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Statistical methods in process management — Capability and performance —

Part 7:
Capability of measurement processes

Méthodes statistiques dans la gestion de processus — Aptitude et performance —

Partie 7: Aptitude des processus de mesure

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Foreword

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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).

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This document was prepared by Technical Committee ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 4, *Applications of statistical methods in product and process management*.

This third edition cancels and replaces the second edition (ISO 22514-7:2021), which has been technically revised. It also incorporates the Amendment ISO 22514-7:2021/Amd.1:2024.

The main changes are as follows:

— update of the International Standard with the changes from the Amendment;

— change of the Scope;

— numbering of formulae has been added;

— Formula (57) has been corrected;

— former Table 12 has been changed to Table 10;

— Clause 12 has been deleted, it will be moved to ISO 22514-5;

— Annex C has been added.

A list of all parts in the ISO 22514 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of a measurement process is to produce measurement results obtained from defined characteristics on parts or processes. The capability of a measurement process is derived from the statistical properties of measurements from a measurement process that is operating in a predictable manner.

Calculations of capability and performance indices are based on measurement results. The uncertainty of the measurement process used to generate capability and performance indices are estimated before the indices can be meaningful. The actual measurement uncertainty should be adequately small.

If the measurement process is used to judge whether a characteristic of a product conforms to a specification or not, the uncertainty of the measurement process is compared to the specification itself. If the measurement process is used for process control of a characteristic, the uncertainty should be compared with the process variation. Limits of acceptability are stated for both cases.

The quality of measurement results is given by the uncertainty of the measurement process. This is defined by the statistical properties of multiple measurements, or estimates of properties, based on the knowledge of the measurement process.

The methods specified in this document address the implementation uncertainty (for more information on implementation uncertainty, see ISO 17450-2). Therefore, they are only useful if it is known that the method uncertainty and the specification uncertainty are small compared to the implementation uncertainty. This document specifies methods to define and calculate capability indices for measurement processes based on estimated uncertainties. The approach given in ISO/IEC Guide 98-3 (GUM) is the basis of this approach.

Statistical methods in process management — Capability and performance —

Part 7:
Capability of measurement processes

1 Scope

This document defines a procedure to validate measuring systems and a measurement process in order to state whether a given measurement process can satisfy the requirements for a specific measurement task with a recommendation of acceptance criteria. The acceptance criteria are defined as a capability figure (C_{MS}, C_{MP}) or a capability ratio (Q_{MS}, Q_{MP}).

NOTE This document follows the approach taken in ISO/IEC Guide 98-3 (GUM), and establishes a basic, simplified procedure for stating and combining uncertainty components used to estimate a capability index for an actual measurement process.

This document is primarily developed to be used for simple one-dimensional measurement processes, where it is known that the method uncertainty and the specification uncertainty are small compared to the implementation uncertainty. It can also be used in similar cases, where measurements are used to estimate process capability or process performance.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 3534-2, *Statistics — Vocabulary and symbols — Part 2: Applied statistics*

ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3534-1, ISO 3534-2 and ISO 5725 (all parts) and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
maximum permissible error
maximum permissible measurement error
limit of error
MPE
extreme value of measurement error, with respect to a known *reference quantity value* (3.15), permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system

Note 1 to entry: Usually, the term “maximum permissible errors” or “limits of error” is used where there are two extreme values.

Note 2 to entry: The term “tolerance” cannot be used to designate “maximum permissible error”.

[SOURCE: ISO/IEC Guide 99:2007, 4.26, modified — The abbreviated term "MPE" has been added and the admitted term/synonym “maximum permissible error” has been changed to be the preferred term.]

3.2
measurand
quantity intended to be measured

Note 1 to entry: The specification of a measurand requires knowledge of the kind of quantity, description of the state of the phenomenon, body, or substance carrying the quantity, including any relevant component, and the chemical entities involved.

Note 2 to entry: In the second edition of the VIM and in IEC 60050-300:2001, the measurand is defined as the “quantity subject to measurement”.

Note 3 to entry: The measurement, including the measuring system and the conditions under which the measurement is carried out, might change the phenomenon, body, or substance such that the quantity being measured may differ from the measurand as defined. In this case, adequate correction is necessary.

EXAMPLE 1 The potential difference between the terminals of a battery may decrease when using a voltmeter with a significant internal conductance to perform the measurement. The open-circuit potential difference can be calculated from the internal resistances of the battery and the voltmeter.

EXAMPLE 2 The length of a steel rod in equilibrium with the ambient Celsius temperature of 23 °C is different from the length at the specified temperature of 20 °C, which is the measurand. In this case, a correction is necessary.

Note 4 to entry: In chemistry, “analyte”, or the name of a substance or compound, are terms sometimes used for “measurand”. This usage is erroneous because these terms do not refer to quantities.

