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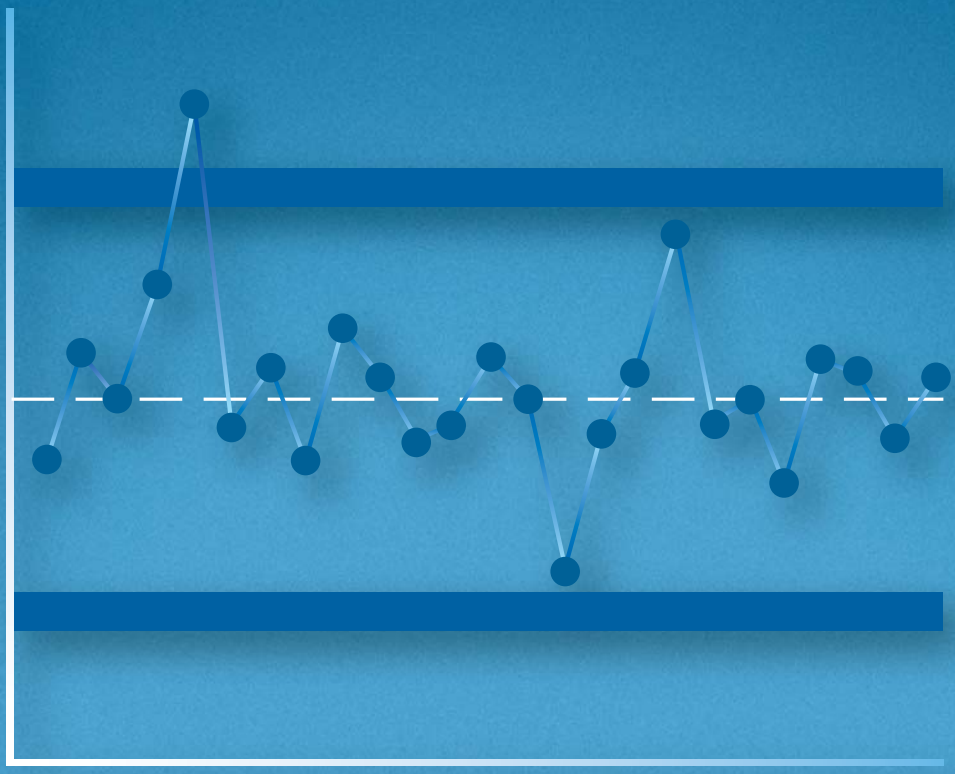

Quality Management in the Bosch Group | Technical Statistics

# 7. Statistical Process Control **SPC**

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**Quality Management in the Bosch Group**
**Technical Statistics**

# Booklet No. 7

# Statistical Process Control
# SPC

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**5th Edition, November 2020**

1st Edition, 09.1987

All minimum requirements specified in this booklet for capability and performance criteria correspond to the status at the time of printing (issue date). [CDQ 0301] is relevant for the current definition.

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# 1 Introduction

Statistical Process Control (SPC) is a procedure for open or closed loop control of manufacturing processes, based on statistical methods.

Random samples of parts are taken from the manufacturing process according to process-specific sampling rules. Their characteristics are measured and entered in control charts.

According to [CDQ 0301], the use of the Solara® / qs-STAT® / procella® / O-QIS® software package is prescribed within Bosch. It calculates capability and performance indices and operates control charts in accordance with the used evaluation strategy.

Statistical indicators are calculated from the measurements and used to assess the current status of the process. If necessary, the process is corrected with suitable actions. Statistical principles must be observed when taking random samples.

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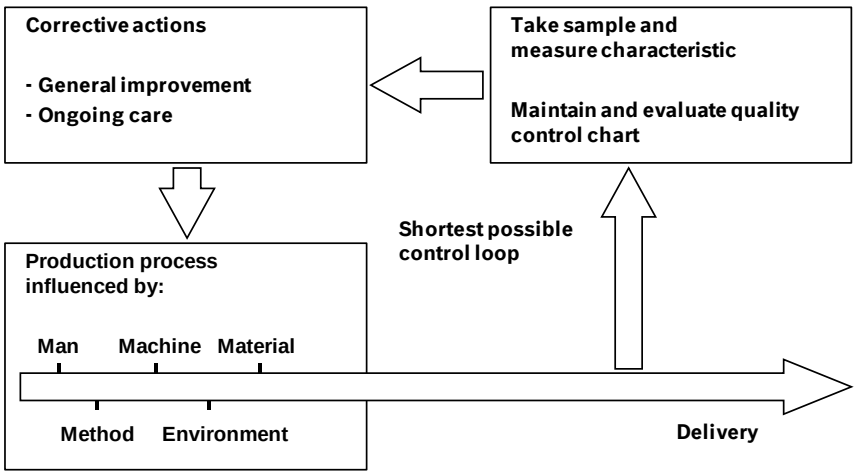


Fig. 1.1: Illustration of the SPC control loop

The control chart method was developed by Walter Andrew Shewhart (1891-1967) in the 1920´s and described in detail in his book “Economic Control of Quality of Manufactured Product” [Shew 1931].

SPC is used at RB in a common manner in all divisions. The procedure is defined in [CD 00301] in agreement with all business divisions.

Current questions on use of SPC and related topics are discussed in a work group (Functional Council). Results that are helpful for daily work and of general interest can be summarized and published as QA Information.

SPC is an application of inductive statistics. Not all parts have been measured, as would be the case for 100% inspection. A small set of data, the random sample measurements, is used to estimate parameters of the entire population.

In order to correctly interpret results, we have to know which mathematical model to use, where its limits are and to what extent it can be used for practical reasons, even if it differs from the real situation.

We differentiate between discrete (countable) and continuous (measurable) characteristics. Control charts can be used for both types of characteristics.

Statistical process control is based on the concept that many inputs can influence a process. The “5 M´s” – man, machine, material, milieu, method – are the primary groups of inputs. Each “M” can be subdivided, e.g. milieu in temperature, humidity, vibration, contamination, lighting, ....

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Despite careful process control, uncontrolled, random effects of several inputs cause deviation of actual characteristic values from their targets (usually the middle of the tolerance range).

The random effects of several inputs ideally result in a normal distribution for the characteristic. Many situations can be well described with a normal distribution for SPC.

A normal distribution is characterized with two parameters, the mean $\mu$ and the standard deviation $\sigma$.

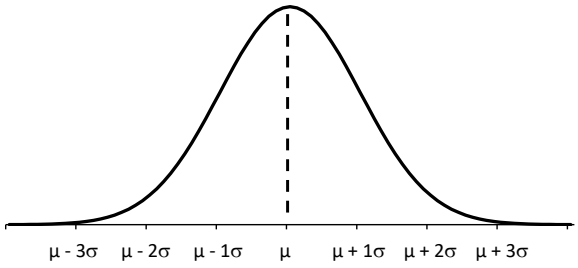


Fig. 1.2

The graph of the density function of a normal distribution is the typical bell-shaped curve, with inflection points at $\mu - \sigma$ and $\mu + \sigma$.

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In SPC, the parameters $\mu$ and $\sigma$ of the population are estimated based on random sample measurements and these estimates are used to assess the current status of the process.

An essential advantage of quality control charts is the fact that the original data and usually also the conditions under which they were determined are documented and remain available. In [Shew 1939] Shewhart explicitely lists the advantages of the original data.

- The measurement results are represented by numerical values (and units of measurement).
- The original data are documented in the order in which they were determined.
- The conditions under which the data were determined and the measurement process are reproducible.

Especially the chronological order of the data is an essential information which is lost during any kind of further data compression.

| **Information** | **given by** | **Number (example)** |
|---|---|---|
| Original data; complete information | individual values $x_i$; | 125 values |
| Means of subgroups | $\bar{x}_j$ | 25 means |
| Histogram | classification and relative frequencies $h_j$ | 7 classes |
| Distribution model with location and variation | $\bar{x}$, $s$ | 2 parameters |
| Process capability index | $C_{pk}$ | 1 index |

*NOTE: [Booklet 3] shows three different representations of data with increasing values, a random sequence of values and a sawtooth-like progression, which differ only in their chronological order. The corresponding distribution model is always the same.*

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# 2 Quality Control — Application of the Control Chart

A prerequisite for SPC incl. regular $Cpk$ verification is, according to [CDQ 0301], a successfully completed

- suitability study of the measuring equipment,
- machine capability analysis (resp. short-term capability analysis) and
- initial long-term process capability analysis.

Capability studies are briefly discussed in Section 3.4 and in detail in [Booklet 9]. The investigation of measurement processes is briefly adressed in Section 3.3.

It cannot be completely avoided that in this chapter also topics are touched, which go clearly beyond the topic of this Booklet on SPC. Meant are for example

- responsibilities, in particular regarding the cooperation of production planning, production and quality management.
- identification and traceability of products, as well as
- the control of nonconforming or potentially nonconforming products (e.g. also blocking)

These topics are only briefly addressed, but will not be discussed in greater depth.

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## 2.1 Basic Rules

The application of SPC requires some basic rules which will be briefly presented here.

1. Setting within the tolerance zone

With two-sided limited tolerance zone it is sensible, to adjust the machine so that the characteristic's values are close to the center point (target value C). If only an upper limit (USL) is given (e.g. concentricity), a setting to the smallest possible value is selected for reasons of economy.

2. When adjusting the machine or the tool, it is unavoidable to check continuously until the correct centered location (according to step 1) is achieved. The inspection interval begins then with the entry of the first measurement results (results of the first sample) in the control chart as first "OK sample".

Since the parts, produced from the beginning of the intervention or adjustment until achievement of the center position, can show greater deviations from the target value, they have to be kept separately and be sorted out, if necessary.

3. After each inspection interval a sample is taken, the considered characteristic is measured and the measurement results are entered in the control chart.

4. In case of a tool breakage or other reasons for a process intervention one must assume, that the parts produced since the beginning of this inspection interval are potentially defective/nonconforming. They are treated according to Section 2.3.

5. In general, after a process intervention it is necessary to proceed with steps 1, 2, and 3.

6. All correctives measures on the process (e.g. according to Chapter 10) and on the parts (Section 2.5) are documented.

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## 2.2 Necessary Documents

The necesssary documents near the machines and or SPC measuring stations include, e.g.

- process data sheet (information about the production process, the production equipment and system-specific settings),
- set-up instruction (work instruction for the set-up of one or several machines),
- inspection instruction (instructions for the conduction of certain quality inspections in the production process),
- regulation for the control of the measuring station (activities for the control of measuring devices),
- basic rules and reaction plan (s. Sections 2.1 and 2.4)
- action catalog (s. Chapter 11, for instance)

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## 2.3 Short Control Loop — Directly at the Machine

In case of unwanted process results, appropriate measures must be taken to achieve the desired result (control loop). Reaction plans must be available in case one or more control criteria are met. The reaction plan must be created specifically for the process, machine or machine type.

The reaction plan must show,

- how the causes can be found and eliminated,
- how the process can be readjusted,
- what to do with the parts produced since the last sample (e.g. sorting instruction).

Thus, the short control loop is essentially about the direct correction measures on the process.

In order to be able to sort out bad parts after an intervention limit has been exceeded, it must be possible to trace back and check the production quantity since the last sampling.

Hint: Rework and repair processes as well as sorting inspections involve further quality risks, e.g. due to

- mix-ups of products or components incl. mixing of variants,
- damage of parts by disassembly o rhandling,
- causation of further failure modes, e.g. flashing with wrong software,
- logistics mistakes, quantity deviation, wrong packaging,
- exceedance of maximum storage periods due to violation of the “First In, First Out” (FIFO) principle.

The creation and maintenance of reaction plans can be supported by providing plant, area and process-specific catalogs. Within the scope of the obligatory use of Q-DAS software, the maintenance of action plans/catalogs and the documentation of measures in the software must be ensured.

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## 2.4 Reaction Plan

A reaction plan describes what to do when an intervention is necessary (one of the control criteria is met). This plan must be created specifically for the process, machine or machine type. It should contain all measures necessary to

- detect easily recognizable causes of disturbing influences and
- control the process.

The plan should also include clear instructions on what to do with the parts produced since the last sample. It is advisable to define short designations (codes). See Chapters 10 and 11.

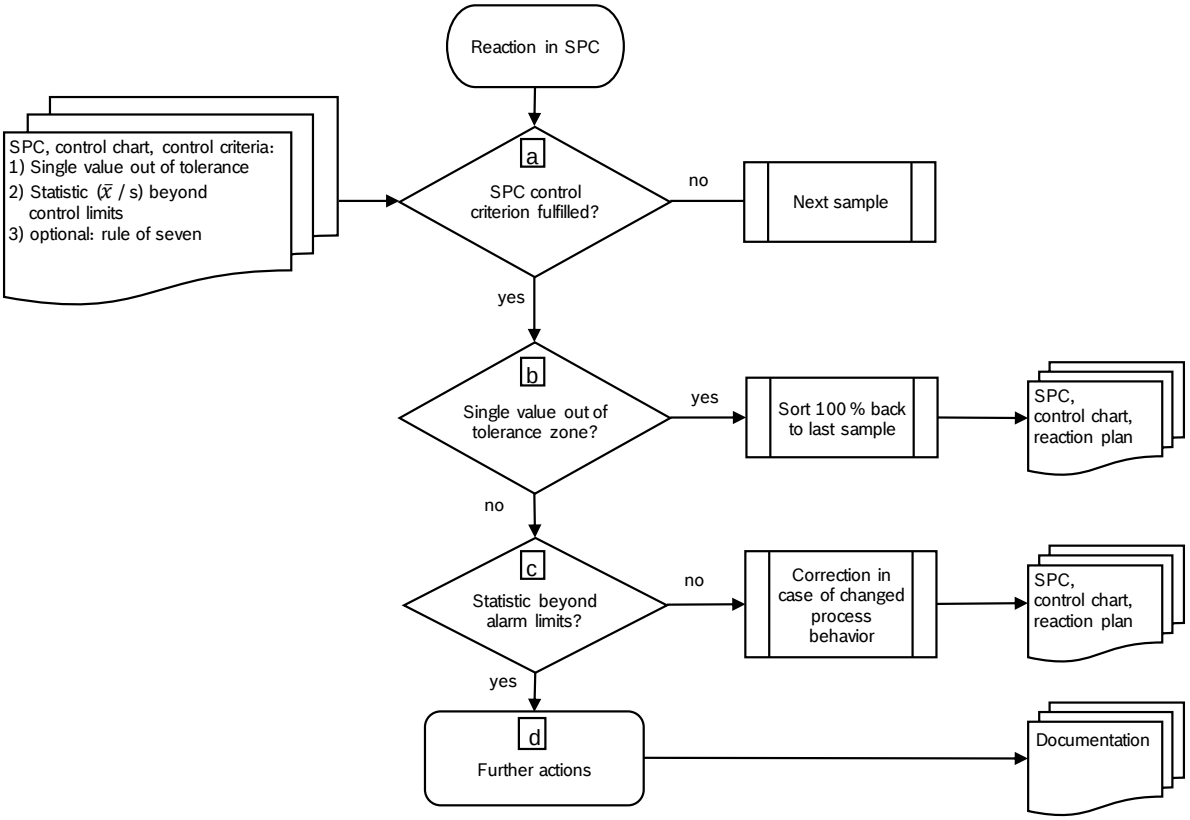


Fig. 2.4: Illustration of the reaction when the control chart responds

**a) Intervention necessary?**

After each entry in the SPC control chart, it has to be checked whether intervention is necessary. An "intervention" is an appropriate reaction to a statistically unusual event, i.e. one of the control criteria listed below is met (e.g. a control limit has been exceeded).

