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Statistical methods in process management — Capability and performance —

Part 8:
Machine performance of a multi-state production process

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

Partie 8: Aptitude machine d'un procédé de production multimodal

Reference number
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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 4, *Applications of statistical methods in process management*.

ISO 22514 consists of the following parts, under the general title *Statistical methods in process management — Capability and performance*:

— *Part 1: General principles and concepts*

— *Part 2: Process capability and performance of time-dependent process models*

— *Part 3: Machine performance studies for measured data on discrete parts*

— *Part 4: Process capability estimates and performance measures [Technical Report]*

— *Part 6: Process capability statistics for characteristics following a multivariate normal distribution*

— *Part 7: Capability of measurement processes*

— *Part 8: Machine performance of a multi-state production process*

Introduction

The methodology introduced through this part of ISO 22514 provides the platform for producing the items required for building a long-term process capability and its leading, for a given product characteristic. This can, for example, make it possible to

— define the in-process or mid-process sampling procedure,

— predict, for batch furnaces, a process capability variation range covering all the parts in the batch load, once a recorded partial load variation has been characterized beforehand, and

— follow, for multi-cavity casting, the changes of extreme variation field based on different positions in the mould, each variation of the mould cavities have been characterized beforehand.

Statistical methods in process management — Capability and performance —

Part 8: Machine performance of a multi-state production process

1 Scope

This part of ISO 22514 aims to define the evaluation method to quantify the short-term capability of a production process (capacity of the production tool, widely termed capability), i.e. the machine performance index, to ensure compliance to a toleranced measurable product characteristic, when said process does not feature any kind of sorting system.

If the production process integrates a sorting system, then this one (clearing away nonconforming parts) should be analysed independently.

This part of ISO 22514 does not aim to define evaluation methods of the capability of a production process that is gauged through long-term observation (capability process or performance process indices).

This part of ISO 22514 defines

— the principles guiding the development of indicators for quantifying capability, and

— the statistical methods to be employed.

The characteristics used to evaluate production process capability have statistical distributions, and it is presumed, a priori, that at least one of these distributions is multi-modal. A distribution is presumed to be multimodal if it results from the marked effect of at least one cause inducing a significant difference between the produced items.

This part of ISO 22514 applies, for example, to characteristics generated by processes such as the following:

— multi-cavity casting: simultaneously producing several identical parts from a mould featuring several cavities.

Since each cavity has its own geometry and its own position in the mould architecture, it can create a systemic difference on the output result;

— multi-fixture machining: a part produced at the same time, but the produced parts are positioned in relation to the production tool by different fixture systems.

Since each fixture has its own geometry, mount clamps, etc., it can create a systematic difference on the output result;

— batch load treatments: heat treatment applied at the same time on a set of identical parts (the batch load), distributed within a pre-defined space of furnace. The position of an item of the batch relative to the furnace can influence the output result.

Each cavity, fixture, or position in the batch load corresponds to a different state. The multi-state process can be understood as the result of the combination of different states within the same process (e.g. cavity, fixture, position in the batch load).

NOTE It needs to be ensured that such systematic differences, if any, constitute only a very small proportion of permissible error so that their impact is harmless and do not affect the capabilities of the process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3534 (all parts), *Statistics — Vocabulary and symbols*

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

ISO 22514-3, *Statistical methods in process management — Capability and performance — Part 3: Machine performance studies for measured data on discrete parts*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

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

3.1
production tool
machine or production machinery performing all the operations necessary for production, from delivered supplies through product deliverable

3.2
process
set of interrelated or interacting activities which transforms inputs into outputs

Note 1 to entry: Inputs to a process are generally outputs of other processes.

Note 2 to entry: Processes in an organization are generally planned and carried out under controlled conditions to add value.

Note 3 to entry: A process where the conformity of the resulting product cannot be readily or economically verified is frequently referred to as a “special process”.

Note 4 to entry: This set includes all the factor resources necessary: production tools, labour, operating procedures, maintenance, etc.

[SOURCE: ISO 9000:2005, 3.4.1]

3.3
equipment (or tools)
interchangeable component of a production tool for producing different products, and which cannot be considered a wear-out component

EXAMPLE Mould of an injection-moulding machine — Counter-example: in machining, a cutting tool cannot be considered as a piece of equipment.

