing
- Inspector
- Inspections Materials
- Sensor
- Inspection setup (calibration)
- Inspection process
- Imaging consideration

Source: MIL-HDBK-1823A

POD DETERMINATION

Test matrix:

- All relevant variables
- Appropriate intervals
- Appropriate step size

Past: Full matrix required
Today: design of experiments, factorial design

Source: MIL-HDBK-1823A

POD DETERMINATION

Test specimen:

- Multiple test specimen variance in condition and size, enough distance between flaws)
- Unfamiliar to inspectors
- relevant
- referenced
- maintained

Source: MIL-HDBK-1823A

POD DETERMINATION

Test design:

- At least 60 targets for hit/miss (120 are better)
- At least 40 targets for quantitative measures

- For determination of false positives: 3 times as much unflawed measurements, number also depending on required false positive rate
- (e. g. FP rate required to be 1%: > 100 possibilities required)

- Complete independence and some fully unflawed specimen

- Everything as close to real testing situation as possible!

Source: MIL-HDBK-1823A

POD DETERMINATION

Very important: Report!

a. The description of the NDE system,
b. The experimental design,
c. The individual test results, and
d. The summary test results.

Source: MIL-HDBK-1823A

POD DETERMINATION

Public conception:

“The number of inspections (of the same object) increases POD”

Source: MIL-HDBK-1823A

POD DETERMINATION

Public misconception!

“The number of inspections (of the same object) increases POD”

This only increases the confidence in your observation/judgement, but not POD.

Thought experiment: Barrel with red and green apples.

Source: MIL-HDBK-1823A

POD DETERMINATION

How to get a POD curve from a (large) set of experiments/measurements:
Prerequisites:

1. linearity of the parameter â and a
2. uniform variance of the system responses â
3. uncorrelated observations â
4. multivariate normal distribution of the â errors

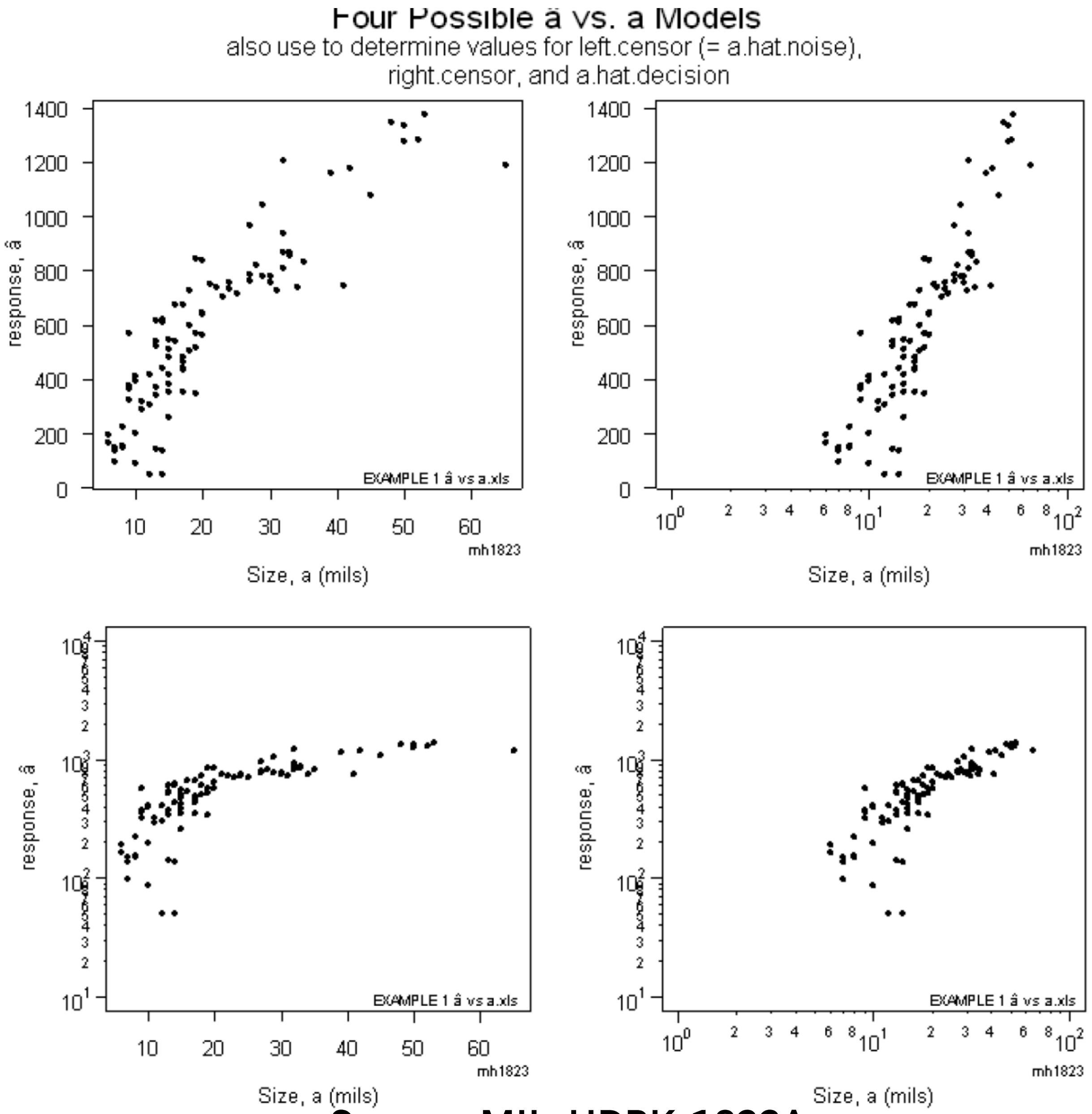
a: experimental parameter(e. g. crack size)
â: system response

Source: MIL-HDBK-1823A

POD DETERMINATION

How to get a POD curve from a (large) set of experiments/measurements: (Generalized) linear models for â vs. a!

