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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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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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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 process management*.

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 have to be estimated before the indices can be meaningful. The actual measurement uncertainty needs to 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 has to be compared to the specification itself. If the measurement process is used for process control of a characteristic, the uncertainty needs to be compared with the process variation. Limits of acceptability have to be 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 described in this part of ISO 22514 only 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 part of ISO 22514 describes methods to define and calculate capability indices for measurement processes based on estimated uncertainties. The approach given in ISO/IEC Guide 98-3, *Guide to the expression of uncertainty in measurements* (*GUM*), is the basis of this approach.

DRAFT INTERNATIONAL STANDARD **ISO/DIS 22514-7:2020(E)**

Statistical methods in process management — Capability and performance —

Part 7:
Capability of measurement processes

1 Scope

This part of ISO 22514 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}) or a capability ratio (Q_{MS}).

NOTE 1 This part of ISO 22514 follows the approach taken in ISO/IEC Guide 98-3, *Guide to the expression of the uncertainty in measurement (GUM)*, and establishes a basic, simplified procedure for stating and combining uncertainty components used to estimate a capability index for an actual measurement process.

NOTE 2 This part of ISO 22514 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. It is not suitable for complex geometrical measurement processes, such as surface texture, form, orientation and position measurements that rely on several measurement points or simultaneous measurements in several directions.

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 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 5725-3, *Accuracy (trueness and precision) of measurement methods and results — Part 3: Intermediate measures of the precision of a standard measurement method*

ISO 5725-4, *Accuracy (trueness and precision) of measurement methods and results — Part 4: Basic methods for the determination of the trueness of a standard measurement method*

ISO 5725-5, *Accuracy (trueness and precision) of measurement methods and results — Part 5: Alternative methods for the determination of the precision of a standard measurement method*

ISO 5725-6, *Accuracy (trueness and precision) of measurement methods and results — Part 6: Use in practice of accuracy values*

ISO 7870-1, *Control charts — Part 1: General guidelines*

ISO/IEC Guide 98-3:2008, *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 terminological databases for use in standardization at the following addresses:

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

IEC Electropedia: available at http://www.electropedia.org/

3.1

maximum permissible measurement error
maximum permissible error
limit of error
MPE
extreme value of measurement error, with respect to a known reference quantity value, 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" can not be used to designate 'maximum permissible error'.

[SOURCE: ISO/IEC Guide 99:2007, 4.26, modified abbreviation "MPE" was added]

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 will be 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, 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 (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 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, 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 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, ISO 13528, ISO/TS 21748, ISO 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 determined by means other than a Type A evaluation of measurement uncertainty

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,
- 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 uncertainty of measurement
standard uncertainty of measurement
standard uncertainty
measurement uncertainty 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 that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model

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 measurement uncertainty
expanded uncertainty
product of a combined standard measurement uncertainty 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 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 the GUM) and simply “uncertainty” in IEC documents.

[SOURCE: ISO/IEC Guide 99:2007, 2.35]

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 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 may be more representative of the measurand than others. This may 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. 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 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 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.
- 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]

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.

Note 3 to entry: Resolution not necessarily linear.

[SOURCE: ISO/IEC Guide 99:2007, 4.14 modified: "provided by a measuring equipment" in definition added, Note 2 and 3 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, 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 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,

d) a comparison of measurement standards.

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

3.16
measurement repeatability
repeatability
measurement precision under repeatability conditions of measurement

[SOURCE: ISO/IEC Guide 99:2007, 2.21]

3.17
measurement reproducibility
reproducibility
measurement precision under reproducibility conditions of measurement

[SOURCE: ISO/IEC Guide 99:2007, 2.25, modified: Note deleted.]

3.18
stability of a measurement process
property of a measurement process, 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
B_{i}	Bias
β_0	intercept of the calibration function
$\widehat{\beta}_0$ β_0	estimated intercept of the calibration function
β_1	slope of the calibration function
$\widehat{\beta}_1$	estimated slope of the calibration function
C_{MP}	measurement process capability index
C_{MS}	measuring system capability index
C_{p}	process capability index
C_{pk}	minimum process capability index

$C_{p,obs}$	observed process capability index
$C_{p,p}$	real process capability index
d_{LR}	interval from the last reference value, for which all operators have assessed the result as unsatisfied to the first reference value, for which all operators have the result as approved
d_{UR}	from the last reference value, for which all operators have assessed the result as approved to the first reference value, for which all operators have the result as unsatisfied
d	average interval
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
L_{SL}	lower specification limit
M_{PE}	maximum permissible error (of the measuring system) (MPE-value)
m_{ji}	frequencies in the Bowker-test
N	number of standards
n	number of measurements
P	Probability
P_p	process performance index
$P_{p, obs}$	observed process performance index
$P_{p, p}$	real process performance index
Q_{attr}	attributive measurement process capability ratio
Q_{MS}	measuring system capability ratio
Q_{MP}	measurement process capability ratio
R_E	resolution of measuring system
s	sample standard deviation (for the measuring system repeatability)
T	Temperature
$t_{1-(\alpha/2)}$	the two-sided critical value of Student's *t* distribution
U	upper specification limit
U_{SL}	upper specification limit
u_α	standard uncertainty on the coefficient of expansion

u_{AV}	standard uncertainty from the operator's repeatability
u_{BI}	standard uncertainty from the measurement bias
u_{CAL}	calibration standard uncertainty on a standard
u_{MP}	combined standard uncertainty on measurement process
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_{attr}	uncertainty on an attributive measurement
U_{CAL}	uncertainty on the calibration of a standard
U_{MS}	uncertainty of the measuring system
U_{MP}	uncertainty of the measurement process
y_j	j th measurement value
$\bar{y}$	average of all measurements
$\overline{y_g}$	arithmetic mean of all the sample values
x_i	i th measurement input quantity
x_{m}	reference quantity value

4.2 Abbreviated terms

ANOVA	analysis of variance
DOE	design of experiments
GPS	geometrical product specifications
R&R	repeatability and reproducibility
GUM	guide to the expression of the uncertainty of measurement (ISO/IEC Guide 98-3)
MPE	maximum permissible error
SPC	statistical process control
VIM	international vocabulary of metrology

5 Basic principles

5.1 General

The method described in this part of ISO 22514 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 must utilize the general current method for determining the measurement uncertainty that is described in ISO/IEC Guide 98-3.

The following method addresses the implementation uncertainty (see also ISO 17450-2). Therefore, it shall be determined before the method are applied that the method uncertainty and the specification uncertainty is small compared to the implementation uncertainty. Further, the method is not suitable and shall not be used for complex geometrical measurement processes, such as surface texture, form, orientation and location measurements that rely on several measurement points or simultaneous measurements in several directions, or both.

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, 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.

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

The combined expanded uncertainty should be substantially smaller than the specification 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 can not 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 needs to fully understand the model to be used.