3.4
process operation
step in the production process leading to a final or intermediate product status

3.5
toleranced characteristic of the product
quantitative characteristic of the product, and for which the *upper specification limits* (ISO 3534-2) and/or *lower specification limits* (ISO 3534-2) are prescribed

3.6
dispersion interval (or dispersion of a characteristic)
interval within which all items are produced

Note 1 to entry: Where the dispersion interval is estimated based on statistical methods, it is estimated based on its reference interval (ISO 3534-2).

Note 2 to entry: Any one process carries as many dispersion intervals as it does characteristics produced. For example, a product presenting four different characteristics, i.e. length, width, height, and weight, is produced including systematic (controllable) and random (uncontrollable) sources of variation by a single production tool in a single operation. This operation is thus associated with four different dispersion intervals.

3.7
intrinsic dispersion interval (or instantaneous dispersion)
observable dispersion interval for a characteristic observed on produced items over a period during which the process implementation parameters have not varied: same operator, same method, same equipment, same batch of homogeneous raw materials, same temperature, etc.

Note 1 to entry: The underlying statistical distribution is called intrinsic (or instantaneous) distribution.

Note 2 to entry: In the event of drift in a process setting (such as drift caused by tool wear-out), it is common practice to include this drift in the production dispersion instead of integrating it into the estimate of intrinsic dispersion.

Note 3 to entry: This intrinsic dispersion interval is also called instantaneous dispersion because it affects production at a given point in time.

Note 4 to entry: Any one process operation carries as many intrinsic dispersion intervals as it does characteristics produced. A product presenting four different characteristics, i.e. length, width, height, and weight, is produced in a single operation. This operation is thus associated with four different intrinsic dispersion intervals.

Note 5 to entry: The intrinsic dispersion interval is same as natural or inherent spread.

Note 6 to entry: In some industries, the intrinsic dispersion interval is called "production tool dispersion"; the production tool featuring machine and its equipment.

3.8
intrinsic factor
internal condition to the production process and involved in the intrinsic dispersion interval, and which has different aspects, each produced item comes across only one of these aspects

EXAMPLE 1 The cavities of a mould; each cavity defines one aspect of the "cavity" factor; machining fixtures assumed to be identical; each fixture defines one aspect of the "fixture" factor.

EXAMPLE 2 If two different speeds are applied during the same production process to manufacture the product (a first run at low speed followed by a second run at high speed), then the speed is not an intrinsic factor.

3.9
process state
specific configuration of the full set of intrinsic factors, where each intrinsic factor takes one of its states

EXAMPLE See Figure 1.

This setup involves six states:

— State C1 F1;

— State C2 F1;

— State C3 F1;

— State C1 F2;

— State C2 F2;

— State C3 F2.

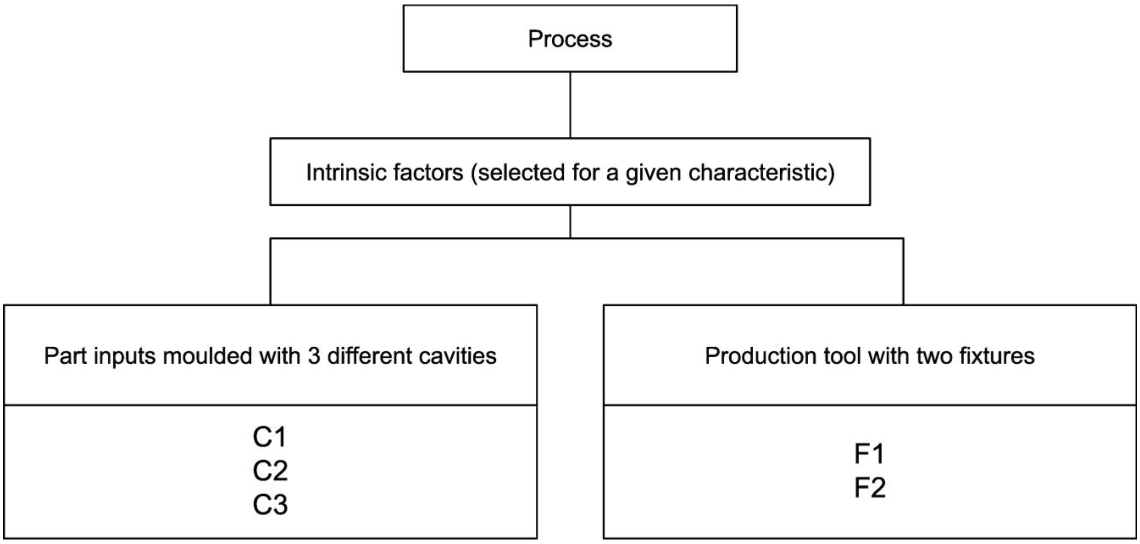

Figure 1 — Process with two intrinsic factors (cavity identifier, fixture udentifier)

Note 1 to entry: One process state generates one statistical distribution. The statistical distributions tied to the different states of the process can be similar or different.