1) Make it linear



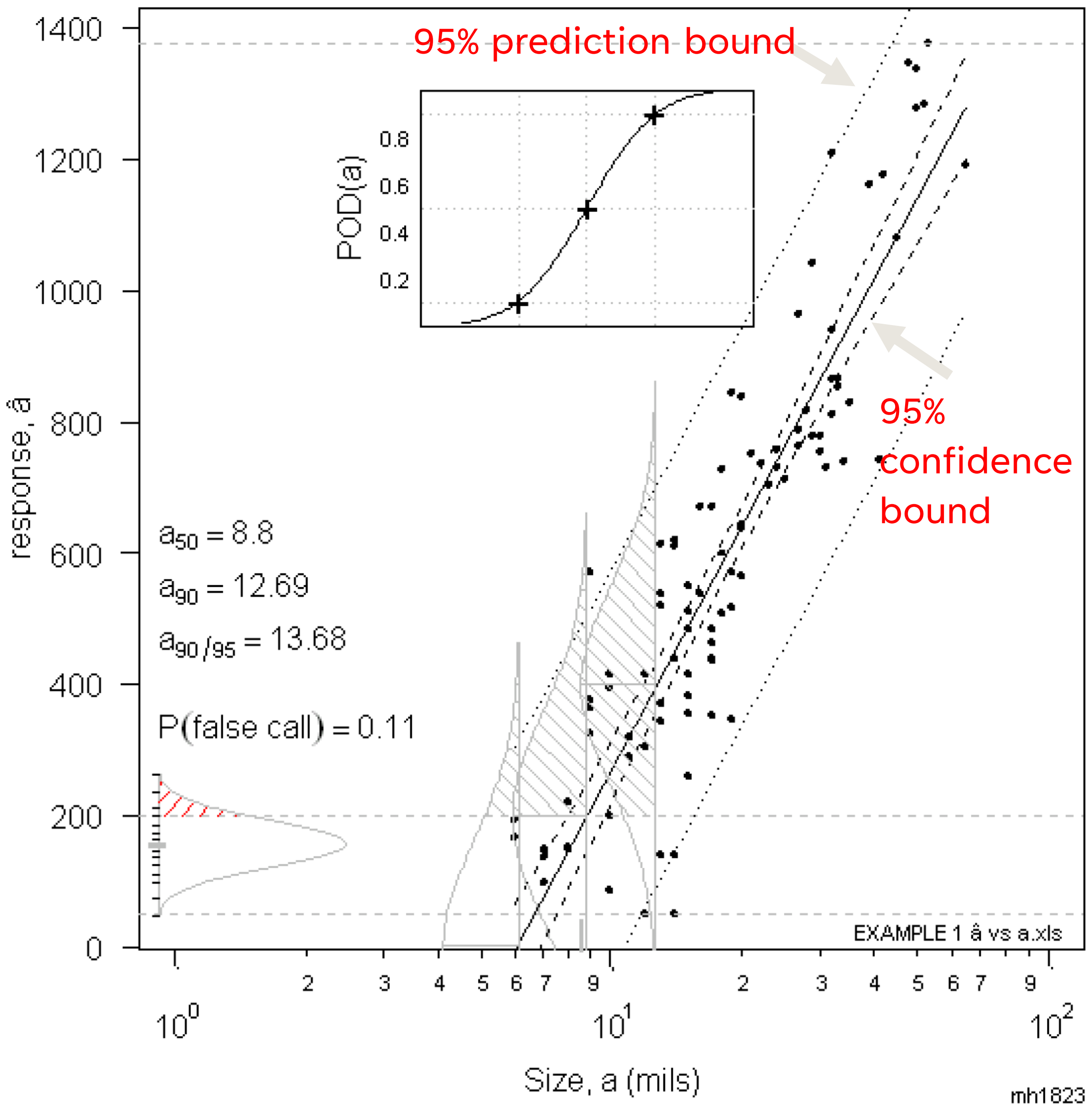
Source: MIL-HDBK-1823A

POD DETERMINATION

2) Evaluate

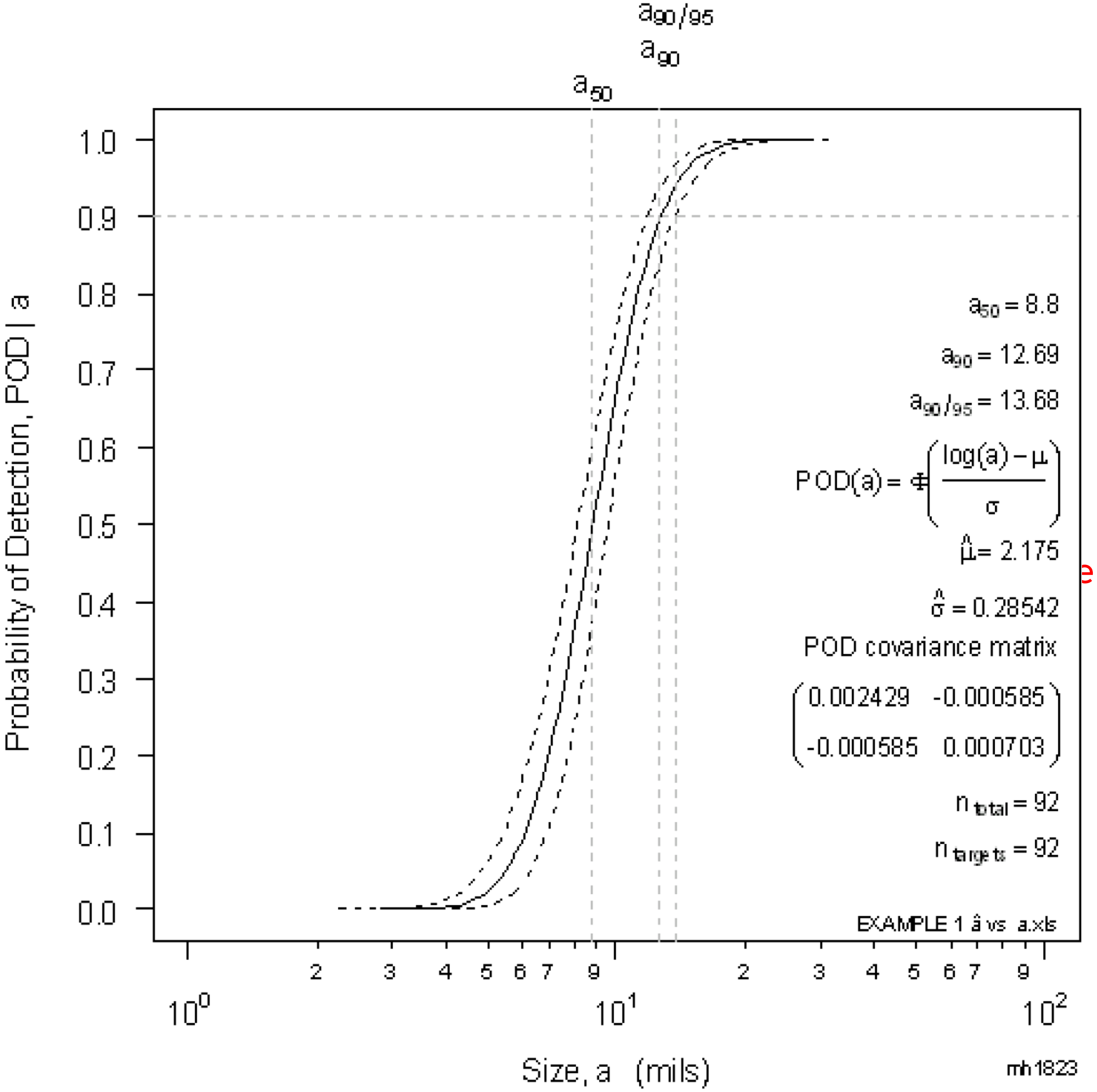
Censoring:
Left:
signals indiscernible from noise.
Right:
100% of measuring range.