[SOURCE: ISO/IEC Guide 99:2007, 2.3]

3.3
measurement uncertainty
uncertainty of measurement
uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a *measurand* (3.2), based on the information used

Note 1 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Note 2 to entry: The parameter may be, for example, a standard deviation called *standard measurement uncertainty* (3.6) (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by *Type A evaluation of measurement uncertainty* (3.4) from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by *Type B evaluation of measurement uncertainty* (3.5), can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[SOURCE: ISO/IEC Guide 99:2007, 2.26]

3.4
Type A evaluation of measurement uncertainty
Type A evaluation
evaluation of a component of *measurement uncertainty* (3.3) by statistical analysis of measurement quantity values obtained under defined measurement conditions

Note 1 to entry: For various types of measurement conditions, see repeatability condition of measurement, intermediate precision condition of measurement, and reproducibility condition of measurement.

Note 2 to entry: For information about statistical analysis, see e.g. ISO/IEC Guide 98-3.

Note 3 to entry: See also ISO/IEC Guide 98-3:2008, 2.3.2, ISO 5725 (all parts), ISO 13528, ISO 21748, ISO/TS 21749.

[SOURCE: ISO/IEC Guide 99:2007, 2.28]

3.5
Type B evaluation of measurement uncertainty
Type B evaluation
evaluation of a component of *measurement uncertainty* (3.3) determined by means other than a *Type A evaluation of measurement uncertainty* (3.4)

EXAMPLE Evaluation based on information

— associated with authoritative published quantity values,

— associated with the quantity value of a certified reference material,

— obtained from a calibration certificate,

— about drift,

— obtained from the accuracy class of a verified measuring instrument, and

— obtained from limits deduced through personal experience.

Note 1 to entry: See also ISO/IEC Guide 98-3:2008, 2.3.3.

[SOURCE: ISO/IEC Guide 99:2007, 2.29]

3.6
standard measurement uncertainty
standard uncertainty of measurement
standard uncertainty
measurement uncertainty (3.3) expressed as a standard deviation

[SOURCE: ISO/IEC Guide 99:2007, 2.30]

3.7
combined standard measurement uncertainty
combined standard uncertainty
standard measurement uncertainty (3.6) that is obtained using the individual standard measurement uncertainties associated with the input quantities in a *measurement model* (3.11)

Note 1 to entry: In case of correlations of input quantities in a measurement model, covariances must also be taken into account when calculating the combined standard measurement uncertainty; see also ISO/IEC Guide 98-3:2008, 2.3.4.

[SOURCE: ISO/IEC Guide 99:2007, 2.31]

3.8
expanded uncertainty
expanded measurement uncertainty
product of a *combined standard measurement uncertainty* (3.7) and a factor larger than the number one

Note 1 to entry: The factor depends upon the type of probability distribution of the output quantity in a *measurement model* (3.11) and on the selected coverage probability.

Note 2 to entry: The term "factor" in this definition refers to a coverage factor.

Note 3 to entry: Expanded measurement uncertainty is termed "overall uncertainty" in paragraph 5 of Recommendation INC-1 (1980) (see ISO/IEC Guide 98-3) and simply "uncertainty" in IEC documents.

[SOURCE: ISO/IEC Guide 99:2007, 2.35; modified: the admitted term/synonym "expanded uncertainty" has been changed to be the preferred term]

3.9
measurement bias
bias
estimate of a systematic measurement error

[SOURCE: ISO/IEC Guide 99:2007, 2.18]

3.10
measurement result
set of quantity values being attributed to a *measurand* (3.2), together with any other available relevant information

Note 1 to entry: A measurement result generally contains "relevant information" about the set of quantity values, such that some can be more representative of the measurand than others. This can be expressed in the form of a probability density function (PDF).

Note 2 to entry: A measurement result is generally expressed as a single measured quantity value and a *measurement uncertainty* (3.3). If the measurement uncertainty is considered to be negligible for some purpose, the measurement result may be expressed as a single measured quantity value. In many fields, this is the common way of expressing a measurement result.

Note 3 to entry: In the traditional literature and in the previous edition of the VIM, measurement result was defined as a value attributed to a measurand and explained to mean an indication, or an uncorrected result, or a corrected result, according to the context.

3.11
measurement model
model of measurement
model
mathematical relation among all quantities known to be involved in a measurement

Note 1 to entry: A general form of a measurement model is the equation $h(Y, X_1, \ldots, X_n) = 0$, where Y, the output quantity in the measurement model, is the *measurand* (3.2), the quantity value of which is to be inferred from information about input quantities in the measurement model $X_1, \ldots, X_n$.

Note 2 to entry: In more complex cases, where there are two or more output quantities in a measurement model, the measurement model consists of more than one equation.