Control criteria:

- A single value is outside the tolerance zone.
- A sample's statistic (e.g. $\bar{x}$ or $s$) is outside the control limits.
- Optional: An unusual sequence of points is observed — rule of seven (i.e. seven points in a row on one side of the average line, seven measurement values with continuously increasing or decreasing tendency). For processes with systematic changes of the location ($\bar{x}$), e.g. for processes with a trend, this rule cannot be applied.

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In this case, it has to be checked whether the process behavior has actually changed, and, if this is confirmed, after determination of the cause (according to the reaction plan) the original process state has to be restored.

*NOTE: Due to the operation characteristics of the control charts there is an error probability of about 1 % for the exceedance of control limits, although the process behavior is unchanged (s. Chapter 13).*

**b) Single value outside the tolerance zone?**

In case of individual values outside the tolerance range, all parts of the production lot manufactured since the last random sample must be sorted (d).

**c) Alarm limit exceeded?**

Process-related control limits ( $LCL$ , $UCL$ ) are only dependent on the process variation and independent of the characteristic's tolerance (natural control limits).

They are defined so that for a process which is only affected by random causes 99 % of the means or standard deviations lie within their control limits.

If the control limits are exceeded, it must therefore be assumed that systematic, non-random influences (non-random causes) have an effect on the process. These influences must be corrected or removed by appropriate measures (action plan).

Tolerance-related control limits aim at compliance with the tolerance and not at a process improvement; therefore, they cannot be used for stabilizing and centering a process.

Tolerance-related control limits can be used to support the decision according to Section 2.2. These limits are then called alarm limits ($LAL$, $UAL$). The formula for their calculation contain the limits $LCL$ and $UCL$ (s. Chapter 8).

If the monitored statistic (e.g. $\bar{x}$) is still within the alarm limits, sorting of the parts produced since the last sample is not necessary. However, it has to be checked whether the process behavior has changed, and, if this is the case, perform corresponding corrective measures.

**d) Sorting inspection**

All parts produced since the last sampling are 100 % inspected and sorted (s. Section 2.5).

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## 2.5 Further Measures

As mentioned at the beginning of the chapter, some topics are touched here that go far beyond the actual scope of this booklet. With the formulation „further measures“ those measures are meant which cannot be allocated to the short control loop.

### 2.5.1 Sorting Inspection

A sorting inspection is a 100% inspection and means that products/components are with respect to defined characteristics and separated according to the individual results (e.g. conforming / nonconforming). The inspection can be carried out visually or using technical means, e.g. using measurement systems or gages.

It is self-evident, that the parts must still be accessible, if a sorting inspection is necessary due to a quality risk.

However, the measures necessary in this context are highly dependent on where the parts are located and what their status is.

The valid sorting instructions have to be applied, in particular regarding handling and identification of the parts, equipment and staff briefing/training.

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### 2.5.2 Decision about the sorted Parts

In the framework of a sorting inspection the parts are separated based on the inspection results. As a further step, it must be decided what has to be done with the parts, produced since the last sample.

This can mean that these parts are

- conforming parts are further processes or deliverd,
- non-conforming parts are reworked or
- scrapped.

The measures are documented. Details are regulated in [CDQ 0503] and [CDQ 0509].

### 2.5.3 Risks in Connection with Rework and Repair Processes

In general, rework and repair processes as well as sorting inspections involve further quality risks, e. g. due to

- Mix-ups of products or components incl. mixing of variants
- Damage of parts by disassembly or handling
- Causation of further failure modes
- Logistics mistakes, e.g. quantity deviation, wrong packaging
- Exceedance of maximum storage periods due to violation of the “First In, First Out” (FIFO) principle

*NOTE: In the broadest sense, a sorting inspection is rework of products with unclear status.*

To avoid such risks, appropriate safeguarding measures and approvals are necessary. In particular, effective measures must prevent

- further processing,
- unintended use, and
- the delivery

of nonconforming or incorrectly labeled products or products whose status is not identifiable (potentially nonconforming products). See [CDQ 0503]. For this purpose, blocking, identification, sorting and sorting-out must be clearly regulated.

## 2.6 Long Control Loop — Long-Term Analysis

An SPC concept always requires the implementation of long-term analyses and measures for quality improvement. They aim at

- achieving and maintaining capable process results,
- demonstrating the process capability, as well as
- continuously improving the processes.

For this purpose, the process behavior must be evaluated regularly to determine whether it has changed compared to the initial situation (pre-production run) or to a previous analysis. This includes the aspects described in the following sections.

Part of the long control loop is also the analysis of causes, i.e. the discovery of the causes of disturbing influences that lead to an intervention according to the Sections 2.1 and 2.3 and are not easily recognizable.

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*NOTE: Terms like analysis, tracking and evaluation are often used synonymously in everyday language. In the context of this booklet they have slightly different meanings.*

*Analysis: Decomposition, systematic investigation of an issue and its causes*

*Monitoring: tracking, observation, surveillance, ongoing investigation, activities to find out something*

*Evaluation: Summary, condensation, presentation of the essentials, interpretation, evaluation of data, derivation of measures*

### 2.6.1 Long-Term Monitoring

The original specifications for the control chart (type of chart, sampling interval and size, distribution model, control limits) reflect the understanding of the process behavior at the time of the pre-production run which is limited due to the small data basis of e.g. 125 values.

Within the framework of long-term monitoring, the conclusions regarding the process behavior that became apparent in the initial capability study, can be checked using the larger database which is then usually available.

*NOTE: Depending on the inspection plan, there may be exceptional situations where even after a longer period of time only a rather small database is available.*

### 2.6.2 Long-term Analysis — Organizational Questions

- Who evaluates the data (completed control chart or after defined time)?
- What does the analysis refer to (e.g. product, process, machine)?
- How often is the evaluation performed (e.g. monthly)?
- Which indices are calculated ($C_p$, $C_{pk}$ or $P_p$, $P_{pk}$)?
- Which process-specific data base is used (e.g. per quantity or per time unit)?
- Which method, which tool is used to represent the analysis results as $C_{pk}$ overview on a monthly basis (e.g. M-QIS module of the Q-DAS-Software)?
- Which detailed analysis of the specific process situation is important, e.g. regarding
  - the average process location; systematic changes of the process location (trend, stepwise variation, between-batch variation),
  - the distribution model, indices used,
  - tool changes, maintenance activities?

### 2.6.3 Long-Term Evaluation — Calculation, Representation, Documentation

The following values can be calculated and documented:

- $\bar{\bar{x}}$ (bzw. $\tilde{\bar{x}}$ ) Section 6.1
- $\bar{s}$ (bzw. $\bar{R}$ ) Section 6.2
- $\hat{\sigma}$ Section 6.2
- $C_p$ und $C_{pk}$ bzw. $s$ [Booklet 9]
- $P_p$ und $P_{pk}$ und $s$ [Booklet 9]

The corresponding requirements (e.g. defined minimum values) have to be observed and it must be checked whether the distribution parameters and capability indices $C_p$ and $C_{pk}$ or process performance indices $P_p$ and $P_{pk}$ have changed compared with the pre-production rund or the previous control charts. Procedures for the calculation of these indices are described in [Booklet 9].

It is recommended to regularly carry out a higher-level evaluation regarding. $C_{pk}$ or $P_{pk}$.

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### 2.6.4 Communication, Implementation and Pursuit of Measures

The communication, implementation and tracking of measures need organizational regulations which cover for example the following aspects:

- Function-specific Information and communication (e.g. specific for Production, Production Planning and Quality Management)
  - How are the results provided (e.g. via automatic e-mailing, WorkOn, BGN page)?
  - Who gets which information?
  - How often is the information submitted?
  - Which format is used (e.g. overview of all processes or detailed reports on individual characteristics)?
- Regular check of the long-term analysis results, decision on measures and their tracking, e.g.
  - dealing with non-capable processes
  - recalculation of control limits
  - review/update of inspection and process planning
- Retention of documented information in accordance with valid central procedures (e.g. CD 02981)
- Concept for storage and archiving of data and reports in accordance to valid central procedures.

Example:

| | **Management** | **Production Planner** | **Production** |
|---|---|---|---|
| Frequency | monthly | weekly | weekly |
| Content | • Histogram of process indices (capable, conditionally capable, not capable)<br>• For non-capable processes presentation of the indices from the last six months | • Processes relevant for the planner: cabalities calculated for the last 4 weeks | • Evaluation of the value progression for the individual characteristics |

## 2.6.5 Plant-specific Regulations and Solutions

**Responsibilities**

The responsibility for long-term analyses usually lies with Production. Quality Management supports e.g. regarding the calculations and representation of the evaluation results. It can be sensible to implement plant-specific solutions which take the local conditions into account. [CD 00301] describes various roles with tasks regarding

- management of characteristics
- classification of characteristics (incl. special characteristics)
- integrated quality planning
- software applications (software key-user)

**Recalculation of Control Limits**

Essential changes on the process like technical improvements, maintenance/repair, internal / external relocation or design changes in the produc can have effects on the

- process behavior,
- middle position and variation of the process,
- tolerance definitions.

Then it may be necessary to repeat capability studies and recalculate control limits. Otherwise the control limits must be kept constant.

**Dealing with non-capable Processes**

Ensure that each non-capable production process only delivers parts that conform to all specifications. This can be achieved either by an inspection (e.g. 100% inspection) using a capable measurement process or other adequate measures (e.g. functional testing during successive process steps, risk analysis, decision/approval of management), cf. [CDQ 0301] and [IATF 16949].

**Review of Inspection Planning / Inspection Strategy**

The long control loop also includes the necessity for a regular check/review and adaption of the inspection planning, e.g. regarding the questions

- Should/must SPC characteristics be added or removed?
- Is it sensible to modify the sample interval or sample size?
- Is it sensible to replace the SPC rules for a characteristic by other measures, e.g. implementation of 100% inspection?

## 2.6.6 Software Support

According to [CD 00301], Bosch-internally the current version of the software package Solara® / qs-STAT® / procella® / O-QIS® is used to evaluate capability studies and maintain control charts. These modules allow you to maintain control charts, calculate capability indices according to the defined Bosch evaluation strategy and to evaluate and monitor such data in the long term. The Bosch evaluation strategy fulfills the minimum requirements for statistical calculations described in [CD 00301].

For data transfer and storage the use of the „Automotive Quality Data Exchange Format“ AQDEF is mandatory.

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# 3 Planning

The planning takes place within the framework of “Management of Characteristics“ according to CD 00301. Responsibilities are defined there.

## 3.1 Inspection Strategy

Statististical process control of a characteristic with regular Cpk verification is one of the preventive inspection strategies in series production.

Reactive measures for failure detection include the application of an acceptance control chart with regular $C_{pk}$ verification and sampling inspection according to a sampling plan, for instance.

The definition of the inspection strategy requires, among others, the analysis of the cause-effect relationships between process characteristics and product characteristics, taking into account disturbance / noise and control variables. Knowledge of these relationships is a prerequisite for the process to be influenced (controlled) with regard to the inspected characteristic (product characteristic).

Usually, production equipment can directly be influenced so that the inspected characteristic (product characteristic) can be changed in the desired way (short control loop).

If a characteristic cannot be measured directly, it may be possible to determine a substitute inspection characteristic that is known to be related to it.

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## 3.2 Definition of SPC Characteristics

In the framework of “Management of Characteristics“ a classification is made. Product characteristics are allocated to classes A, B, C. Essential decision criterion for this allocation is, among others, robustness.

- Robustness is understood as the capability of a system to maintain its function even with variations in material properties, manufacturing parameters, as well as ambient, operational and usage conditions.
- Functional robustness: A product characteristic is “not functionally robust”, if it solely and immediately leads to a failure when the limits of the characteristic’s tolerance interval are exceeded.
- Robustness regarding the manufacturing method: A product characteristics is “not manufacturing method robust”, if it is failure sensitive with respect to the chosen manufacturing method. That means that there is a high probability of exceeding one or both limits of the characteristic’s tolerance interval due to the chosen manufacturing method.

In case of an existing process it may prove necessary to add new SPC characteristics. However, there can be reasons (e.g. change of the production method or introduction of 100% inspection) to substitute the previous SPC control by other measures.

SPC characteristics can be product or process characteristics.