Source: MIL-HDBK-1823A



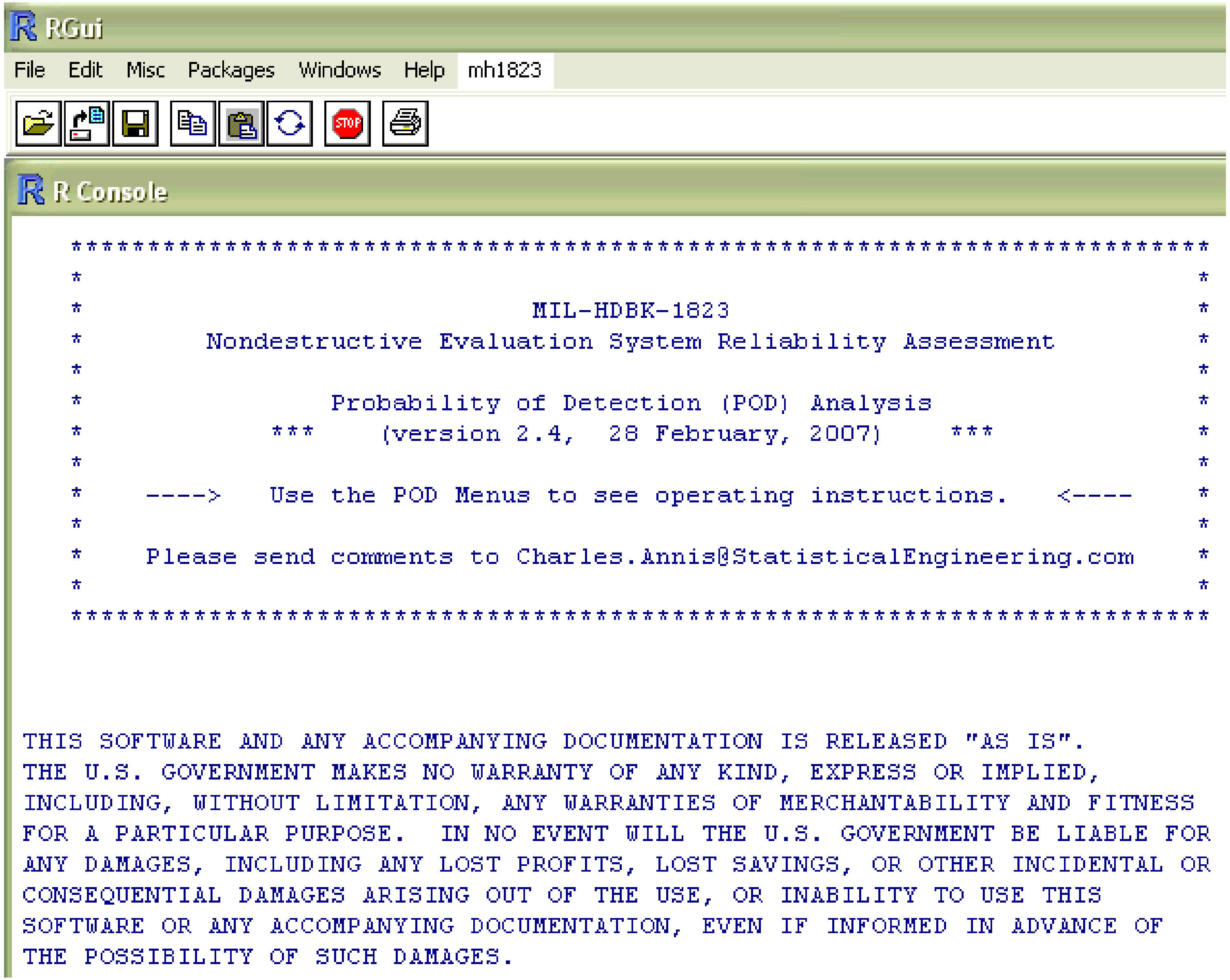
POD DETERM

2) Generate POD(a) from a vs â via Delta method



Source: MIL-HDBK-1823A

POD SOFTWARE



Source: MIL-HDBK-1823A

ROC

ROC
Receiver Operation Charateristic

Characterization of accuracy
of a NDE system

Debated!
- Size effect not included

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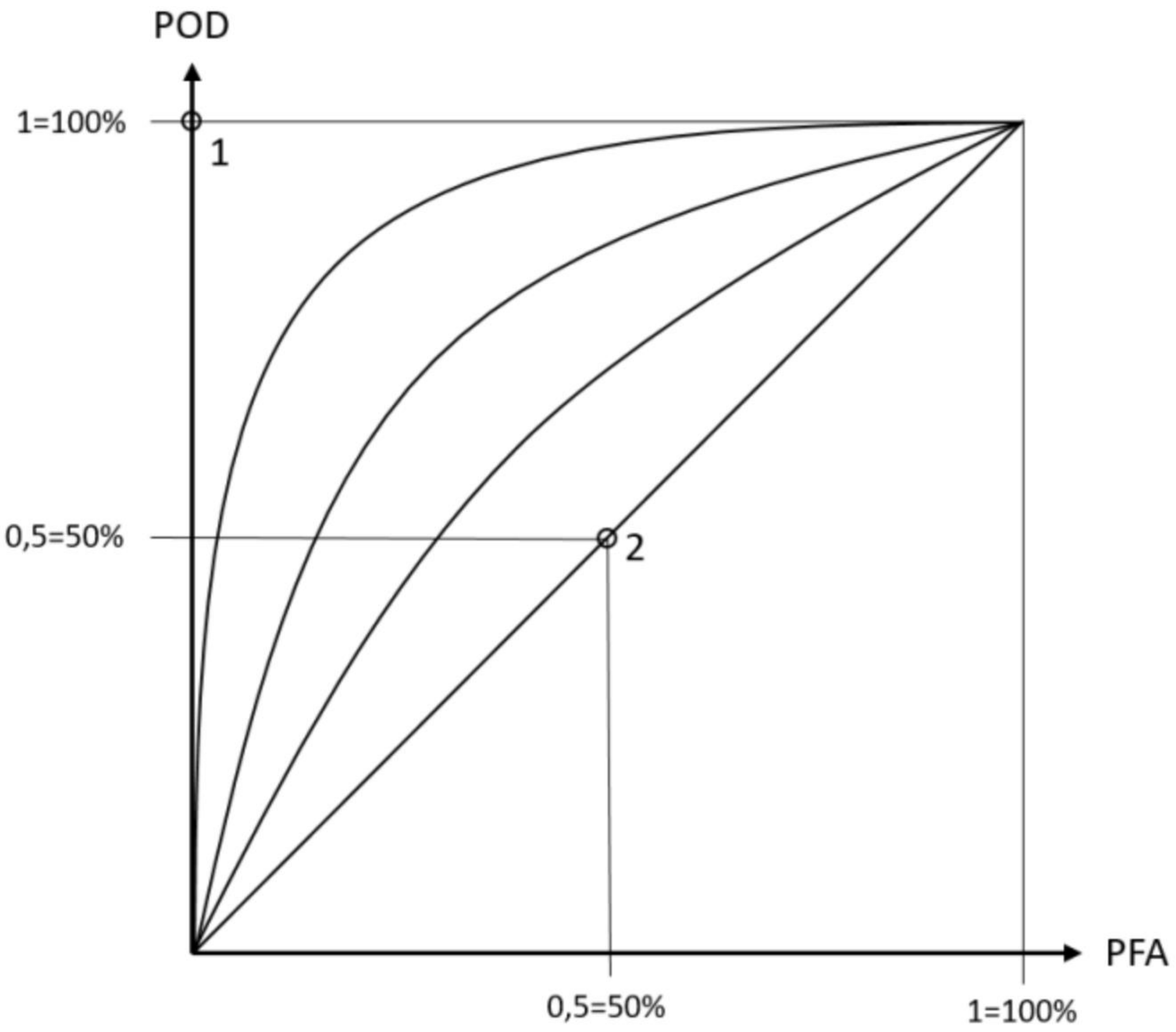
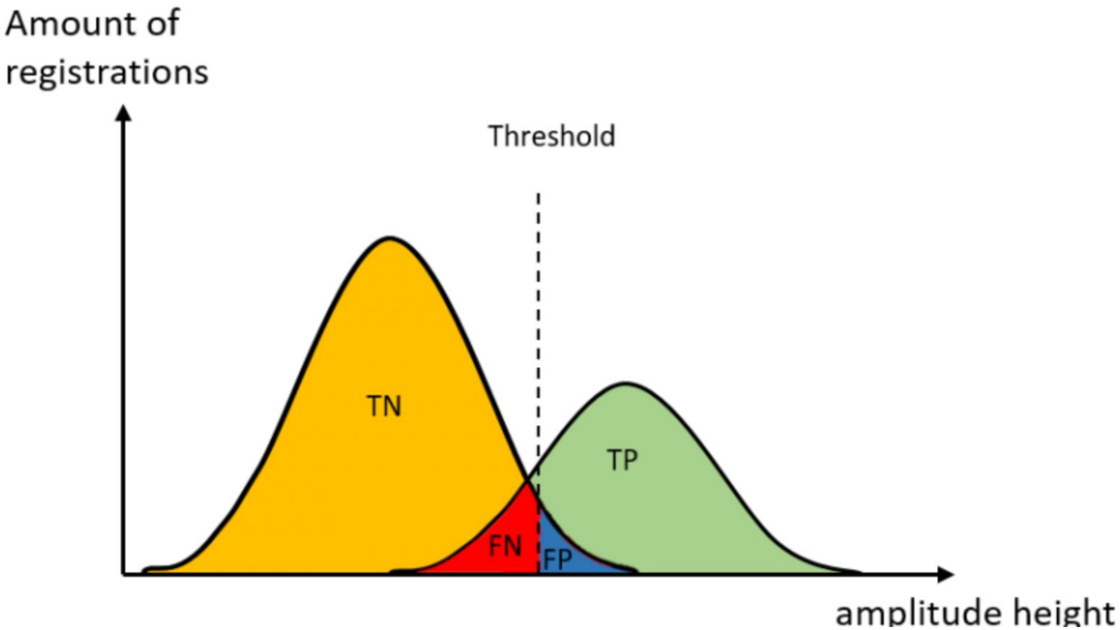