[SOURCE: ISO/IEC Guide 99:2007, 2.48]

3.12
measurement task
quantification of a *measurand* (3.2) according to its definition

Note 1 to entry: The measurement task is synonymous with the purpose of applying the measurement procedure.

Note 2 to entry: The measurement task can be used, e.g.

— to compare the *measurement results* (3.10) with one or two specification limits in order to state whether the value of the measurand is an admissible value,

— to state whether the measurand characterizing a manufacturing process is within the specifications given, and

— to obtain a confidence interval of given average length for the difference between two values of the same measurand.

3.13
measurement process
set of operations to determine the value of a quantity

[SOURCE: ISO 9000:2015, 3.11.5]

3.14
resolution
smallest change in a quantity being measured that causes a perceptible change in the corresponding indication provided by a measuring equipment

Note 1 to entry: Resolution can depend on, for example, noise (internal or external) or friction. It may also depend on the value of a quantity being measured.

Note 2 to entry: For a digital displaying device, the resolution is equal to the digital step.

[SOURCE: ISO/IEC Guide 99:2007, 4.14 modified - "provided by a measuring equipment" has been added in the definition, note 3 to entry has been added.]

3.15
reference quantity value
reference value
quantity value used as a basis for comparison with values of quantities of the same kind

Note 1 to entry: A reference quantity value can be a true quantity value of a *measurand* (3.2), in which case it is unknown, or a conventional quantity value, in which case it is known.

Note 2 to entry: A reference quantity value with associated *measurement uncertainty* (3.3) is usually provided with reference to:

a) a material, e.g. a certified reference material,

b) a device, e.g. a stabilized laser,

c) a reference measurement procedure, and

d) a comparison of measurement standards.

[SOURCE: ISO/IEC Guide 99:2007, 5.18]

3.16
repeatability
measurement repeatability
measurement precision under repeatability conditions of measurement

[SOURCE: ISO/IEC Guide 99:2007, 2.21; modified: the admitted term/synonym “repeatability” has been changed to be the preferred term]

3.17
reproducibility
measurement reproducibility
measurement precision under reproducibility conditions of measurement

[SOURCE: ISO/IEC Guide 99:2007, 2.25, modified — The Note has been deleted and the admitted term/synonym “reproducibility” has been changed to be the preferred term.]

3.18
measurement process stability
property of a *measurement process* (3.13), whereby its properties remain constant in time

3.19
item
entity
object
anything that can be described and considered separately

4 Symbols and abbreviated terms

4.1 Symbols

a	half width of a distribution of possible values of input quantity
a_{OBJ}	maximal form deviation
α	significance level
α_T	temperature expansion coefficient
B_{I}	bias
$B_{\mathrm{I\,max}}$	maximal found bias
$\bar{B}_{\mathrm{I}}$	arithmetic mean of biases
C_{MP}	measurement process capability index
$C_{\mathrm{MP\,min}}$	minimum measurement process capability index
C_{MS}	measuring system capability index
$C_{\mathrm{MS\,min}}$	minimum measuring system capability index
C_{p}	process capability index
C_{pk}	minimum process capability index
$C_{\mathrm{p\,obs}}$	observed process capability index
$C_{\mathrm{p\,real}}$	real process capability index
Δ	process dispersion/variation
Δ_{U}	50 % process dispersion/variation to upper limit
Δ_{L}	50 % process dispersion/variation to lower limit
$F_{1-\alpha/2}$	critical value in a F- test
k	coverage factor
K	total number of replicate measurements on one reference. The reference can be a reference standard or a reference workpiece
k_{CAL}	coverage factor from the calibration certificate
l	measured length

L	lower specification limit
M_{PE1}	maximum permissible error (of the first characteristic)
M_{PE2}	maximum permissible error (of the second characteristic)
M_{PE}	maximum permissible error (of the measuring system) (MPE-value)
N	number of standards
n	number of measurements
P_p	process performance index
$P_{p\ obs}$	observed process performance index
$P_{p\ real}$	real process performance index
$Q_{MS\ min}$	minimum measuring system capability ratio
Q_{MS}	measuring system capability ratio
$Q_{MP\ min}$	minimum measurement process capability ratio
Q_{MP}	measurement process capability ratio
R_E	resolution of measuring system
s	sample standard deviation (on the mean bias)
s_A	standard deviation (on the measuring system repeatability, ANOVA)
S_{eff}	is the estimated “true” standard deviation;
s_{EV}	standard deviation (on the measuring system repeatability)
s_{LIN}	standard deviation (from the linearity system repeatability)
s_{obs}	standard deviation (the observed standard deviation)
s_p	standard deviation (from the process)
s_{RES}	standard deviation (on the mean bias)
T	temperature
ΔT	temperature difference
$t_{1-\alpha/2}$	the two-sided critical value of Student's t distribution
U-L	tolerance
U	upper specification limit
u	standard uncertainty
u_α	standard uncertainty on the coefficient of expansion
u_{AV}	standard uncertainty from the operator's reproducibility
u_{BI}	standard uncertainty from the measurement bias