*NOTE 1: The definitions of robustness are only applicable to product characteristics.*

*NOTE 2: In general, process characteristics are variables that cannot be easily measured and monitored / controlled "in situ" by sensors, e.g. concentrations of substances in solutions, pH values or proportions of carbon and accompanying elements in molten steel.*

*NOTE 3: According to [Booklet 10], Procedure 5, a control chart is also useful for monitoring the long-term behavior of a measurement process. The evaluation of the measuring system’s stability allows the proof of consistently correct measurement results. However, a measurement process is not controllable in terms of an SPC process.*

## 3.3 Definition of the Inspection Method

This planning step includes, among others, the definition of:

- inspection type
- location and personnel
- measurement and test procedure
- inspection timing / sequence and quantity-related definitions

The suitability of the IMT equipment for an inspection task has to be proven by a capability study. In special cases, a measurement process with known measurement uncertainty can be applied.

- In case of recurrent measurements of the same type, e.g. in the production flow, measurement process capabilities according to [Booklet 10] are preferably determined.
- In case of varying measuring tasks, e.g. in development and test departments, measurement uncertainties according to [Booklet 8] are preferably determined.

Measuring unit and reference value must correspond to the quantities selected for the measurement process.

*NOTE: IMT equipment according to the definition in "Terms and Definitions" is subject to control. IMT equipment serves for the proof of conformity in the framework of "Management of Characteristics", for instance.*

*Software, used for the creation of measurement results is also subject to this mandatory control. Such software must be validated in appropriate form.*

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## 3.4 Capability of Production Equipment and Processes

Process capability studies must be performed for new or modified production processes (machines) ([IATF 16949], [CD 00301] and [Booklet 9]). Also after extensive repair.

In short-term studies (studies of machine capability), characteristics of product parts are evaluated which have been manufactured in a continuous production run in an uninterrupted sequence, so that possibly only the influence of the machine is active.

In contrast, the parts to be measured originate in studies of long-term capability (process capability) from a larger, more representative period for the series production, so that possibly all influences on the process, which are to be expected, take effect.

Particularly during series rump-up, there are frequently not enough product parts available nor can enough parts be taken out of the manufacturing process over a sufficient period of time. Nevertheless, as an alternative, or in addition to the machine capability, at least a preliminary conclusion about the expected manufacturing process capability can be demanded (see “Initial Process Capability” [AIAG PPAP] and “Preliminary process capability” [VDA-4]). In this case, a short-term study is conducted, which can differ from the long-term study in the following points.

- Type of sampling: The parts to be studied can be taken out of the manufacturing process in shorter intervals, if necessary in extreme cases, one immediately after the other.
- Number of parts: It is permissible if there are not sufficient parts available, to take less than the required 125 parts for the long-term study.
- Limits for capability and performance indices: The increased limit of 1.67 applies if there are more than 125 parts. If there are less than 125 parts, the limit is raised depending on the number of parts at the same value as in the long-term study with reduced quantities.
- Designation of statistical indices: Capability indexes are designated with $Cp{-}ST$ und $Cpk{-}ST$ and performance indexes with $Pp{-}ST$ und $Ppk{-}ST$ (short-term).

*NOTE: The general definition of SPC does not presume process capability. However, if capability is not given, then additional actions are necessary to ensure that the quality requirements for manufactured products are fulfilled.*

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## 3.5 Types of Characteristics and Control Charts

This booklet only deals with continuous characteristics. Refer to Chapter “Terms and Definitions” for these and other types of characteristics. In measurement technology, physical variables are defined as continuous characteristics.

According to [CDQ 0301], the use of the Solara® / qs-STAT® / procella® / O-QIS® software package is prescribed within Bosch. It calculates capability and performance indices and operates control charts in accordance with the used evaluation strategy.

A control chart consists of a chart-like grid for entering numerical data from measured samples and a diagram to visualize the statistical indices for the process location and variation calculated from the data.

Modern SPC software offers the possibility to

- transfer measured data directly to the SPC software,
- generate the graphical representations automatically and
- be configured according to practical aspects.

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| Control charts for continuous characteristics | |
|---|---|
| Control charts for process location | Control charts for process variation |
| $\bar{x}$ chart | $s$ chart |
| $\tilde{x}$ chart | $R$ chart |
| $x$ chart | |

If a characteristic can be measured, then a control chart for continuous characteristics must be used. Normally the $\bar{x} - s$ chart with sample size $n = 5$ is used.

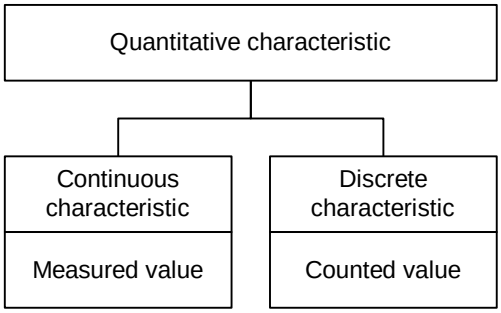


Fig. 3.5: Types of characteristics

Countable characteristics are special discrete characteristics. Their resulting values are “counts”. For example, the number of "bad" parts (non OK parts) resulting from an inspection with a limit gage is a countable characteristic.

*NOTE: In the past, also control charts for discrete characteristics have been used, where the number or proportion of nonconforming units (np chart, p chart) or the number or proportion of defects per unit (c chart, u chart) is used as the characteristic to be controlled.*

*Due to the following disadvantages, control charts for discrete characteristics are no longer up-to-date:*

- *The existence of defects is a prerequisite for the functioning of these types of charts. Thus, they stabilize rather than eliminate the undesirable condition.*
- *For small error proportions, unrealistic sample sizes of several hundred parts are required.*
- *Due to the large random variation ranges of the characteristics, the response sensitivity is limited, i.e. until significant changes are detected, more entries are required than with a control chart for continuous characteristics.*

### 3.5.1 Selection of the Control Chart

Independent of the type of process, the process-related and also the tolerance-related control limits should be calculated. Knowledge and comparison of both types of control limits is important for correct selection of the type of chart (refer to the explanation).

Selection of the control chart is performed with the flow chart below.

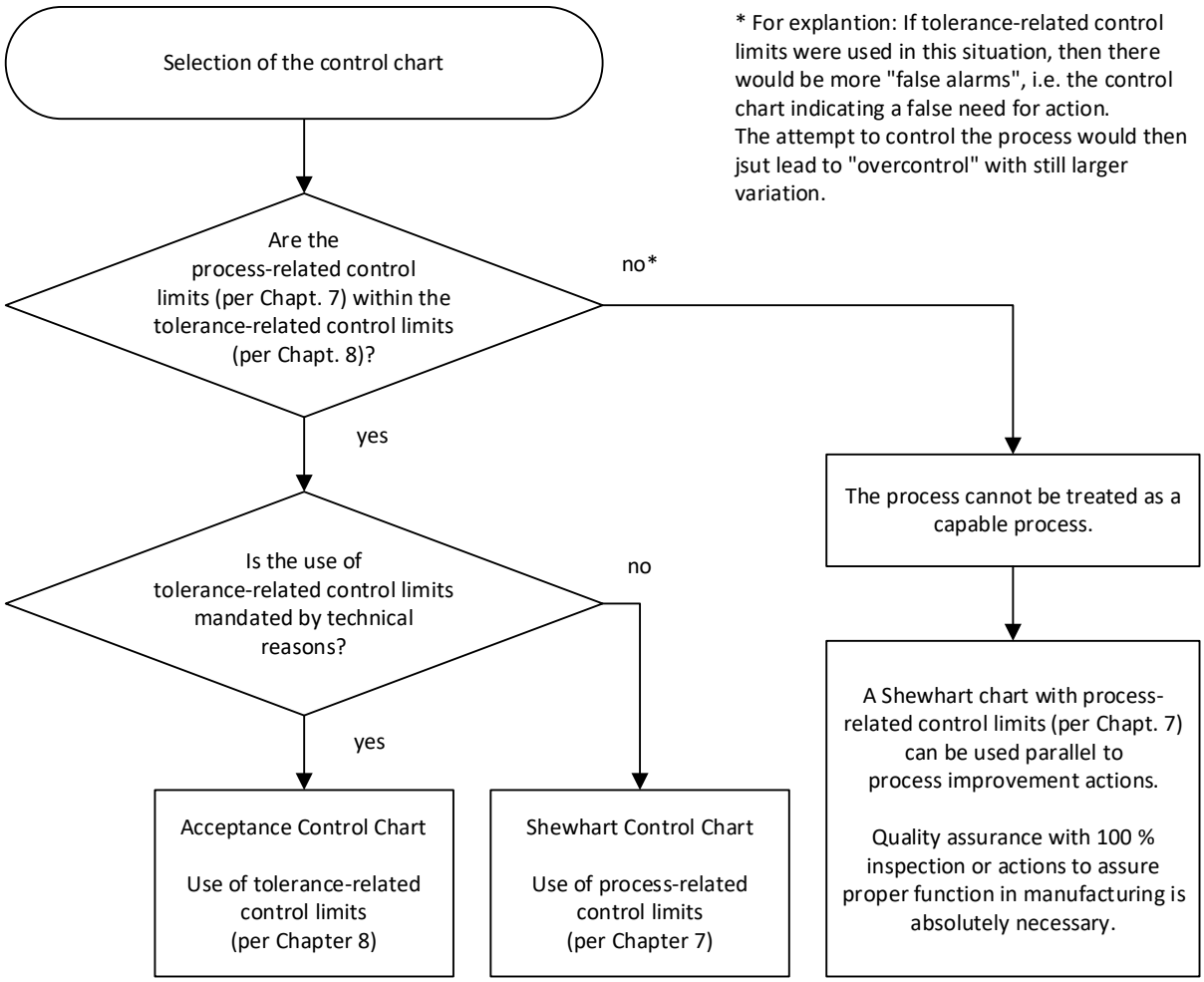


Fig. 3.5.1: Flow chart for selecting the quality control chart

When using the Shewhart chart, tolerance-related control limits can be used to assist in decision making in the framework of a sorting procedure (refer to Section 2.4). These limits are then referred to as alarm limits.

It is not permissible to draw tolerance-related control limits (alarm limits) as lines in Shewhart control charts.

## 3.6 Sample Size

The appropriate sample size is a compromise between process performance, desired accuracy of the selected control chart (type I and type II errors, operation characteristic) and the need for an acceptable amount of testing.

Normally $n = 5$ is selected. Smaller samples should only be selected if absolutely necessary.

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### 3.6.1 Properties of the Different Types of Control Charts

| | **Properties** |
|---|---|
| **Average chart** | • For the same sample size, better sensitivity or selectivity than the $\tilde{x} - R$ and the individual data charts with respect to a shift of the average location as well as to an increase of the standard deviation $\sigma$.<br>• For $n \geq 4$ insensitive to deviation of the population from the normal distribution<br>• Preferred chart for use with computers |
| **Chart for moving indices** | • Can also be used for destructive or complicated testing<br>• This chart has a delayed reaction to suddenly occurring process changes.<br>• The control limits are the same as for “normal” average charts |
| **Average chart with extended limits** | • Preferred chart for processes with systematic changes of the average |
| **Acceptance control chart** | • Due to the tolerance-related control limits, the process is controlled worse than with process-related control limits. |
| **Individual data chart** | • Presentation of all individual data from the random sample, so the chart is especially easy to understand and to fill out, lending it suitable for simple documentation of the manufacturing process.<br>• No calculation is necessary to use the chart.<br>• The individual data chart reacts to both a shift of the average location as well as to an increase of the standard deviation of a characteristic.<br>• Compared to the $\bar{x} - s$ chart and the $\tilde{x} - R$ chart less sensitivity or selectivity with respect to a shift of the average location as well as to an increase of the standard deviation $\sigma$.<br>• A decrease of $\sigma$ is not indicated by going below a limit value.<br>• More sensitivity to deviations of the population from a normal distribution than with the average chart.<br>• Potential confusion of users from the fact that, for example, the $UCL$ increases with larger sample sizes n.<br>• Evaluation, such as calculation of $C_{pk}$, is more complicated, because the original data is usually not recorded numerically (e.g. only points on the graph). |

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## 3.7 Defining the Sampling Interval

When a control chart triggers action, i.e. when the control limits are exceeded, the root cause must be determined as described in Section 2.1, reaction to the disturbance initiated with suitable actions (refer to the reaction catalog in Chapter 11) and a decision made on what to do with the parts produced since the last random sample was taken. In order to limit the financial "damage" caused by potentially necessary sorting or rework, the random sample interval — the time between taking two random samples — should not be too long.

The sampling interval must be individually determined for each process and must be modified if the process performance has permanently changed.

It is not possible to derive or justify the sampling interval from the percentage of defects. A defect level well below 1 % cannot be detected on a practical basis with random samples. A 100 % test would be necessary, but this is not the goal of SPC. SPC is used to detect process changes.

The following text lists a few examples of SPC criteria to be followed.

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1. After setup, elimination of disturbances or after tooling changes or readjustment, measure continuously (100 % or with random samples) until the process is correctly centered (the average of several measurements/medians!). The last measurements can be used as the first random sample for further process monitoring (and entered in the control chart).

2. Sampling intervals for ongoing process control can be defined in the following manner, selecting the shortest interval appropriate for the process.

- Definition corresponding to the expected average frequency of disturbances (as determined in the trial run or as is known from previous process experience).

  Approximately 10 samples within this time period.

- Definition depending on specified preventive tooling changes or readjustment intervals.

  Approximately 3 samples within this time period.

- Specification of tooling changes or readjustment depending on SPC samples.

  Approximately 5 samples within the average tooling life or readjustment interval.

But at least once for the production quantity that can still be contained (e.g. delivery lot, transfer to the next process, defined lots for connected production lines)!

3. Take a final sample at the end of a series, before switching to a different product type, in order to confirm process capability until the end of the series.

Note: The inspection interval is defined based on quantities (or time periods) in a manner that detects process changes before defects are produced. More frequent testing is necessary for unstable processes.

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**First-off / last-off part inspections**

IATF 16949 demands measures to ensure that the products meet the requirements after a planned or unplanned interruption.

First-off / last-off part inspections, e.g. after set-up processes, are intended to avoid problems in the context of a batch production or lotwise release (material mixing, incorrect set-up).

The procedure can be easily integrated into the SPC systematics by testing not only a first-off and last off part, but a group of first and last parts with the defined „sample size“ n. It is important that these are really the first and last parts and not, for example, any parts from the first and last palette.