PFA

PFA
Possibility of false alarms

$$PFA = P(FP) = \frac{FP}{(FP + TN)}$$



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FALSE POSITIVES

***Sensitivity, Specificity*, positive predictive value, and negative predictive value**

Relationship between POD and false positives depends on
- The inspection
- frequency of defectives in the population being inspected

a. An NDE demonstration inspection is performed on a known test piece:
(1) *Sensitivity:* "The part has a defect. What is the probability that the test will be positive?" P(+|defect).
(2) *Specificity,* P(-|no defect): "The part does not have a defect. What is the probability that the test will be negative?"

b. An inspection is performed on a part with uncertain history:
(1) *Positive Predictive Value (PPV),* P(defect|+): "The NDE system indicates a positive result, a hit. What is the probability that the part actually has a defect (of the size being inspected for)?"
(2) *Negative Predictive Value (NPV),* P(no defect|-): "The NDE system passed the part, giving a negative test result. What is the probability that the part is defect-free?"

Source: MIL-HDBK-1823A

FALSE POSITIVES

TABLE I-II. Generic contingency table of possible inspection outcomes.

	defect present (+)	defect absent (-)	Totals
Test result positive (+)	**a**	**b**	**a + b**
Test result negative (-)	**c**	**d**	**c + d**
Totals	**a + c**	**b + d**	**a+b+c+d**

Source: MIL-HDBK-1823A

FALSE POSITIVES

„Good inspection“ (specitivity (POD) = 0.9, sensitivity=0.9
)

TABLE I-III. Contingency table of possible inspection outcomes – “good” inspection.

	defect present (+)		defect absent (-)		Totals
Test result positive (+)	**27**	0.9	**997**	0.1	**1024**
Test result negative (-)	**3**	0.1	**8973**	0.9	**8976**
Totals	**30**		**9970**		**10000**

sensitivity, P(+|defect)	0.9	(true positive)
specificity, P(-|no defect)	0.9	(true negative)
PPV, P(defect|+)	**0.02637**	(fraction positive with defect)
NPV, P(no defect|-)	0.99967	(fraction negative without defect)

Source: MIL-HDBK-1823A

FALSE POSITIVES

„Bad inspection“ (specitivity (POD) = 0.5, sensitivity=0.5)

TABLE I-IV. Contingency table of possible inspection outcomes – coin-toss result.

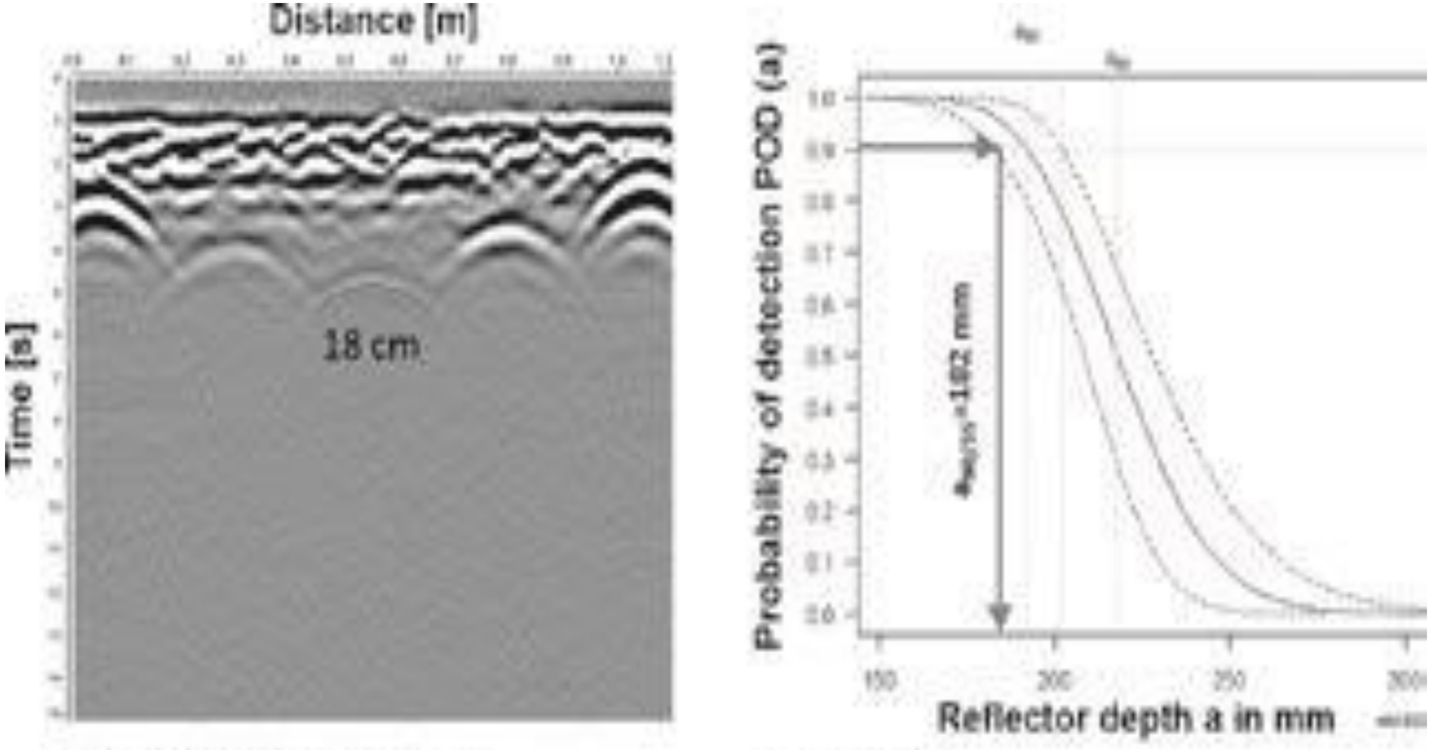
	defect present (+)		defect absent (-)		Totals
Test result positive (+)	**15**	0.5	**4985**	0.5	**5000**
Test result negative (-)	**15**	0.5	**4985**	0.5	**5000**
Totals	**30**		**9970**		**10000**