u_{CAL}	calibration standard uncertainty on a standard
u_{EV}	standard uncertainty from maximum value of repeatability or resolution
u_{EVR}	standard uncertainty from repeatability on standards
u_{EVO}	standard uncertainty from repeatability on test parts
u_{GV}	standard uncertainty from reproducibility of the measuring system
u_{IAi}	standard uncertainty from interactions
u_{LIN}	standard uncertainty from linearity of the measuring system
u_{MP}	combined standard uncertainty on measurement process
u_{MPE}	standard uncertainty calculated based on maximum permissible error
u_{MS}	combined standard uncertainty on measuring system
$u_{\mathrm{MS\text{-}REST}}$	standard uncertainty from other influence components not included in the analysis of the measuring system
u_{OBJ}	standard uncertainty from test part inhomogeneity
u_{RE}	standard uncertainty from resolution of measuring system
u_{REST}	standard uncertainty from other influence components not included in the analysis of the measurement process
u_{STAB}	standard uncertainty from the stability of measuring system
u_{T}	standard uncertainty from temperature
u_{TA}	standard uncertainty from expansion coefficients
u_{TD}	standard uncertainty from temperature difference between workpiece and measuring system
U_{CAL}	expanded uncertainty on the calibration of a standard
U_{MS}	expanded uncertainty of the measuring system
U_{MP}	expanded uncertainty of the measurement process
U_{LIN}	expanded uncertainty from linearity of the measuring system
$X_{0,135\,\%}$	0,135 % quantile of process dispersion
$X_{50\,\%}$	50 % quantile of process dispersion
$X_{99,865\,\%}$	99,865 % quantile of process dispersion
x_i	i^{th} measurement input quantity
x_{m}	reference quantity value
X_{mid}	process midpoint
X_{nom}	nominal value/operating point
$\bar{x}_{\mathrm{g}}$	arithmetic mean of all the sample values

$\bar{y}$ average of all measurements

4.2 Abbreviated terms

ANOVA	analysis of variance
GPS	geometrical product specifications
GUM	guide to the expression of the uncertainty of measurement (ISO/IEC Guide 98-3)
MPE	maximum permissible error
MPL	maximum permissible error limit
SPC	statistical process control
VIM	international vocabulary of metrology (ISO/IEC Guide 99)

5 Basic principles

5.1 General

The method described in this document covers a large part of the estimation of measurement uncertainty that occurs in practice. In some cases, where the preconditions set out for this method (no correlation between influence components, no sensitivity factors, simple linear model present) are not present, the user shall utilize the general current method for determining the measurement uncertainty that is described in ISO/IEC Guide 98-3 (GUM).

The following method addresses the implementation uncertainty (see also ISO 17450-2). Therefore, it shall be determined before the method is applied that the method uncertainty and the specification uncertainty is small compared to the implementation uncertainty. Further, the method can be used also for more complex geometrical measurement processes, such as coordinate measurements, surface texture and location measurements that rely on several measurement points or simultaneous measurements in several directions, or both (see an example in Annex C).

The ISO/IEC Guide 98-3 (GUM) permits the evaluation of standard uncertainties by any appropriate means. It distinguishes the evaluation by the statistical treatment of repeated observations as a Type A evaluation of uncertainty, and the evaluation by any other means as a Type B evaluation of uncertainty. In evaluating the combined standard uncertainty, both types of evaluation are to be characterized by squared standard uncertainties and treated in the same way. The standard uncertainties can be aggregated to obtain the (combined) standard measurement uncertainty. This evaluation of uncertainty is carried out, according to ISO/IEC Guide 98-3 (GUM), using the law of, propagation of uncertainty. Full details of this procedure and the additional assumptions on which it is based are given in ISO/IEC Guide 98-3 (G UM).

To assess a measuring system or a measurement process, the capability ratio Q_{MS} or Q_{MP} or the capability index C_{MS} or C_{MP} can be calculated based on the combined standard measurement uncertainty and the specification.

The combined expanded uncertainty should be substantially smaller than the tolerance of the characteristic being measured.

If the uncertainty components estimated from an experiment (Type A evaluation) do not correspond to the expected spread of these components in the actual measurement process, then these components cannot be estimated experimentally. Instead, they should be derived through the use of a mathematical model (Type B evaluation e.g. constant temperature in a measuring laboratory when conducting a study and the normal temperature variations of the place of the future application). The practitioner should fully understand the model to be used.