It is recommended to take another sample also in the middle of the interval.

*NOTE: The first parts produced after the set-up process can hardly be called a random sample. But here it is rather a matter of proving that the process is mastered and that all products meet the requirements.*

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# 4 Preparation and Use of Control Charts

## 4.1 Preparation of the Control Chart

For the function of the control chart and the short control loop, you basically only need a representation of the

- center point $C$ of the tolerance zone and the
- control limits for the statistics used, usually $\bar{x}$ and s.

The scale (scaling) for $\bar{x}$ (or $\tilde{x}$ ) and s (or R) as well as the control limits and center lines should be clearly recognizable in the diagrams.

In most cases, however, further information is immediately visible or at least retrievable, e.g. reference value and unit as well as the lower and upper specification limit.

*NOTE: If, in addition to the control limits LCL and UCL, the characteristic limits LSL and USL ("tolerance limits") are also displayed in the control chart, there is a risk that the statistics are erroneously compared with LSL and USL (s. also Section 4.3.2).*

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## 4.2 Use of Control Charts

It must be determined who is in charge of the control chart and who has to carry out the interventions.

If the chart is maintained using a computer, the measured values may have to be entered via a keyboard. Modern SPC software offers the possibility to transfer measurement data directly into the SPC software and to generate the graphical representations automatically.

The steps in detail:

- Entry of the individual measurement values $x_i$
- Calculation of the statistics $\bar{x}$ (or $\tilde{x}$ ) and s (or $R$)
- Representation of the statistics $\bar{x}$ (or $\tilde{x}$ ) and s (or $R$ ) in the corresponding diagram and connection of the point sequence by lines.

If an entry is outside of the control limits, then control actions per the action plan (Section 2.2) must be initiated.

The measures carried out are noted on the chart (or reference is made to the back).

Note: In order to be able to sort out bad parts after a control limit was exceeded, it is essential to be able to trace the production quantity manufactured since the last random sample was taken.

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## 4.3 Evaluation and Control Criteria

After each entry, check whether one of the two chart traces indicates a reason for intervention, i.e. whether a control criteria is fulfilled.

Intervention means, in general, adequate reaction to an event that is unusual in a statistical sense (one of the control criteria is fulfilled). This means that we have to check whether the process behavior has actually changed, and if this is confirmed, the original process behavior has to be re-established with suitable actions after the causes have been determined. Then we have to decide on what to do with the parts manufactured since the last random sample, e.g. with a sorting instruction. This means that we must always be able to still access these parts if there is a quality risk.

In order to ensure a simple and effective procedure, a process-specific reaction plan for causes, actions and dealing with parts is created when the control chart is being prepared. When control is necessary, the appropriate random sample statistic is marked on the control chart and the causes, actions and disposition of parts are documented (refer to Chapter 10) on the back of the chart (if appropriate, in coded form).

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### 4.3.1 Control criteria

- The control chart indicates the need for action, i.e. at least one random sample statistic is outside of the control limits.
- Individual data are out of tolerance (at least one).

  *NOTE: The control chart does not necessarily indicate the need for action in this case.*
- Optional: There is an unusual sequence of points, i.e. at least 7 points in a row on one side of the average line, or forming a continuously increasing or decreasing trend (rule of 7, refer to the following figure).

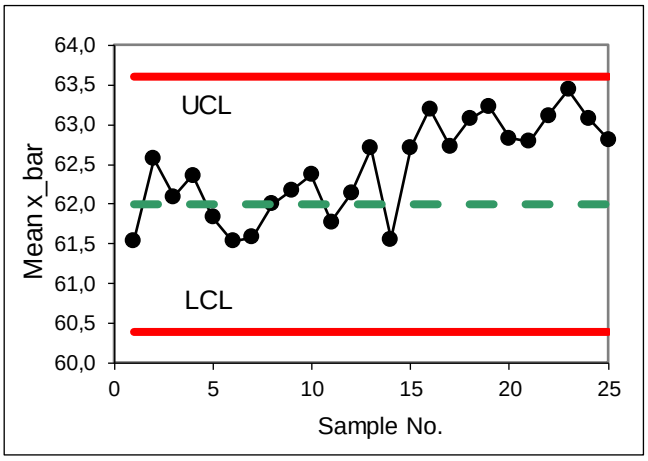


Fig. 4.3.1:
Illustration of the “rule of seven”

Note: The rule of seven, in the simplest case (seven points on one side of the average line), is based on the assumed random process behavior and the at least approximately normal distribution of the random sample statistics. Of course, it cannot be used for processes with systematic changes of the average.

Since for average charts and stable process behavior, each point has a 50 % probability of being above or below the average line, independent of the previous point, the probability of seven points in a row being on one side of the average line is $(0{,}5)^7 = 0{,}008 < 1\ \%$.

This is why it is called an “unusual sequence of points”.

Use of the rule of 7 in this case (the same as comparing a random sample statistic with the control limits) is a statistical test with a proba-bility of error (type I error) of ≈ 1 %.

For the given assumptions, the probability that at least 7 points in a row form a continuously increasing or decreasing trend is also very low.

### 4.3.2 Which comparisons can be made?

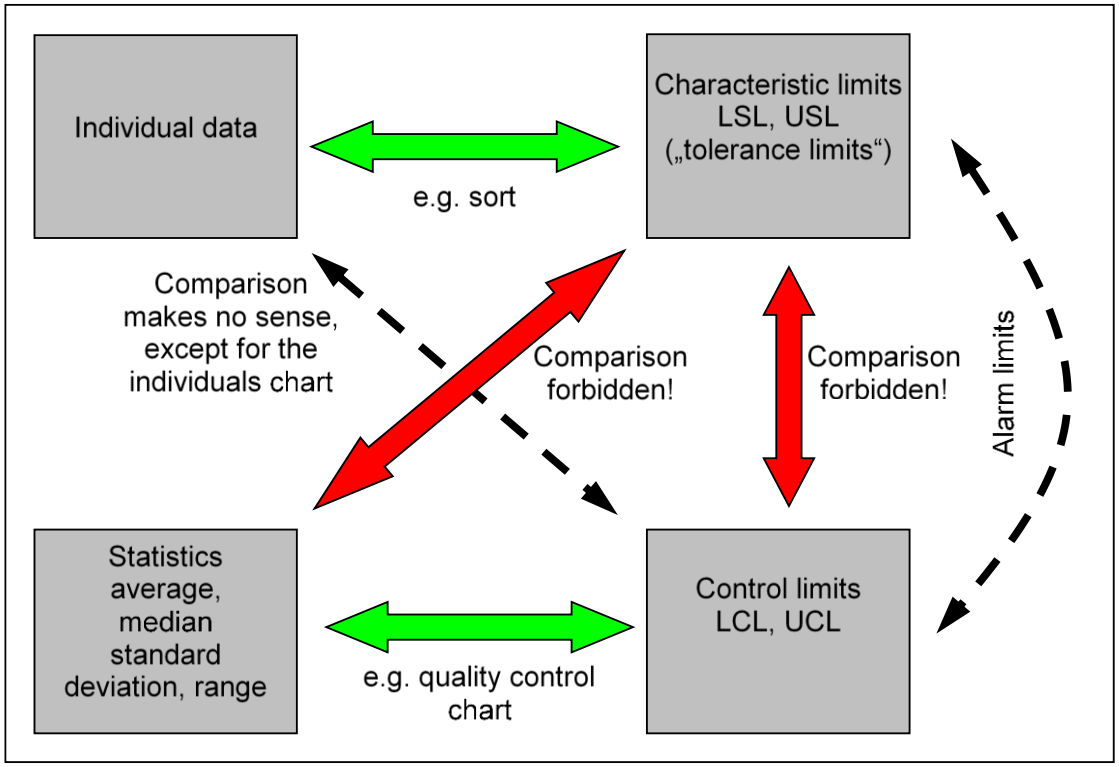


Fig. 4.3.2: Permitted and prohibited comparisons

As the figure in Chapter 7 shows, the distribution of averages $\bar{x}$ is significantly “narrower” than the distribution of the individual data. If a random value average is outside of the control limits but still inside of the “tolerance limits”, then possibly individual measurements were outside of the tolerance range. This is why it is not allowed to compare statistical values with characteristic specifications $LSL$ and $USL$ (“tolerance limits”).

For the same reason, it is not allowed to compare the difference $UCL - LCL$ with the tolerance $USL - LSL$. The distance between the process-related control limits is dependent on the amount of process variation and may not be interpreted as a “reduced tolerance”.

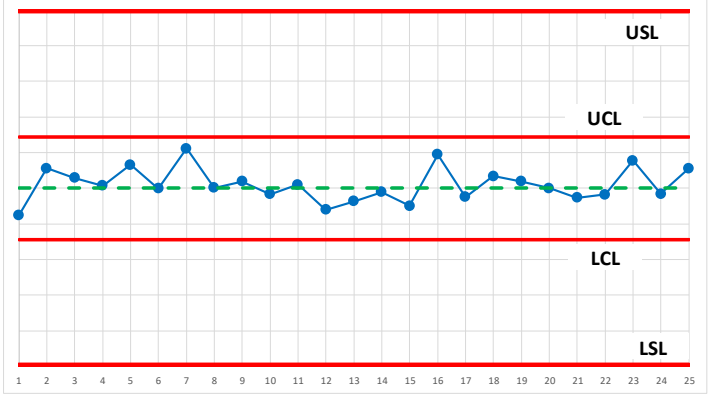


Fig. 4.3.3

This figure illustrates the proportions for an average chart with $n = 5$. When $C_p = 1.33$ the distance of the control limits $UCL - LCL$ corresponds to about 30 % of the tolerance.

Comparison of process-related control limits $LCL$ and $UCL$ with tolerance-related control limits (alarm limits) per Chapter 8 allows us to assess the amount of variation and the quality capability of a process.

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## 4.4 Documentation

Define when the evaluation results and/or overall summaries are to be submitted. Define the type and location for archiving. Archiving durations are defined in [CD 02981], for instance.

# 5 Determining Statistical Distribution Parameters

## 5.1 Pre-Production Run

Definition of control limits requires knowledge or estimation of the distribution parameters. This is determined with a pre-production run (trial run) with sample size and interval as specified in Sections 3.6 and 3.7. For an adequate number of parts for initial calculations, take a representative number of unsorted parts, at least $m = 25$ samples (with $n = 5$ for example), yielding no fewer than 125 measured values.

It is important to assess the graphs of the measured values themselves, the means and the standard deviations. Their curves can often deliver information on process performance characteristics (e.g. trends, cyclical variations).

In general, the parameters of the resulting process distribution are already known from the capability study (Section 3.4.).

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## 5.2 Disturbances

If non-random influences (disturbances) occur frequently during the trial run, then the process is not stable (not in control). The causes of the disturbances must be determined and eliminated before process control is implemented (repeat the trial run).

## 5.3 Statistical Calculations

In the framework of currently available statistical software, complicated mathematical procedures are no longer an obstacle and their application is of course permissible and quite common when using such programs. According to [CDQ 0301], the use of the Solara® / qs-STAT® / procella® / O-QIS® software package is prescribed within Bosch. It calculates capability and performance indices and operates control charts in accordance with the used evaluation strategy.

*NOTE: The procedures described below were originally developed to enable calculation with the aid of a pocket calculator. They are usually also contained in corresponding statistics programs.*

Hint: Due to the software support available today, the procedures in connection with the preparation, management and evaluation of control charts allow a better adaptation to process-specific conditions (e.g. process models) than is possible with manual calculation procedures. However, they also inevitably bring along higher requirements regarding statistical knowledge and the handling of statistical software. The requirements for personnel and training must take this into account.

In every division and every plant a fully trained SPC specialist should be available as contact person.

# 6 Formulas for Determining the Distribution Parameters

## 6.1 Process Average

Parameter $\mu$ is estimated by

$$\hat{\mu} = \bar{\bar{x}} = \frac{1}{m} \cdot \sum_{j=1}^{m} \bar{x}_j = \frac{sum\ of\ \bar{x}\ values}{number\ of\ samples}$$

or

$$\hat{\mu} = \tilde{\bar{x}} = \frac{1}{m} \cdot \sum_{j=1}^{m} \tilde{x}_j = \frac{sum\ of\ medians}{number\ of\ samples}$$

Example (Chapter 12)

$$\hat{\mu} = \bar{\bar{x}} = \frac{62.6+62.8+\cdots+62.0}{25} = 62.3$$

$$\hat{\mu} = \tilde{\bar{x}} = \frac{63+63+\cdots+62}{25} = 62.4$$

If $\hat{\mu}$ significantly deviates from the center point $C$ for a characteristic with two-sided limits, then this deviation should be corrected by adjusting the machine.

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## 6.2 Process Variation

Parameter $\sigma$ is estimated by

**a)**

$$\hat{\sigma} = \sqrt{\frac{1}{m} \cdot \sum_{j=1}^{m} s_j^2}$$

$$\hat{\sigma} = \sqrt{\frac{sum\ of\ variances}{number\ of\ samples}}$$

Example (Chapter 12)

$$\hat{\sigma} = \sqrt{\frac{0.55^2+0.45^2+\cdots+2.55^2}{25}} = 1.41$$

Note: When moving averages are used $\hat{\sigma} = s$ is calculated directly from at least 25 individual measurements.

or

**b)**

$$\hat{\sigma} = \frac{\bar{s}}{a_n} \quad \text{with} \quad \bar{s} = \frac{1}{m} \cdot \sum_{j=1}^{m} s_j$$

$$\bar{s} = \frac{Sum\ of\ standard\ deviations}{number\ of\ samples}$$

$$\hat{\sigma} = \sqrt{\frac{0.55^2+0.45^2+\cdots+2.55^2}{25}} = 1.41$$

$$\hat{\sigma} = \frac{\bar{s}}{a_n} = \frac{1.27}{0.94} = 1.35$$

See Chapter 9 for additional values

| $n$ | $a_n$ |
|---|---|
| 3 | 0.89 |
| 5 | 0.94 |
| 7 | 0.96 |

or

**c)**

$$\hat{\sigma} = \frac{\bar{R}}{d_n} \quad \text{with} \quad \bar{R} = \frac{1}{m} \cdot \sum_{j=1}^{m} R_j$$

$$\bar{s} = \frac{sum\ of\ ranges}{number\ of\ samples}$$

$$\bar{R} = \frac{1+1+\cdots+6}{25} = 2.96$$

$$\hat{\sigma} = \frac{\bar{R}}{d_n} = \frac{2.96}{2.33} = 1.27$$

See Chapter 9 for additional values

| $n$ | $d_n$ |
|---|---|
| 3 | 1.69 |
| 5 | 2.33 |
| 7 | 2.70 |

Note: The use of table values $a_n$ and $d_n$ presupposes a normal distribution.