sensitivity, P(+|defect)	0.5	(true positive)
specificity, P(-|no defect)	0.5	(true negative)
PPV, P(defect|+)	0.003	(fraction positive with defect)
NPV, P(no defect|-)	0.997	(fraction negative without defect)

Source: MIL-HDBK-1823A

POD IN NDT-CE

Detection of rebar in concrete by radar, Taffe & Feistkorn 2013

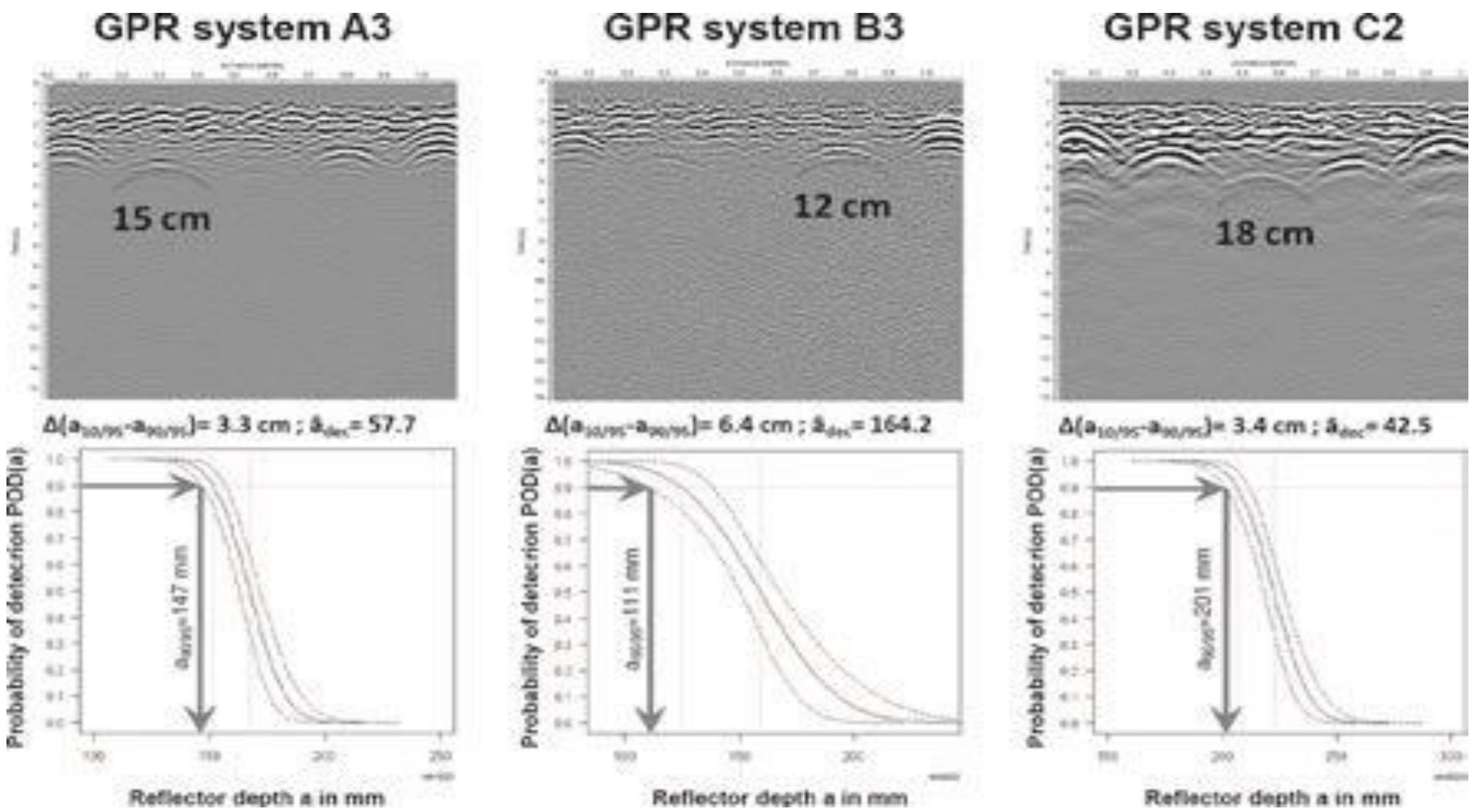


B-scan recorded with GPR

POD curve

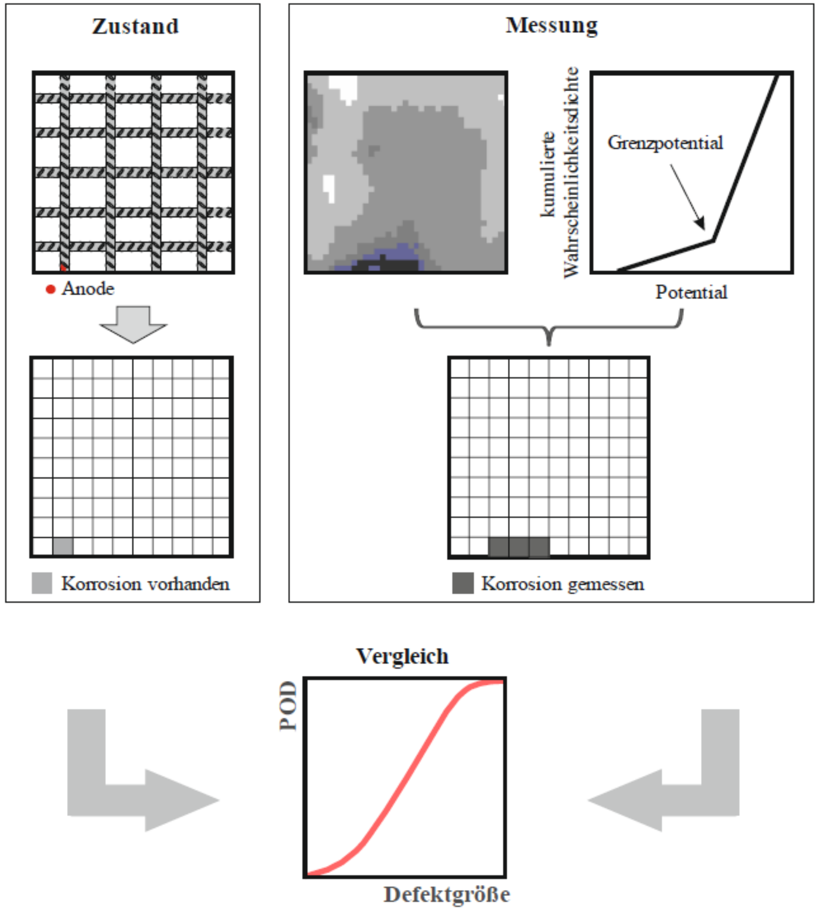