Note 2 to entry: For a simple process that only produces one part at a time using single equipment and a single quality of inputs, there will, a priori, be only one state. From the moment that several parts are produced simultaneously under different conditions (different equipment, different positions in the batch load, etc.), there will, a priori, be different states.

Note 3 to entry: If the production process simultaneously handles a set of p parts, then there can be p different states.

3.10
multi-state (production) process
process through which different states generate statistical distributions that have different dispersion widths and/or dispersion locations (see Figure 2)

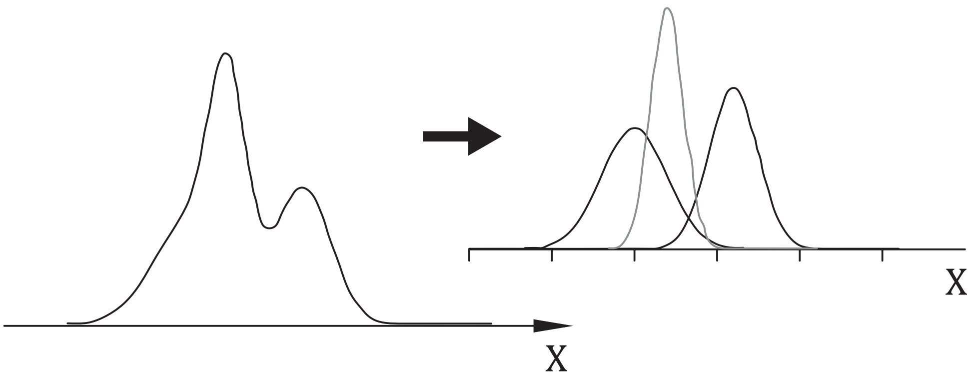

Figure 2 — Example illustrating the distribution of a multi-state process and its breakdown into states that each follow Gaussian distribution

3.11
local intrinsic dispersion (interval)
observable intrinsic dispersion interval associated with one of the process states
EXAMPLES

— local intrinsic dispersion interval connected to mould No. 2 on cavity No. 5;

— local intrinsic dispersion interval at coordinates X = 500, Y = 500, Z = 500 inside the batch furnace;

— local intrinsic dispersion interval on the left-hand side of the conveyer over a given time slot in a continuous furnace.

3.12
global intrinsic dispersion (interval)
observable intrinsic dispersion interval when pooling the results of the combination of different process states

3.13
production dispersion (interval)
observable dispersion interval for a characteristic, observed on produced items over a typical representative period during which the different process implementation parameters may have varied

Note 1 to entry: The parameter that has varied in the production dispersion interval, can be, for example,

— change of operators,

— settings, or

— change in raw material batch, etc.

Note 2 to entry: The underlying statistical distribution is called production distribution.

Note 3 to entry: The production timeframe observed is not standardized. Depending on how the capability indices are used, this time frame is set either internally by the product manufacturer or contractually by agreement between supplier and customer.

3.14
measurement uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (quantity-of-interest)

Note 1 to entry: The parameter defining an interval bounding the result of a measurement and that can be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand, is called enlarged uncertainty.

[SOURCE: adapted to the VIM]

Note 2 to entry: This part of ISO 22514 works on the basis that enlarged uncertainty is evaluated at a 95,44 % confidence level, as is common practice.

4 Symbols and abbreviations

For the purposes of this document, the following symbols and abbreviations apply.