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# 7 Process-related Control Limits

The control limits (lower control limit $LCL$ and upper control limit $UCL$) are set such that 99 % of all the values lie within the control limits in the case of a process which is only affected by random influences (random causes).

If the control limits are exceeded, it must therefore be assumed that systematic, non-random influences (non-random causes) are affecting the process.

These effects must be corrected or eliminated by taking suitable action (e.g. adjustment).

Relation between the variance (standard deviation $\sigma_x$) of the single values (original values, individuals) and the variance (standard deviation $\sigma_{\bar{x}}$) of the mean values: $\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$

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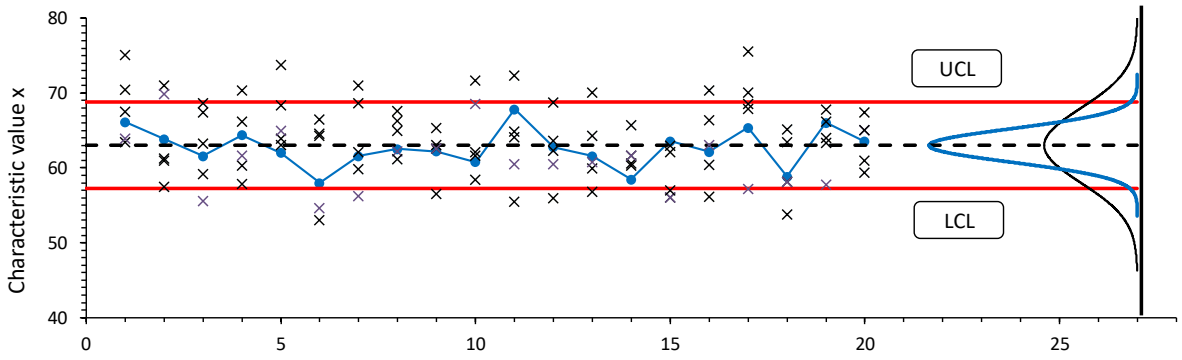


Fig. 7: Schematic about the functionality of a mean chart with $n = 5$. In order to illustrate the relationships, the mean values (points) as well as the individual values (crosses) from each sample are represented. The means like the individual values show a variation around the process average $\mu$; however, the variation of the means is smaller by the factor $\frac{1}{\sqrt{5}}$ than that of the individual values.

# 7.1 Natural Control Limits for Stable Processes

## 7.1.1 Control Limits for Location Control Charts

For two-sided tolerances, the limits for controlling the mean must always be based on the center point $C$. $C$ is replaced by the process mean $\hat{\mu} = \bar{\bar{x}}$ for processes where the center point $C$ cannot be achieved or for characteristics with one-sided limits.

| | | | |
|---|---|---|---|
| Average Chart | $UCL = C + \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$<br>$LCL = C - \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$<br>Also possible for normal distributions:*<br>$UCL = C + A^* \cdot \bar{s}$<br>$LCL = C - A^* \cdot \bar{s}$ | | $UCL = 62 + \frac{2.58}{\sqrt{5}} \cdot 1.35 = 63.6$<br>$LCL = 62 - \frac{2.58}{\sqrt{5}} \cdot 1.35 = 60.4$<br><br>$UCL = 62 + 1.23 \cdot 1.27 = 63.6$<br>$LCL = 62 - 1.23 \cdot 1.27 = 60.4$ |
| Median Chart | $UCL = C + \frac{2.58}{\sqrt{n}} \cdot c_n \cdot \hat{\sigma}$<br>$LCL = C - \frac{2.58}{\sqrt{n}} \cdot c_n \cdot \hat{\sigma}$<br>Also possible for normal distributions:*<br>$UCL = C + C_E \cdot \bar{R}$<br>$LCL = C - C_E \cdot \bar{R}$ | | $UCL = 62 + \frac{2.58}{\sqrt{5}} \cdot 1.2 \cdot 1.35 = 63.9$<br>$LCL = 62 - \frac{2.58}{\sqrt{5}} \cdot 1.2 \cdot 1.35 = 60.1$<br><br>$UCL = 62 + 0.59 \cdot 2.96 = 63.7$<br>$LCL = 62 - 0.59 \cdot 2.96 = 60.3$ |
| | Note: Use of the median-R chart is only appropriate when charts are manually filled out, without computer support. | | |
| Individual Data Chart | $UCL = C + E_E' \cdot \hat{\sigma}$<br>$.LCL = C - E_E' \cdot \hat{\sigma}$<br>Also possible for normal distributions:*<br>$UCL = C + E_E \cdot \bar{R}$<br>$LCL = C - E_E \cdot \bar{R}$ | | $UCL = 62 + 3.09 \cdot 1.35 = 66.2$<br>$LCL = 62 - 3.09 \cdot 1.35 = 57.8$<br><br>$UCL = 62 + 1.33 \cdot 2.96 = 65.9$<br>$LCL = 62 - 1.33 \cdot 2.96 = 58.1$ |
| | * Do not use for moving calculation of indices! | | |

| | $n$ | $A^*$ | $C_E$ | $c_n$ | $E_E'$ | $E_E$ | | |
|---|---|---|---|---|---|---|---|---|
| | 3 | 1.68 | 1.02 | 1.16 | 2.93 | 1.73 | | Estimated values $\hat{\mu}$ and $\hat{\sigma}$ are calculated per Sections 6.1 and 6.2. |
| | 5 | 1.23 | 0.59 | 1.20 | 3.09 | 1.33 | | |
| | 7 | 1.02 | 0.44 | 1.21 | 3.19 | 1.18 | | |
| | See Chapter 9 for additional values | | | | | | | |

Comments on the individual data chart:

Use an $\bar{x} - s$ chart to perform the capability study (trial run). Estimate $\hat{\mu}$ and $\hat{\sigma}$ for the mean $\mu$ and the standard deviation $\sigma$ of the population from at least $m = 25$ random samples (with, for example, $n = 5$), for a minimum of 125 measurements.

These formulas are based on the assumption of normally distributed individual values. Deviations from the normal distribution can cause larger fractions nonconforming.

Fill out the chart by periodically taking random samples of size $n$ (e.g. $n = 5$), numerically entering the data in the chart (if possible) and displaying the individual data in the chart graph.

To evaluate the chart (e.g. ongoing calculation of $C_p$ and $C_{pk}$ indices), it is necessary to calculate jeweils $\bar{x}$ and $s$ or $\tilde{x}$ and $R$ from the random sample data ($n$ measurements) for the full control chart and to continue as with an $\bar{x} - s$ chart according to [Booklet 9].

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**Control limits based on Pearson distributions**

Due to the central limit theorem of statistics, means $\bar{x}_j$ of samples, each consisting of $n \geq 5$ individual values, can be regarded as approximately normally distributed.

For this reason, the formula for control limits of the average and median chart in the above table contain the 0.5% quantile -2.58 and the 99.5% quantile +2.58 of the standard normal distribution.

However, [Booklet 9] describes several distributions as potential resulting process distributions which can occur in practice in the case of unilaterally limited characteristics:

- Lognormal distribution
- Rayleigh distribution
- Folded normal distribution
- Weibull distribution

The sample means of such skewed distributions and small $n$ are no longer necessariy normally distributed. This also applies to the mixture distribution. It can be sensible then to use a Pearson chart.

Compared to the corresponding Shewhart chart, this has the advantage of slightly wider control limits. They consider the skewness of the distribution of the original values and are therefore asymmetrical to the mean value. However, the disadvantage is that the control limits are more complicated to calculate and can practically only be done with the help of a computer.

In this case, a distribution from the family of Pearson distributions is best fitted to the sample means. The control limits of the Pearson chart then correspond to the 0.5% and 99.5% quantiles of this distribution, for instance.

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### 7.1.2 Control charts with moving averages

The $\bar{x}$ chart with a moving average is a special case of the $\bar{x}$ chart. For this chart, only single random samples are taken (i.e. $n = 1$). This chart can be considered e.g. in case of destructive or expensive inspection and monitoring of process characteristics (e.g. bath concentration).

$n$ sample measurements are formally grouped as a random sample and the average of these $n$ measurements is calculated as the mean.

For each new measurement from a single random sample that is added to the group, the first measurement of the last group is deleted, yielding a new group of size $n$, for which the new average is calculated.

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Example for $n = 1(3)$:

| | |
|---|---|
| **3 7 4** | $\rightarrow \bar{x}_1 = 4.7$ |
| 3 **7 4 9** | $\rightarrow \bar{x}_2 = 6.7$ |
| 3 7 **4 9 2** | $\rightarrow \bar{x}_3 = 5.0$ |
| 3 7 4 **9 2 8** | $\rightarrow \bar{x}_4 = 6.3$ |

Of course, moving averages calculated in this manner are not mutually independent. That is why this chart has a delayed reaction to sudden process changes. The control limits correspond to those for "normal" average charts:

$$LCL = C - \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma} \qquad UCL = C + \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$$

Calculation of $\hat{\sigma}$ according to Section 3.5 a)

Control limits for $n = 1(3)$:

$$LCL = C - 1.5 \cdot \hat{\sigma} \qquad UCL = C + 1.5 \cdot \hat{\sigma}$$

This approach for moving sample measurements can also be applied to the variation, so that an $\bar{x} - s$ chart with a moving average and moving standard deviation can be used.

After intervention in the process or process changes, previously obtained measurements may no longer be used to calculate moving indices.

*NOTE: In case of the der $\bar{x}$ chart with moving average there is a greater probability for the occurence of "unusual sequences of points". This is why the rule of seven must not be applied to this chart type.*

**EWMA Control Chart**

The standard [ISO 7870-6] describes the EWMA control chart with exponentially weighted sample values (Exponentially Weighted Moving Average). A smoothing factor $\lambda$ with $0 < \lambda < 1$ causes values further back to have a weaker influence, the last value has the greatest influence.

Area of application:

- Low production rates, small quantities (often the reason to select a control chart with $n = 1$)
- Elaborate inspection (time, costs)
- Small deviations from the target value should be detected (e.g. also with automated 100% inspection)

The applied test statistic is $y_i = \lambda \cdot x_i + (1-\lambda) \cdot y_{i-1}$. $\quad y_0 = C$

Due to this recursive calculation all previous sample results $x_i$ are contained in the test statistic $y_i$. The larger λ is, the less the effect of previous values $x_i$ on the current test statistic $y_i$.

Example: $y_4 = \lambda \cdot x_4 + (1-\lambda) \cdot \lambda \cdot x_3 + (1-\lambda)^2 \cdot \lambda \cdot x_2 + (1-\lambda)^3 \cdot \lambda \cdot x_1 + (1-\lambda)^4 \cdot C$

For $\lambda = 0.2$ is $(1-\lambda)^3 \cdot \lambda \approx 0.1$. The third-last sample value is therefore only considered with a weight of approx. 10 %.

Summarized notation: $y_t = \lambda \cdot \sum_{i=0}^{t-1} (1-\lambda)^i x_{t-i} + (1-\lambda)^i \cdot C$

The control limits of this chart are recalculated for each sample value.

$$LCL = C - 2{,}58 \cdot \sqrt{\frac{\lambda}{2-\lambda} \cdot [1-(1-\lambda)^{2 \cdot i}]} \cdot \hat{\sigma} \qquad UCL = C + 2.58 \cdot \sqrt{\frac{\lambda}{2-\lambda} \cdot [1-(1-\lambda)^{2 \cdot i}]} \cdot \hat{\sigma}$$

They are therefore variable in time. Their distance from each other initially increases, but asymptotically approaches a constant value dependent on $\lambda$:

$$LCL = C - 2.58 \cdot \sqrt{\frac{\lambda}{2-\lambda}} \cdot \hat{\sigma} \qquad UCL = C + 2.58 \cdot \sqrt{\frac{\lambda}{2-\lambda}} \cdot \hat{\sigma}$$

After every intervention the control limits are reset to their initial values and the numbering of the samples starts again at $i = 1$.

The calculation of the control limits presupposes a known and constant process standard deviation $\hat{\sigma}$. The number 2.58 is the 99.5% quantile of the standard normal distribution.

A typical value of $\lambda$ is $\lambda = 0.2$. Due to the expression $(1-\lambda)^{2 \cdot \mathrm{i}}$ under the square root the control limits reach their respective constant values $\mathrm{EG} = \mathrm{C} \pm 2.58 \cdot \sqrt{\frac{\lambda}{2-\lambda}} \cdot \hat{\sigma}$ after a few samples, and the faster, the greater λ is. This is the reason why often these constant control limits are used. On the other hand, the smaller $\lambda$ is, the greater the sensitivity of the EWMA card to small mean value deviations.

Advantage

- The EWMA chart reacts sensitively to small changes of the average location.

Disadvantages

- The test statistic is not immediately understandable.
- When variable control limits are used, this can be irritating for the user.