POD IN NDT-CE

Detection of rebar in concrete by radar, Taffe & Feistkorn 2013



POD IN NDT-CE

Potential mapping of rebar corrosion, Kessler, PhD thesis, 2013



POD IN NDT-CE

Potential mapping of rebar corrosion, Kessler, PhD thesis, 2013

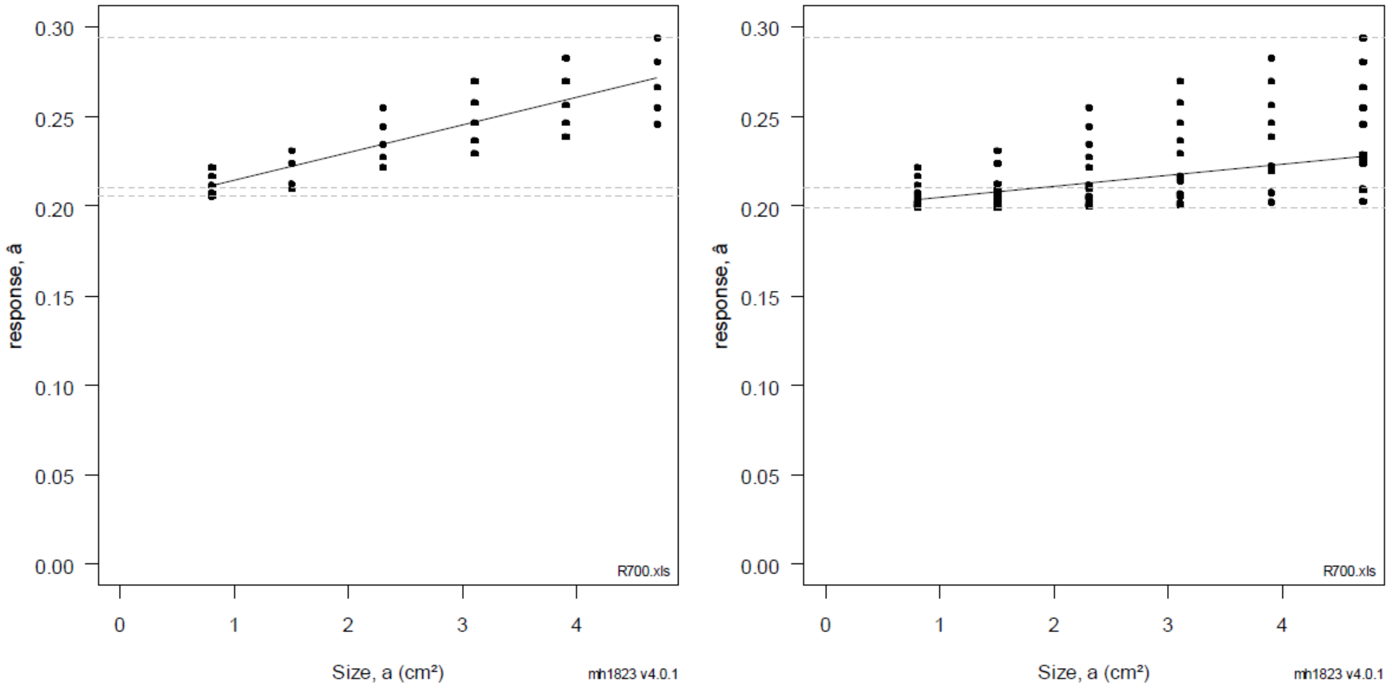


Bild 7-2: Gemessene Potentiale in Abhängigkeit der Defektgröße: Elektrolytwiderstand 700 Ωm; Messraster 5 x 5 cm² (links) und 20 x 20 cm² (rechts).