L	lower specification limit
U	upper specification limit
T	specified tolerance (= $U - L$)
Di	generic term used to denote the width of intrinsic dispersion
Dig	width of the global intrinsic dispersion
k	number of investigated states
n	sampling size (number of measured parts per state), which is considered the same for all states
N	total sample size (total number of parts sampled: $N = n \cdot k$)

Di_j width of the local intrinsic dispersion in state j

Dil width of the local intrinsic dispersion when widths are not state-dependent

$Di_{l,j}$ half-width of the bottom-slope side of the local intrinsic dispersion interval in state j (see Figure 3)

$Di_{u,j}$ half-width of the top-slope side of the local intrinsic dispersion interval in state j (see Figure 3)

$Di_{l,el}$ half-width of the bottom-slope side of the local intrinsic dispersion interval of the state with the smallest dispersion bound

$Di_{u,er}$ half-width of the top-slope side of the local intrinsic dispersion of the state with the highest dispersion bound

Di_l half-width of the bottom-slope side of the local intrinsic dispersion when widths are not state-dependent

Di_u half-width of the top-slope side of the local intrinsic dispersion when widths are not state-dependent

$X_{\alpha\,\%}$ quantile at α % of the distribution without taking into account the different states

$X_{\alpha\,\%,j}$ quantile at α % of the distribution of state j

$\overline{x}_j$ mean of state j

$\tilde{x}_j$ median of state j

$\overline{\overline{X}}$ mean of the values of samples, once outliers have been eliminated

Δm range of extreme locations of local intrinsic dispersion intervals when this difference is significantly different from zero

Δm^* maximal value of the observable Δm when the relative locations of the different local intrinsic dispersion intervals vary independently of each other over time

Δa amplitude of the outlier (expressed algebraically), in the event an outlier is recorded

5 Preliminary technical analysis of the process

5.1 General

The preliminary analysis is designed to determine the intrinsic factors and their aspects, and thus, to define the process states liable to be found.

For a process operation, an assumption should be made, per characteristic, on whether or not the process produces a multimodal distribution. If it is assumed to be multimodal, then it will be necessary to define the states liable to be found.

5.2 Identification of intrinsic factors

The analyst tasked with this upstream preliminary analysis shall first define the intrinsic factors liable to act as sources of differentiation and thus generate different statistical distributions. The analyst shall also define the various different aspects possible for each intrinsic factor identified.

EXAMPLES

— part positioning in relation to the machine (multi-station fixtures, heat treatment load);

— product-machine interface (different fixtures, different clampings, etc.);

— different mounting patterns (guide-slots, die cavities, positions on the conveyor, etc.).

5.3 Determination of process-specific states

The process analyst shall integrate different constraint factors (economic, organizational, etc.) so as to shortlist only the specific states deemed representative of extreme process states.

EXAMPLES

— for a heat treatment process involving a batch furnace, where each load contains 300 parts, the process analyst could, for example, select four positions from the 300 states possible: one at the furnace gate, one near the back of the furnace, and two near the centre (one at load centre and one at the top of the load), which the analyst's knowledge of the furnace tells them when are the extreme state effects;

— for a cylinder head machining process for which 400 fixtures (adapters) are used, the process analyst could only select six fixtures. Based on an analysis of the geometric surveys taken on these fixtures (defects tied to the support bases, defects tied to clamping quality, etc.), the analyst shall select a series of occurrences tied to these surveys (extreme cases, possibly combined with some intermediate cases).

One process operation can generate different observable characteristics. These characteristics are often impacted differently in different process states. This can guide the analyst to select states according to categories of characteristics.

At this point, the analyst shall arbitrate between the options to select the states. Their selection shall also take into account the process knowledge needed in order to lead root cause analysis as a step toward building a process tracking system.

The number of states envisaged, a priori, at this early stage can be revised when defining which sampling plan to apply. The aim is to determine the best trade-off between number of states investigated and the quality of the knowledge on each of these states.

Examples are presented in Annex A.

6 Preliminary verifications before calculating the machine performance indices

6.1 Measurement system

Regardless of the process to qualify and the characteristic, it is first necessary to start by verifying that the measurement uncertainty is compatible with the pre-set capability objectives defining the maximum permissible global intrinsic dispersion.

This is done by running an estimate of measurement uncertainty taking into account the various sources of error: repeatability, reproducibility, bias error, etc.

This step can be determined using the GUM (Guide to the expression of uncertainty in measurement) and the ISO 5725 series of International Standards. The analysts can turn to an approach of the measurement uncertainty estimation set out, for example, in ISO 22514-7 or in the guide MSA (measurement systems analysis).

In order to move on to qualify the process, the measurement uncertainty shall not be too high. Excessively high measurement uncertainty impacts significantly on any estimates of real product dispersions, making it difficult to differentiate between process states.

A necessary prerequisite is that the enlarged uncertainty shall be less, for example, than a sixth of the maximum acceptable global intrinsic dispersion in order to make sure the judgement on the production tool does not become overly biased.