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## 7.1.3 Control Limits for Variation Control Charts

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | The control limits to monitor the variation (depending on $n$) relate to $\hat{\sigma}$ and $\bar{s}$ and likewise $\bar{R}$ (= "Central line"). | | | | | | | Note: Formula a) must be used in the case of moving s calculation. Calculation of $\hat{\sigma}$ per Section 6.2 a). |
| | a) generally applicable formula (also for moving $\bar{x} - s$ chart) | | | | | | | Example (Chapter 12): |
| | $UCL = B'_{Eob} \cdot \hat{\sigma}$<br>$LCL = B'_{Eun} \cdot \hat{\sigma}$ | | | | | | | $UCL = 1.93 \cdot 1.35 = 2.6$<br>$LCL = 0.23 \cdot 1.35 = 0.3$ |
| | b) for standard $\bar{x} - s$ chart | | | | | | | |
| | $UCL = B^*_{Eob} \cdot \bar{s}$<br>$LCL = B^*_{Eun} \cdot \bar{s}$ | | | | | | | $UCL = 2.05 \cdot 1.27 = 2.6$<br>$LCL = 0.24 \cdot 1.27 = 0.3$ |
| | $R$ chart | | | | | | | |
| | $UCL = D_{Eob} \cdot \bar{R}$<br>$LCL = D_{Eun} \cdot \bar{R}$ | | | | | | | $UCL = 2.1 \cdot 2.96 = 6.2$<br>$LCL = 0.24 \cdot 2.96 = 0.7$ |
| | | | | | | | | |
| | $n$ | $B'_{Eun}$ | $B'_{Eob}$ | $B^*_{Eun}$ | $B^*_{Eob}$ | $D_{Eun}$ | $D_{Eob}$ | |
| | 3 | 0.07 | 2.30 | 0.08 | 2.60 | 0.08 | 2.61 | |
| | 5 | 0.23 | 1.93 | 0.24 | 2.05 | 0.24 | 2.10 | |
| | 7 | 0.34 | 1.76 | 0.35 | 1.88 | 0.34 | 1.91 | |
| | See Chapter 9 for additional values | | | | | | | |

The standard deviations s cannot become less than zero. They are subject to a distribution whose density function is strongly asymmetrical (right-skewed) for small sample sizes. The mean value $\bar{s}$ which is entered as a dashed line in the chart diagram is therefore below the middle between $LCL$ and $UCL$. As a tendency, slightly more values (points) can be expected below this line than above. This also applies when using the ranges R and the average range $\bar{R}$.

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## 7.2 Control Limits for Processes with Systematic Changes in the Average

If changes of the mean need to be considered as a process-specific feature (trend, lot steps) and it is not economical to prevent such changes of the mean, then it is necessary to extend the "natural control limits".

The procedure for calculating an average chart with extended control limits is shown below.

The overall variation consists of both the "inner" variation of the random samples and of the "outer" variation between the random samples.

| **Calculation procedure** | | **Control limits for the mean** |
|---|---|---|
| **Standard deviation of the means**<br><br>$\hat{\sigma}_{\bar{x}} = s_{\bar{x}} = \sqrt{\frac{1}{m-1} \cdot \sum_{j=1}^{m} \left(\bar{x}_j - \bar{\bar{x}}\right)^2}$<br><br>Calculation of $\hat{\mu}$ according to Section 6.1 | | $UCL = C + 2.58 \cdot \hat{\sigma}_{\bar{x}}$<br>$LCL = C - 2.58 \cdot \hat{\sigma}_{\bar{x}}$<br>$C$ is the center point<br><br>Note: For processes that cannot be controlled about the mean, replace *C* with the process mean $\hat{\mu}$. |
| | | |
| **Determining outer variation with analysis of variance (ANOVA)**<br>The variation between random samples $\hat{\sigma}_{add}$ can be determined with analysis of variance using suitable software (ANOVA model II). | | $UCL = \hat{\mu} + \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma} + 1.5 \cdot \hat{\sigma}_{add}$<br>$LCL = \hat{\mu} - \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma} - 1.5 \cdot \hat{\sigma}_{add}$<br><br>Calculate the inner variation (standard deviation) $\hat{\sigma}$ according to Section 6.2 |
| **Total standard deviation** (standard deviation of all individual measurements)<br><br>$\hat{\sigma} = s_{total} = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} (x_i - \bar{\bar{x}})^2}$<br><br>with $N = n \cdot m$<br><br>Calculation of $\hat{\mu}$ according to Section 6.1 | | $UCL = \hat{\mu} + \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$<br>$LCL = \hat{\mu} - \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$ |
| **Estimating the upper and lower process location limits**<br><br>$\hat{\mu}_{max}$ = Average of the 3 largest $\bar{x}_i$<br>$\hat{\mu}_{min}$ = Average of the 3 smallest $\bar{x}_i$<br><br>Calculation of $\hat{\sigma}$ according to Section 6.2 | | $UCL = \hat{\mu}_{max} + \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$<br>$LCL = \hat{\mu}_{min} - \frac{2.58}{\sqrt{n}} \cdot \hat{\sigma}$ |

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# 8 Tolerance-Related Control Limits — Acceptance Control Chart

For processes with system-related average changes, the control limits can be based on tolerances in special cases (e.g. mechanical processing with stepped bores, internal turning tools, form disk). A prerequisite for this is that the inner variation is small enough compared to the tolerance ($\hat{\sigma}$ per Section 6.2), i.e. $T \geq 10 \cdot \hat{\sigma}$.

When tolerance-related control limits are used, the process is always controlled worse than when natural control limits are used, since they focus on staying within the tolerance and not on improving the process (stabilization, centering).

Control limits for tolerance-related $\bar{x}$ or $\tilde{x}$ charts are calculated using the following formulas:

$$LCL = LSL + k_A \cdot \hat{\sigma} \qquad UCL = USL - k_A \cdot \hat{\sigma}$$

$k_A$ is called the delimitation factor (for calculating $\hat{\sigma}$ refer to the formula below).

Control limits for corresponding $s$ or $R$ charts are calculated according to Section 7.1.3.

*NOTE: Tolerance-related control limits can be used to support the decision according to Section 2.4. These limits are then called alarm limits (LAL, UAL).*

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**Specifying the delimitation factor**

The delimitation factor is specified so that a nonconforming fraction of $p = 1\ \%$ is indicated with a probability of $P_A = 99\ \%$.

In the following formulas, $u_{1-p}$ and $u_{P_A}$ are the percentage points (quantiles) of the normal distribution of the probabilities $1 - p$ or $P_A$ or $\sqrt{1 - P_A}$.

**Average chart**

$$k_A = u_{1-p} + \frac{1}{\sqrt{n}} \cdot u_{P_A}$$

$p = 1\ \%$ and $P_A = 99\%$ yield:

| $n$ | $k_A$ |
|---|---|
| 3 | 3.67 |
| 4 | 3.49 |
| 5 | 3.37 |
| 6 | 3.28 |

| $n$ | $k_A$ |
|---|---|
| 7 | 3.21 |
| 8 | 3.15 |
| 9 | 3.10 |
| 10 | 3.06 |

**Individual data chart**

$$k_E = u_{1-p} - u_{\sqrt[n]{1-P_A}}$$

$p = 1\ \%$ and $P_A = 99\%$ yield:

| $n$ | $k_E$ |
|---|---|
| 3 | 3.11 |
| 4 | 2.80 |
| 5 | 2.58 |
| 6 | 2.42 |

| $n$ | $k_E$ |
|---|---|
| 7 | 2.28 |
| 8 | 2.17 |
| 9 | 2.07 |
| 10 | 1.99 |

# 9 Tables

**Table 1**
Constants to estimate the standard deviation (Section 6.2)

| n | $a_n$ | $d_n$ | |
|---|---|---|---|
| 2 | 0.798 | 1.128 | |
| 3 | 0.886 | 1.693 | |
| 4 | 0.921 | 2.059 | |
| 5 | 0.940 | 2.326 | |
| 6 | 0.952 | 2.534 | |
| 7 | 0.059 | 2.704 | |
| 8 | 0.965 | 2.847 | |
| 9 | 0.969 | 2.970 | |
| 10 | 0.973 | 3.078 | |

**Table 2a**
Constants to estimate the control limits of the individual data chart (Section 7.1.1)

| n | $E_E'$ | | |
|---|---|---|---|
| 2 | 2.807 | | |
| 3 | 2.934 | | |
| 4 | 3.023 | | |
| 5 | 3.089 | | |
| 6 | 3.143 | | |
| 7 | 3.188 | | |
| 8 | 3.226 | | |
| 9 | 3.260 | | |
| 10 | 3.289 | | |

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**Table 2b**
Constants to determine the control limits (Section 7.1)

| | Location | | | Variation | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\tilde{x} - R$ | $\bar{x} - s$ | $x - R$ | s Chart | | | | R Chart | |
| n | $C_E$ | $A^*$ | $E_E$ | $B'_{Eun}$ | $B'_{Eob}$ | $B^*_{Eun}$ | $B^*_{Eob}$ | $D_{Eun}$ | $D_{Eob}$ |
| 2 | 1.614 | 2.283 | 2.487 | 0.006 | 2.807 | 0.008 | 3.518 | 0.008 | 3.518 |
| 3 | 1.019 | 1.678 | 1.734 | 0.071 | 2.302 | 0.080 | 2.597 | 0.080 | 2.614 |
| 4 | 0.683 | 1.398 | 1.468 | 0.155 | 2.069 | 0.168 | 2.245 | 0.166 | 2.280 |
| 5 | 0.593 | 1.225 | 1.328 | 0.227 | 1.927 | 0.242 | 2.050 | 0.239 | 2.100 |
| 6 | 0.471 | 1.105 | 1.240 | 0.287 | 1.830 | 0.302 | 1.924 | 0.296 | 1.986 |
| 7 | 0.437 | 1.015 | 1.179 | 0.336 | 1.758 | 0.350 | 1.883 | 0.341 | 1.906 |
| 8 | 0.371 | 0.944 | 1.133 | 0.376 | 1.702 | 0.390 | 1.764 | 0.378 | 1.846 |
| 9 | 0.354 | 0.886 | 1.098 | 0.410 | 1.657 | 0.423 | 1.709 | 0.408 | 1.798 |
| 10 | 0.311 | 0.837 | 1.069 | 0.439 | 1.619 | 0.451 | 1.664 | 0.434 | 1.760 |
| | | | | | | | | | |
| $\tilde{x}$ | $UCL = C + C_E \cdot \bar{R}$<br>$LCL = C - C_E \cdot \bar{R}$ | | | $UCL = B'_{Eob} \cdot \hat{\sigma}$<br>$LCL = B'_{Eob} \cdot \hat{\sigma}$ | | | | $UCL = D_{Eob} \cdot \bar{R}$<br>$LCL = D_{Eun} \cdot \bar{R}$ | |
| $\bar{x}$ | $UCL = C + A^* \cdot \bar{s}$<br>$LCL = C - A^* \cdot \bar{s}$ | | | $UCL = B^*_{Eob} \cdot \bar{s}$<br>$LCL = B^*_{Eun} \cdot \bar{s}$ | | | | | |
| $x$ | $UCL = C + E_E \cdot \bar{R}$<br>$LCL = C - E_E \cdot \bar{R}$ | | | | | | | | |

# 10 Example of an Event Code for Mechanically Processed Parts

It is necessary to make a distinction between the event code that the machine operator needs and the event code for his foreman. The event codes for the foreman may not be used by the machine operator, nor may he make the decisions.

The following plan for the operator level is divided up into causes, action and handling of parts/goods.

| **Causes** | | |
|---|---|---|
| C1 Batch change in the materials<br>C2 Batch change in processing<br><br>K1 Calibration not correct<br>K2 Reference standard defective<br><br>M1 Machine defect, mechanical<br>M2 Machine defect, electrical<br>M3 Machine defect, hydraulic<br>M4 Machine failure in the conveyor system<br><br>P1 Individual value not plausible<br>P2 Measuring/inspection equipment defective<br><br>S1 Work piece clamping device, tool life | | S2 Work piece clamping device, breakage<br>S3 Work piece limit stop defective<br>S4 Work piece drive unit defective<br><br>V1 Incoming goods are dirty<br>V2 Inspection instrument is dirty<br>V3 Machine is dirty<br>V4 Preparation/condition nonconforming<br><br>W0 Tool defective<br>W1 Tool, end of tool life<br>W2 Tool, breakage<br>W3 Tool holder defective<br>W4 Tool dressing device defective<br><br>Z1 Determine other causes |

| **Action** | | |
|---|---|---|
| A1 Termination of the inspection during a sample, since the values up to now have all been outside the plausibility area.<br><br>A2 Termination of the inspection after completing a sample, since it is beyond the control limits and it is expected that it will affect subsequent characteristics.<br><br>A3 Termination of the inspection so that it can be resumed later.<br><br>K3 Calibration repeated<br>K4 Calibration repeated with new standard<br>K5 Calibration carried out<br><br>M5 Machine adjusted | | M6 Machine cleaned<br>M7 Machine serviced/repaired<br><br>P3 Inspection equipment changed<br>P4 Inspection controller changed<br>P5 Inspection equipment adjusted<br>P6 Inspection equipment cleaned<br>P7 Inspection repeated<br><br>S5 Tool holder changed<br>S6 Work piece limit stop corrected<br>S7 Work piece drive unit corrected<br><br>W5 Tool adjusted<br>W6 Tool changed<br>W7 Tool holding device corrected<br>W8 Tool dressed<br>W9 Tool dressing device corrected |

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| **Handling of the Parts/Goods** | | |
|---|---|---|
| T1 Control limits exceeded; a recheck did not reveal any necessity for sorting; parts/goods delivered as OK<br><br>T2 100% sorted, OK portion was delivered<br><br>T3 Parts/goods delivered with concession [1)]<br><br>T4 Parts/goods blocked; rework required | | T5 Parts/goods to be scrapped [1)]<br><br>T6 100 % sorted, concession portion delivered [1)]<br><br>T7 100 % sorted, OK or concession portion delivered, rework portion kept [1)]<br><br>Z3 Determine other form of handling<br><br>[1)] As a rule, the machine operator does not make the decisions on these matters. |

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# 11 Reaction Catalog

A reaction catalog needs to be created especially for the specific process being controlled (machine, test location).

The event codes listed in the previous sections are only meant to be examples, which in this case refer to a mechanical manufacturing process.

**Example: Reaction Catalog for SPC**

Measuring station no.: 82

If the control chart reacts the following actions must be taken and entered in the chart.