POD IN NDT-CE

Potential mapping of rebar corrosion, Kessler, PhD thesis, 2013: from data to

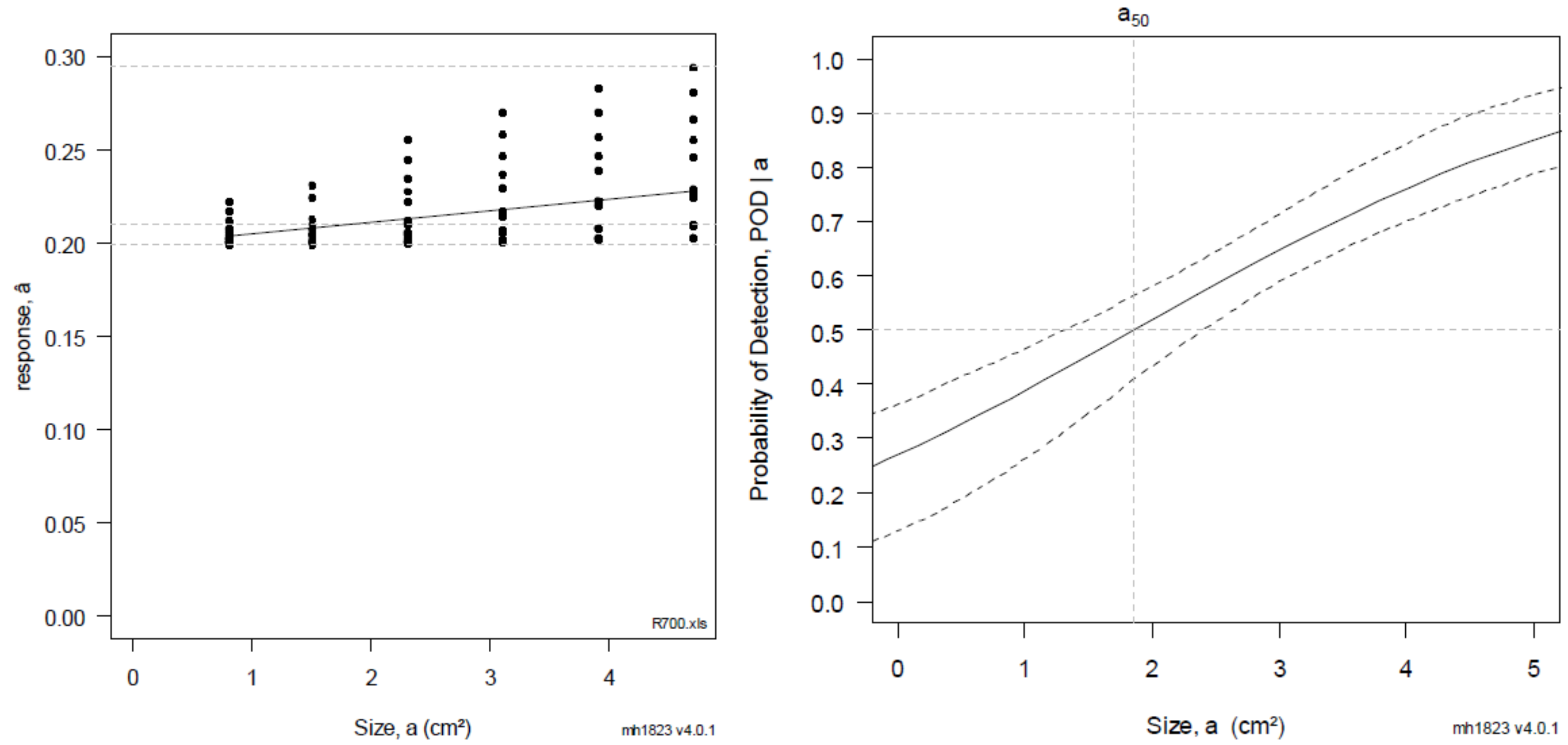


Bild 7-3: Gemessene Potentiale in Abhängigkeit der Defektgröße (links); a vs. â Modell (rechts); Elektrolytwiderstand 700 Ωm; Messraster 20 x 20 cm².

POD IN NDT-CE

Potential mapping of rebar corrosion, Kessler, PhD thesis, 2013: resistivity

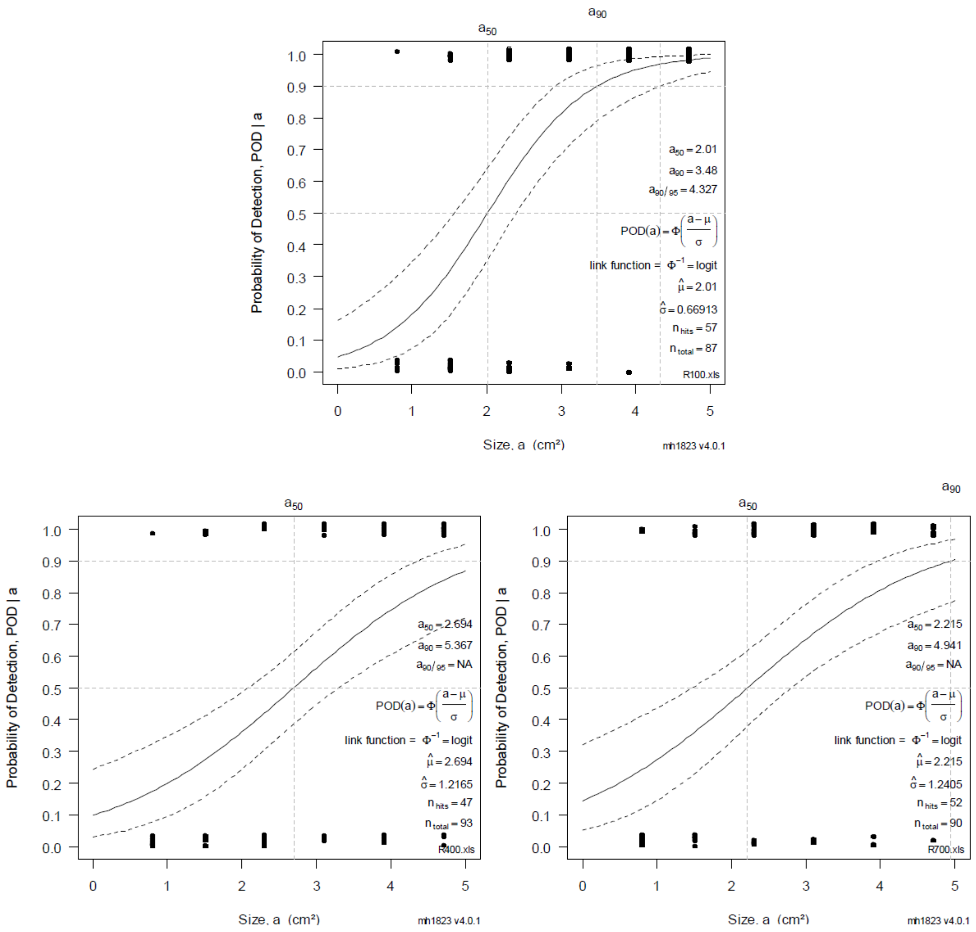


Bild 7-4: POD in Abhängigkeit des Elektrolytwiderstandes: 100 Ωm (oben), 400 Ωm (links), 700 Ωm (rechts); Messraster 15 x 15 cm².

