# INTERNATIONAL STANDARD

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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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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 second edition cancels and replaces the first edition (ISO 22514-7:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— use of the MPE values in the calculations;

— revision of the calculation of the linearity, with amendments in the example in Clause A.1;

— addition of a method to calculate the capability when the specifications of the characteristic of interest is defined as a one-sided specification (new 9.3).

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. It is not suitable for complex geometrical measurement processes, such as surface texture 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 3534-2:2006, *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/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 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 measurement error**
maximum permissible 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.]

**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,

— 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 measurement uncertainty**
expanded 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 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* ([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 ISO/IEC Guide 99 (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 $h(Y, X_1, ..., X_n) = 0$, 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 $X_1, ..., X_n$.

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;

— 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.

Note 3 to entry: Resolution not necessarily linear.

[SOURCE: ISO/IEC Guide 99:2007, 4.14 modified - "provided by a measuring equipment" has been added in the definition, Notes 2 and 3 to entry have 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,

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 — The Note has been deleted.]

**3.18**
**stability of a measurement process**
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 |
| $\alpha$ | significance level |
| $B_i$ | bias |
| $B_{i\,max}$ | maximal found bias |
| $\overline{B}_i$ | arithmetic mean of biases |
| $C_{MP}$ | measurement process capability index |
| $C_{MP\,min}$ | minimum measurement process capability index |
| $C_{MS}$ | measuring system capability index |
| $C_{MS\,min}$ | minimum measuring system capability index |
| $C_p$ | process capability index |
| $C_{pk}$ | minimum process capability index |

| | |
|---|---|
| $C_{\text{p obs}}$ | observed process capability index |
| $C_{\text{p real}}$ | real process capability index |
| $\Delta$ | process dispersion/variation |
| $\Delta_{\text{U}}$ | 50 % process dispersion/variation to upper limit |
| $\Delta_{\text{L}}$ | 50 % process dispersion/variation to lower limit |
| $d_{\text{LR}}$ | 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 |
| $d_{\text{UR}}$ | interval 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 |
| $k$ | coverage factor |
| $K$ | total number of replicate measurements on one reference. The reference can be a reference standard or a reference workpiece |
| $k_{\text{CAL}}$ | coverage factor from the calibration certificate |
| $l$ | measured length |
| $L$ | lower specification limit |
| $M_{\text{PE1}}$ | maximum permissible error (of the first characteristic) |
| $M_{\text{PE2}}$ | maximum permissible error (of the second characteristic) |
| $M_{\text{PE}}$ | maximum permissible error (of the measuring system) (MPE-value) |
| $N$ | number of standards |
| $n$ | number of measurements |
| $n_{ij}$ | $ij$th frequencies of measurement results |
| $n_{ji}$ | $ji$th frequencies of measurement results |
| $P$ | probability |
| $P_{\text{p}}$ | process performance index |
| $P_{\text{p obs}}$ | observed process performance index |
| $P_{\text{p real}}$ | real process performance index |
| $Q_{\text{attr}}$ | attributive measurement process capability ratio |
| $Q_{\text{MS min}}$ | minimum measuring system capability ratio |
| $Q_{\text{MS}}$ | measuring system capability ratio |
| $Q_{\text{MP min}}$ | minimum measurement process capability ratio |
| $Q_{\text{MP}}$ | measurement process capability ratio |
| $R_{\text{E}}$ | resolution of measuring system |

| $s$ | sample standard deviation (on the mean bias) |
| $s_A$ | sample standard deviation (on the measuring system repeatability, ANOVA) |
| $s_{EV}$ | sample standard deviation (on the measuring system repeatability) |
| $s_{LIN}$ | sample standard deviation (from the linearity system repeatability) |
| $s_{obs}$ | sample standard deviation (the observed standard deviation) |
| $s_{RES}$ | sample standard deviation (on the mean bias) |
| $T$ | temperature |
| $\Delta T$ | temperature difference |
| $t_{1-(\alpha/2)}$ | the two-sided critical value of Student's $t$ distribution |
| $U$ | upper specification limit |
| $u$ | standard uncertainty |
| $u_\alpha$ | 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 |
| $u_{MS-REST}$ | 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 |
| $U_{attr}$ | expanded uncertainty on an attributive measurement |
| $U_{CAL}$ | 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 |
| $\bar{x}_g$ | arithmetic mean of all the sample values |
| $y_n$ | $n$th measurement value |
| $y_{nj}$ | $nj$th measurement value |
| $\bar{y}$ | 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