After action on the process take a sample and enter measured values in the control chart!

| **Goods:** | | **Machine:** |
|---|---|---|
| 11. 100% sorting, OK-proportion delivered<br>12. Goods delivered with concession<br>13. Goods held; rework necessary<br>14. Scrap<br><br>**Tool:**<br>21. Dress grinding wheel<br>22. Change grinding wheel<br><br>**Work piece:**<br>31. Change chuck<br>32. Stop dog | | 41. Adjust machine<br>42. Machine defect mech./hydr./pneum.<br>43. Machine defect electrical<br>44. Change dressing tile<br>45. Change dressing rollers<br><br>**Measurement system:**<br>51. Change of gage caliper<br>52. Measurement control/compensation<br><br>**General:**<br>61. Contamination<br>62. Preliminary working/delivery<br>63. Other causes (to be documented) |

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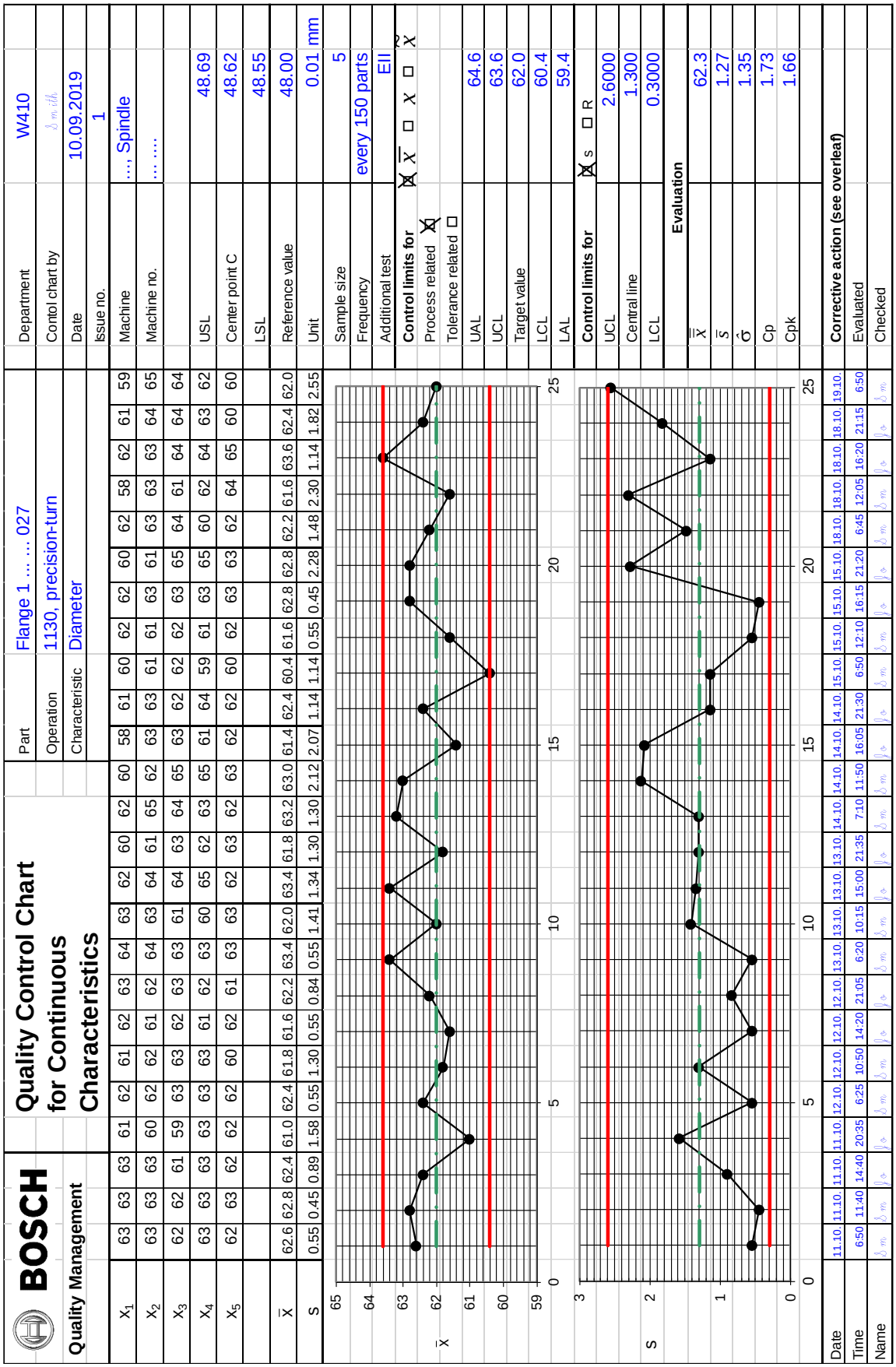
# 12 Example of an $\overline{x} - s$ Chart



# 13 Responsiveness of a Control Chart and Type-1 Error

Keeping a control chart corresponds to the repeated application of a statistical test. For example, the sample mean value $\bar{x}$ is used to check whether the process location has changed or not. The further the real process location moves away from the center point $C$, the more likely it is that the control chart will react to it, i.e. $\bar{x}$ lies outside one of the control limits.

If the probability of intervention as a function of the process shift is represented in units of the standard deviation $\sigma$, an s-shaped curve is obtained as shown in the following figure.

This curve is called operation characteristic of the control chart.

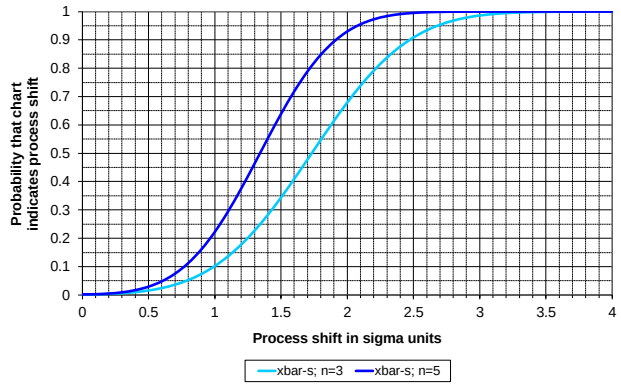



Fig. 13

The curve is steeper at $n = 5$ than at $n = 3$, so the control chart with a larger sample size reacts more sensitively to a change in the process location. A high responsiveness of the average chart must therefore be "bought" by the sample size. The curve for the average chart is also steeper than that of the median chart.

A special feature is not easily recognizable in the presentation. It is the fact that the curve at the lower end still indicates an intervention probability of approx. 1 % at zero displacement. Thus, even with a completely stable centered process, there is a probability of 0.5 % in each case that a sample mean $\bar{x}$ is below $LCL$ or above $UCL$. This error probability is also called a type-1 error.

| | Maximum number of random violations of control limits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| m | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| $\bar{x}$ chart | 4 | 6 | 8 | 10 | 12 | 13 | 15 | 16 | 18 | 19 |
| $s$ chart | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

The above table indicates the maximum number of control limit violations that can occur purely by chance, although the process has not changed. Where $m$ is the number of samples.

*EDITORIAL NOTE: Statistically speaking, the situation corresponds to an urn model (bowl model) in which 99 % of the balls bear the inscription "unchanged process", the remaining 1 % of the balls bear the inscription "changed process" (see [Booklet 2]). If 100 balls are taken out of the urn, with a probability of 99.5 %, no more than 4 will have the inscription "changed process". The number 4 is the upper threshold value of the binomial distribution for a probability of 99.5 %. In the case of the s chart, only the exceeding of the upper control limit is considered, with the associated intervention probability of 0.5%.*

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# 14 Reviews and Maturity Assessments

In the present context of quality management, the word "review" means "to look at things critically once again; to check". The corresponding noun is identical. According to the [ISO 9000] standard, such a "review" is about "determination of the suitability, adequacy or effectiveness" of something to "achieve established objectives". In particular, one attempts to identify, for example, inconsistencies, deficiencies, errors or gaps in a concept or procedure. This usually results in a need for action and corrective or improvement measures are suggested.

The term maturity often appears in connection with an assessment model (maturity model) that is used to assess the "maturity" (quality capability) of an organization, system or process, for example, by means of a catalog of questions or criteria.

*NOTE: The mental link with the development of fruits or living organisms certainly plays a role here.*

The assessment is carried out, for example, using a multi-level scale (1, 2, 3 or red, yellow, green). An even number of levels (e.g. four levels: not or merely rudimentary, largely not, largely, almost complete or complete) has the advantage that there is no "medium" rating. The assessor must therefore decide in the middle range for the worse or better half of the possibilities. A larger number of steps than about three or four steps makes it more difficult to differentiate between them. A quantitative scale has the advantage that the results can be presented quite clearly in the form of a network diagram (radar chart).

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**Review**

To ensure the consistent realization and effectiveness of the control loops as well as the effectiveness and efficiency of the inspection processes in production, it makes sense to carry out regular reviews.

**Maturity Assessment**

Carrying out assessements is recommented, in order to

- check the process of quality planning process regarding its application,
- to assess the maturity of its implementation and
- to derive targeted improvement potentials.

The aspects to be evaluated include, for example, the quality characteristics and the respective associated inspection strategy, the measurement and test processes as well as the implemetation of the quality control loops (big, small).

“SPC-Assessment” is just another name for such a maturity assessment. A major difference is the "flight altitude", i.e. the focus and the level of detail. Typical main and sub criteria are, e.g.

- Personnel and Qualification (qualification of users)
- Planning (measurement/test processes, machine and process characteristics, machine capability)
- Realization (application of the control chart)
- Documentation (of actions)
- Effectiveness (short-term process capability, long-term evaluation)

# List of Symbols

| | |
|---|---|
| $C$ | center point of the tolerance zone (target value) |
| $c_4$ | factor for the determination of $\hat{\sigma}$ from the mean standard deviation $\bar{s}$ *(in older literature also referred to by $a_n$)* |
| $C_g$, $C_{gk}$ | potential and critical measurement process capability index *(MSA, Procedure 1)* |
| $C_m$, $C_{mk}$ | potential and critical process capability index |
| $C_p$, $C_{pk}$ | potential and critical process capability index *(long-term)* |
| $C_{p-ST}$, $C_{pk-ST}$ | potential and critical process capability index *(short-term)* |
| $d_2$ | factor for the determination of $\hat{\sigma}$ from the mean range $\bar{R}$ |
| $i$ | number (index) of the measurement within a sample; $1 \leq i \leq n$ |
| $j$ | number (index) of the measurement within all measurements; $1 \leq j \leq m \cdot n$ |
| $k$ | number (index) of the sample within all samples; $1 \leq k \leq m$ |
| $k_A$ | delimitation factor in the $\bar{x} - s$ chart |
| $k_E$ | delimitation factor in the individual data chart |
| $\lambda$ | smoothing factor for the EWMA chart |
| $LAL$ | Lower Alarm Limit |
| $LCL$ | Lower Control Limit |
| $LL$ | Lower Limit; Lower Specification Limit, minimum value |
| $m$ | number of samples |
| $\mu$ | mean of a population |
| $\hat{\mu}$ | estimating value for the mean of a population |
| $\hat{\mu}_{max}$ | estimating value for the greatest mean |
| $\hat{\mu}_{min}$ | estimating value for the smallest mean |
| $n$ | number of readings per sample *(sample size)* or in a value set |
| n′ | number of parts *(if different from n)* |
| $N$ | total number of all individual values ($N = m \cdot n$) or lot size |
| $P_{p-ST}$, $P_{pk-ST}$ | potential and critical process performance index *(short-term)* |
| $R$ | Range of a value set |
| $R_k$ | Range of sample no. $k$ |
| $\bar{R}$ | mean of ranges |
| $s$ | standard deviation of a sample |
| $s_{total}$ | standard deviation of all individual values |
| $s_{\bar{x}}$ | standard evaluation of the mean values of $m$ samples |
| $\bar{s}$ | mean standard deviation from $m$ samples of the same size |
| $\overline{s^2}$ | mean variance; mean squared standard deviations |

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| | |
|---|---|
| $\sigma$ | standard deviation of the population |
| $\hat{\sigma}$ | estimate value for the standard deviation of the population |
| $\hat{\sigma}_{add}$ | (additional) variance (standard deviation) between samples |
| $T$ | tolerance of a characteristic |
| $u_{1-p}$ | quantile of the standard normal distribution for the probability $1-p$ |
| $UAL$ | Upper Alarm Limit |
| $UCL$ | Upper Control Limit |
| $USL$ | Upper Limit; Upper Specification Limit (of the tolerance zone) |
| $x_i$ | single value no. $i$ of a value set |
| $x_{ik}$ | single value no. $i$ in sample no. $k$ |
| $x_{max}$ | largest individual value of a value set *(maximum)* |
| $x_{min}$ | smallest individual value of a value set *(minimum)* |
| $\bar{x}$ | arithmetric mean |
| $\bar{x}_k$ | arithmetic mean of the individual values in sample no. $k$ |
| $\bar{\bar{x}}$ | mean of mean values (total mean; grand mean) |
| $\tilde{x}$ | median |
| $\tilde{x}_k$ | median of the individual values in sample no. $k$ |
| $\bar{\tilde{x}}$ | mean of medians |

Konstanten: $a_n$, $c_n$, $d_n$, $A$, $A'$, $A^*$, $B'_{Eun}$, $B'_{Eob}$, $B^*_{Eun}$, $B^*_{Eob}$, $C_E$, $D_{Eun}$, $D_{Eob}$, $D'_{ob}$, $E_E$, $E'_E$

Other symbols used only in individual chapters or the use of symbols with different meanings are defined in the appropriate context.