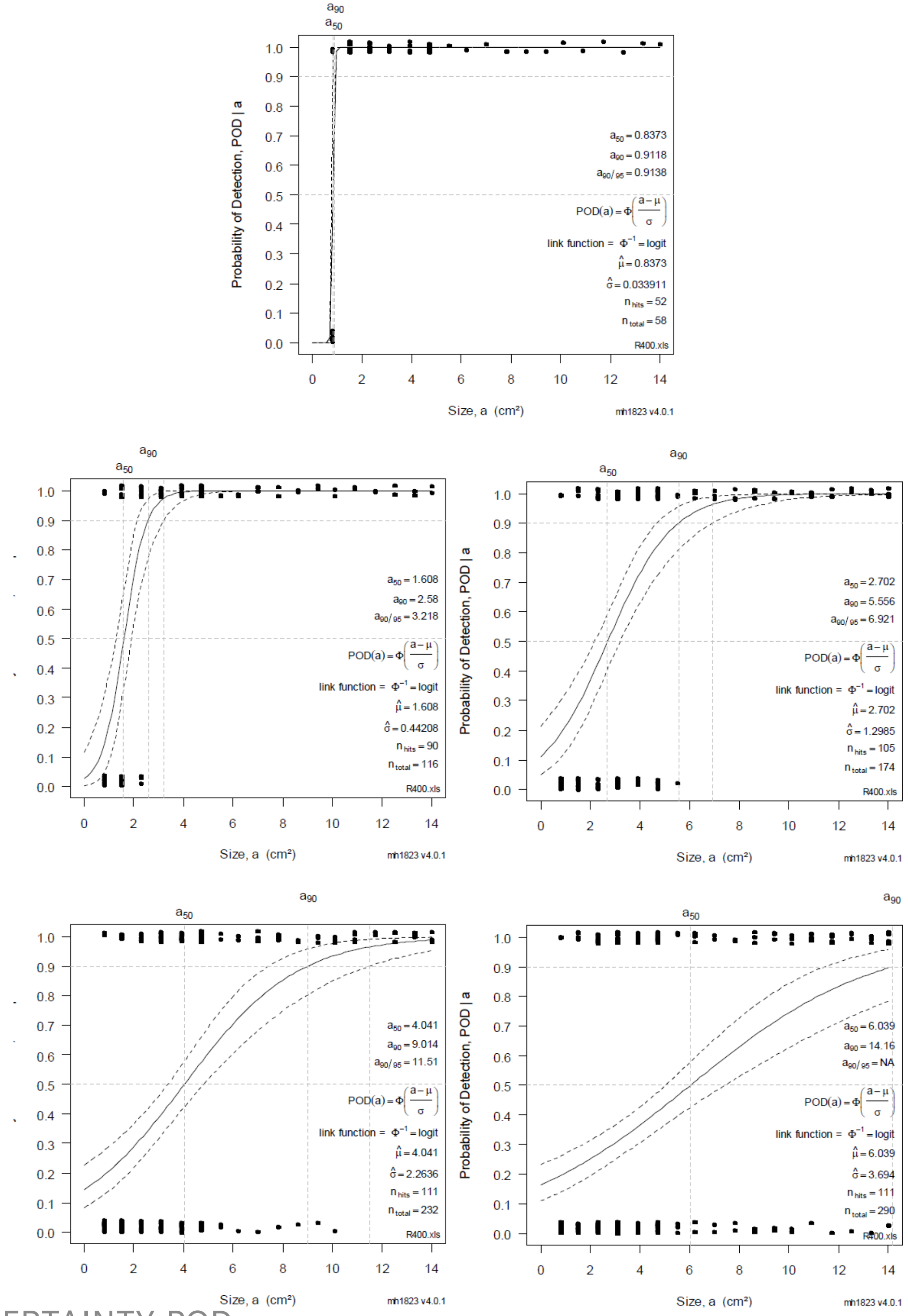
POD IN NDT-CE

Potential mapping of
rebar corrosion,
Kessler, PhD thesis, 2013

Grid interval

Tabelle 7-1: Detektionswahrscheinlichkeit a_{50} und a_{90}

Messraster [cm²]	**a_{50} [cm²]**	**a_{90} [cm²]**
5 x 5	0,84	0,91
10 x 10	1,61	2,60
15 x 15	2,70	5,56
20 x 20	4,04	9,01
25 x 25	6,04	14,20



ild 7-6: POD in Abhängigkeit des Messraster; 5 x 5 cm² (oben), 10 x 10 cm² (2.Reihe links), 15 x 15 cm² (2.Reihe rechts), 20 x 20 cm² (3. Reihe links), 25 x 25 cm² (3.Reihe rechts); R = 400 Ωm.

POD IN NDT-CE

Potential mapping of
rebar corrosion,
Kessler, PhD thesis, 2013

Concrete cover

Tabelle 7-2: Detektionswahrscheinlichkeit a_{50} und a_{90}

Betondeckung [mm]	**a_{50} [cm²]**	**a_{90} [cm²]**
10	2,5	5,2
20	1,7	4,2
30	2,2	4,9
40	2,7	4,9
50	2,3	4,0

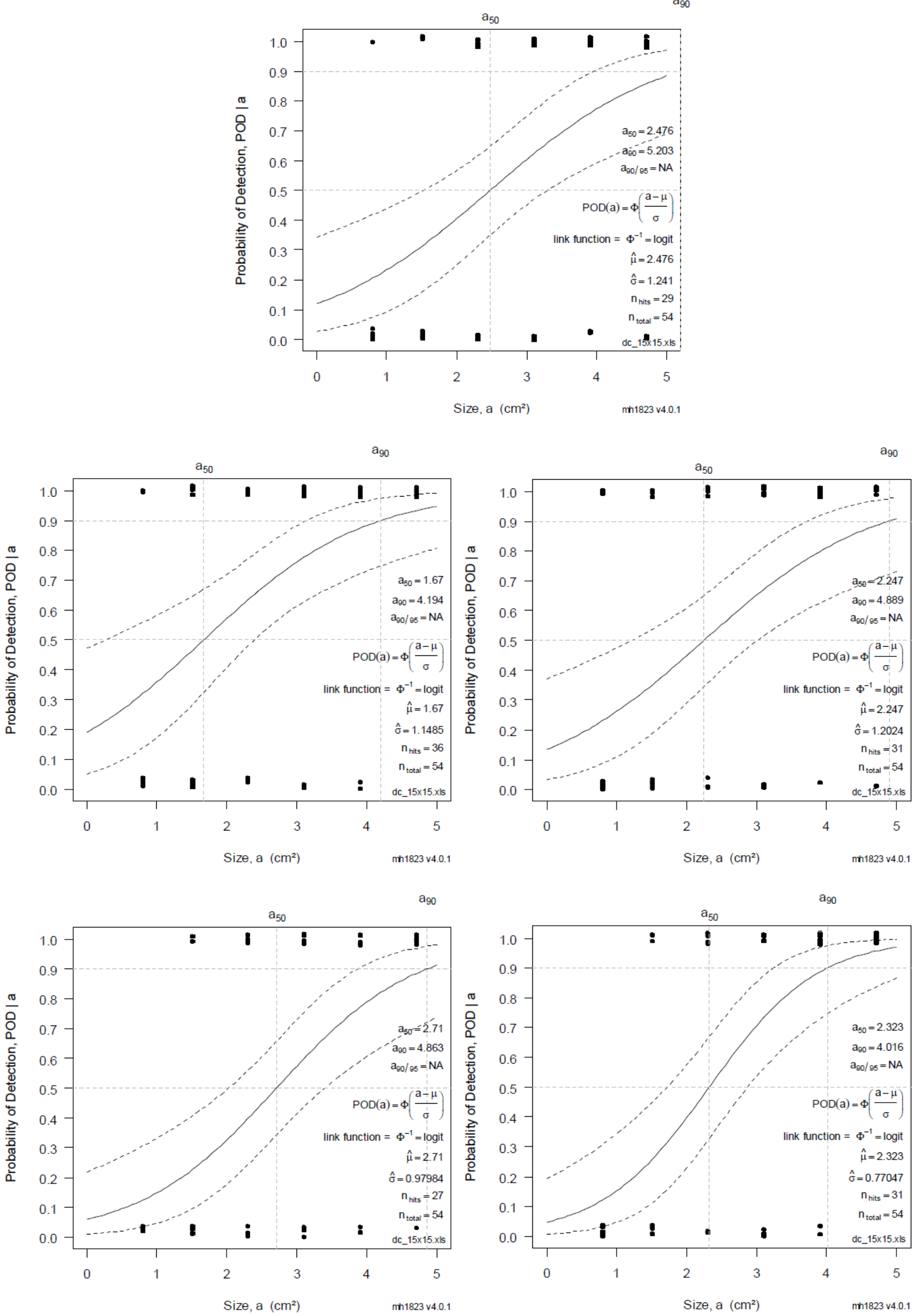


Bild 7-7: POD in Abhängigkeit der Betondeckung; 10 mm (oben), 20 mm (2. Reihe links), 30 mm (2. Reihe rechts), 40 mm² (3. Reihe links), 50 mm (3. Reihe rechts); Messraster 15 x 15 cm².

THANK YOU!

PD Dr. Ernst Niederleithinger

e.niederleithinger@posteo.de