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**Variants of usual abbreviations**

Depending on source and language version several designations and abbreviations are common in the framework of SPC.

| English | | German | |
|---|---|---|---|
| Lower Limit<br>Lower Specification Limit | $LL$ or $L$<br>$LSL$ | $UGW$<br>$USG$ | Unterer Grenzwert<br>Untere Spezifikationsgrenze |
| Upper Limit<br>Upper Specification Limit | $UL$ or $U$<br>$USL$ | $OGW$<br>$OSG$ | Oberer Grenzwert<br>Obere Spezifikationsgrenze |
| Lower Control Limit | $LCL$ | $UEG$ | Untere Eingriffsgrenze |
| Upper Control Limit | $UCL$ | $OEG$ | Obere Eingriffsgrenze |

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# Terms and Definitions

*NOTE 1: The following definitions of terms were taken from the respective standards cited in this document. Corresponding notes were only adopted in single cases if they were considered directly relevant and/or essential for understanding a standardized term. Otherwise, the respective standard should be referenced for notes and examples.*

*NOTE 2: "Editorial notes"are not part of the respective standard.*

*NOTE 3: In some cases, the same term is listed with several definitions from various standards and directives, provided that the definitions do not appear entirely consistent.*

**alarm limits**

Tolerance-related control limits whose violation generally requires increased monitoring of the process.

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**acceptance control chart**

Control chart intended primarily to evaluate whether or not the plotted measure can be expected to satisfy specified tolerances. [ISO 3534-2]

**AQDEF** (Advanced Quality Data Exchange Format)

The name AQDEF is an officially registered trademark of Q-DAS GmbH & Co. KG, Weinheim. AQDEF is a standard for the collection and the cross-system exchange of quality information, among others between measurement systems and and the Q-DAS software products.

**determination**

Activity to determine one or more **characteristics** and its characteristic values [ISO 9000]

**capability**

Suitability of a object *(for example **product**, service, **process**, person, organization, system, resource)* for realization of a result, which will fullfill the **requirements** of this result *(with reference to [ISO 9000])*

**capability**

Suitability of an organization, a system or an process for realisation of a product, which will fullfill the requirements of this product [ISO 22514-1]

**capability index***:* see **process capability index**

**center point of the specification interval**

Arithmetic mean of lower and upper limiting value

NOTE: In many cases the center point corresponds to the imaginary or to the defined target value.

[DIN 55350-12]

**center point of the specification interval**

Arithmetic mean of lower and upper limiting value: $C = \frac{LSL+USL}{2}$

*EDITORIAL NOTE: In the case of characteristics limited on one side above (only USL given), such as roughness (Rz), shape and position (e.g. roundness, rectangularity), it does not make sense to assume* $LSL = 0$ *and consequently set* $C = \frac{USL}{2}$.

**characteristic**

Feature for the recognition and distinction of units. [DIN 55350-12]

**characteristic**

Distinguishing property

*NOTE 1: A characteristic can be inherent or assigned.*

*NOTE 2: A characteristic can be of qualitative or quantitative nature.*

*NOTE 3: There are different classes of characteristics, e. g.:*

- *physical, for example mechanical, electrical, chemical or biological characteristics;*
- *sensory, e. g. regarding smell, touch, taste, sight, hearing;*
- *behavioral, e. g. decency, honesty, truthfulness;*
- *time-related, for example punctuality, reliability, availability;*
- *ergonomic, for example physiological or characteristics related to human safety;*
- *functional, for example top speed of an airplane.*

[ISO 3534-2]

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**conformity**

Fulfilling a requirement [ISO 9000]

**conformity evaluation**

Systematic examination about the degree to which an entity fulfills special requirements

[ISO 3534-2]

**continuous characteristic**

Characteristic whose characteristic values are the measuring values of a physical quantity (for example, weight, length, current, temperature)

*EDITORIAL NOTE: Often imprecisely called "variable characteristic"; see also "continuous scale" [ISO 3534-2]*

**continuous characteristic**

Quantitative characteristic whose co-domain (range of values) is uncountably infinite. [DIN 55350-12]

*EDITORIAL NOTE: The value of such a characteristic is always given as a product of numerical value and unit.*

*EXAMPLES:*

- *Length: 12.54561… m,*
- *Diameter: 3.532… mm.*

*The numerical value of the characteristic "length", for example, can take on every value between 12 and 13; mathematically expressed: every real number on the interval between 12 and 13. In reality, no value of such a continuous characteristic can be measured with infinite accuracy. The number of decimal places is always limited by the number of available digits that can be displayed. In addition, properties of the measurement process can limit the number of useful decimal places.*

**control chart**

Chart on which some statistical measure of a series of samples is plotted in a particular order to steer the process with respect to that measure and to control and reduce variation. [ISO 3534-2]

**countable characteristic**

Special discrete characteristic whose co-domain is given by the set of natural numbers including zero (0, 1, 2, …) or a subset of this set." [DIN 55350-12]

**discrete characteristic**

Characteristic whose characteristic values are counted measurands in a countable unit (e. g. good/bad, right/wrong, red/green/blue)

*EDITORIAL NOTE: Often imprecisely called "attributive characteristic"; see also "discrete scale"*

[ISO 3534-2].

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**discrete characteristic**

Quantitative characteristic whose co-domain is finite or countably infinite. [DIN 55350-12]

*EDITORIAL NOTE (EXAMPLES)*

- *Mass in kg (without decimal places).*
- *Body weight in cm (without decimal places).*
- *Number of "6" when rolling a die 100 times. The result can take on all of the values from 0 to 100. The number is finite.*
- *Number of lightning strikes in Germany during a given year (one can also locate and, of course, record atmospheric lightning using antennae). This number can take on a countably infinite number of values (0, 1, 2, 3, …), although very large values will appear with decreasing probability.*

**entity**

That which can be individually described and considered [ISO 3534-2]

*EDITORIAL NOTE: Not to be confused with "unit" (see [VIM])*

**enumeration**

Determining the measurand "number of ellements in a set", for instance by counting. [DIN 1319-1]

**estimator**

Statistic used in estimation of the parameter Θ. [ISO 3534-1]

**estimation**

Procedure that obtains a statistical representation of a population from a random sample drawn from this population.

*NOTE 1: In particular, the procedure involved in progressing from an estimator to a specific estimate constitutes estimation.*

[ISO 3534-1]

**estimate**

Observed value of an estimator. [ISO 3534-1]

**influence quantity**

Quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result. [VIM]

**inspection**

Conformity assessment through observation and assessment, accompanied — if applicable — by measurement, testing or comparison [ISO 3534-2]

**lower specification limit**

Limit indicating the lower limiting value [ISO 3534-2]

**measurement result**

Set of quantity values that are assigned to a measurand along with any available relevant information [VIM]

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**measuring instrument**

Device, which is used alone or in conjunction with additional facilities for the performance of measurements [VIM]

**measurand**

Quantity which is to be measured [VIM]

**measurement**

Process in which one or more quantity values, that can be reasonably assigned to a quantity, are experimentally determined

*NOTE 2: A measurement means comparing sizes and includes counting*

[VIM]

**measurement process**

Set of activities for determining a quantity value [ISO 9000]

**measurement uncertainty**

Not negative parameter that characterizes the variation of values that is attached to the measurand on the basis of information used [VIM]

**measurement value**

Quantity value which represents a measurement [VIM]

**measuring and test equipment**

Measuring equipment for inspections [DIN 1319-2]

*EDITORIAL NOTE: Measuring equipment for the proof of conformity regarding defined internal, customer, legal and or regulatory quality requirements.*

**measuring system**

Combination of measuring devices and often other devices and, if necessary reagents and utilities, which are arranged and adapted to provide information to obtain readings within certain intervals for quantities of certain types

*NOTE: A measuring system can consist of a single measuring device*

[VIM]

**median** *(engl. median)*

0.5-quantile

*NOTE 1: The median is one of the most commonly applied p-quantiles in practical use. The median of a continuous univariate distribution is such that half of the population is greater or equal to the median and half of the population is less than or equal to the median.*

[ISO 3534-1]

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**median of a sample**

Among the values ordered in ascending numerical order and numbered "1" to "$n$", for odd $n$ the actual value with the number $\frac{n+1}{2}$, for even $n$ usually the mean value of the two actual values with the numbers $\frac{n}{2}$ and $\frac{n}{2}+1$.

Example: For a sample of size 5 ordered by ascending numerical value, the median is the middle of the 5 values.

**nominal characteristic**

Qualitative characteristic whose values have no quantitative relation to each other. [DIN 55350-12]

*EDITORIAL NOTE, Example: The characteristic "color" with the values "red", "yellow", "green".*

*The values of these characteristics can only be classified and differentiated (is equal, is not equal).*

*"The value of a nominal characteristic is often also called attribute. A nominal characteristic with only two, mutually exclusive values is called a dichotomous characteristic, a binary characteristic or an alternative characteristic. It can only take on one of two mutually exclusive values."*

*Examples:*

- *good / bad,*
- *inside / outside the tolerance range (OK / not OK),*
- *defective / not defective,*
- *present / not present.*

*Such data is, for instance, gained using limit gauges or by visual assessment with boundary samples. It is, however, also possible to define a "discrete" continuous characteristic by first measuring it and then classifying the measured value using a category "inside/outside the tolerance range". However, this is rarely sensible due to the associated loss of information. If measurement values exist for a continuous characteristic, they should be used in their original form.*

**ordinal characteristic**

Qualitative characteristic whose values have a quantitative relation to each other. [DIN 55350-12]

*EDITORIAL NOTE, Example:*

- *The characteristic "clothing size" with the values XXS, XS, S, L, XL, XXL, …, 7XL,*
- *The characteristic "(European) shoe size" with the values 14, 15, 16, …, 48, 49.*

*The values of these characteristics can be classified and differentiated, e.g. using the relationships "smaller than", "is equal" or "greater than".*

**population**

Population of the considered entities [ISO 3534-2]

*EDITORIAL NOTE: The term "population" refers to a limited or unlimited number of observable units that are to be considered concurrent within the framework of an existing statistical problem. Such observable units can, for example, come from "observations" or results from "tests" conducted under the same conditions.*

*Examples of finite populations are the number of*

- *students in a school,*
- *eligible voters within a state,*
- *television viewers who watched the final match of the last Football World Cup,*
- *parts in a delivery of goods,*
- *products manufactured within one shift at factory XY.*

*Examples of (theoretically) infinite populations are the number of*

- *points observed when rolling dice,*
- *results determined when repeatedly measuring against a standard of length,*
- *parts that a machine will create, under the assumption that it will retain its current condition for ever.*

*Above all, the previous examples show that a population does not always have to be real; it can also be fictional. Moreover, one can recognize that a statistical problem can sometimes be focused at a prognosis (prediction) of future results.*

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**process**

Set of associated or mutually influencing activities, which uses entries to achieve an intended result [ISO 9000]

*EDITORIAL NOTE: In the context of this Booklet, a process is generally understood to be a sequence of activities and/or procedures in which materials or preprocessed parts/components are further processed and a product is produced. These can be manufacturing or assembly processes, for example. But also a measuring process is a sequence of activities and/or sequences in which something is produced, namely measuring results.*

**parameter**

Index of a family of distributions

*NOTE 1 The parameter may be one-dimensional or multi-dimensional.*

*NOTE 2 Parameters are sometimes referred to as location parameters, particularly if the parameter corresponds directly to the mean of the family of distributions. Some parameters are described as scale parameters, particularly if they are exactly or proportional to the standard deviation of the distribution. Parameters that are neither location nor scale parameters are generally referred to as shape parameters.*

[ISO 3534-1]

*EDITORIAL NOTE 1: Parameters of location (expected value, median), parameters of variability (variance, standard deviation, coefficient of variation) and shape parameters (skewness, kurtosis, excess) are also called functional parameters.*

*EDITORIAL NOTE 2: Colloquially the term process parameter is occasionally used. The standard [ISO 3534-1] refers this term exclusively to parameters of statistical distributions. In connection with processes [ISO 22514-1] uses the term process characteristic.*

**performance index**

Parameter that indicates the performance measure with respect to stipulated specifications

[ISO 22514-1]

**population parameter**

Summary measure of the values of some characteristic of a population

*EXAMPLE Population mean = μ; population standard deviation = σ*

*NOTE Population parameters are usually symbolized by lower case Greek letters in italics.*

[ISO 3534-2]

**process capability index**

Parameter which indicates the capability with respect to given specifications [ISO 22514-1]

**process characteristic**

Inherent characteristic of a process [ISO 22514-1]

*EDITORIAL NOTE: Process characteristics are necessary characteristics to ensure the conformity of the product characteristics. These are characteristics that are transmitted to facilities and equipment, and not on the product.*

*For the term "inherent", see also the editorial note with regard to the term "product characteristic".*

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**process characteristic in control**

Process characteristic, with which the parameters of the distribution of the characteristic values change practically not or only in known way or within known limits [DIN 55350-11]

**process in control** *(engl. translation of DIN 55350-11 not available)*

Process whose main features are process characteristics which are in control [DIN 55350-11]

**process quality**

Required quantified output from process, which is equal to the quality objective (usually fractions nonconforming e.g. defined in ppm). [CD 00301]

**product**

Result of a process [ISO 22514-1], [ISO 3534-2]

**product characteristic**

Inherent characteristic of a product [ISO 22514-1]

*EDITORIAL NOTE: "Inherent" means "an inherent unit" (for example, physical properties such as weight, size, power consumption of a product); therefore an inherent characteristic may be a quality characteristic, but not a "mapped" characteristic (such as, e. g., price, the owner).*

**product characteristic in control**[N2)]

Product characteristic parameters of the distribution of the characteristic values, which virtually do not change or only change in a known manner or within known limits.

*[N2)] National Footnote:*

*ISO 21747 used the English terms "stable process"and "process in a state of statistical control" interchangeably, which DIN ISO 21747 translated as "stable process"and "dominated process".*

*Deviating from that, ISO 22514-1 designated only the behavior after ISO 21747 as "stable process" and "process in a state of statistical control", which DIN ISO 22514-1 translated as "stable process".*

*However, the behavior according to ISO 21747 is designated in ISO 22514-1 as a "product characteristic in control", which is translated as "dominated product characteristic". This important change is not yet considered in DIN ISO 3534-2.*

[ISO 22514-1]

**qualitative characteristic**

Characteristic whose values are allocated to a scale without defined distances.

[DIN 55350-12]

**quality capability**

Suitability of an organization or parts of an organization (e. g. people, procedures, processes, equipment) for realizing a result that will meet the quality requirements of this result *(with reference to [ISO 22514-1, 3.3.2] and [ISO 9000, 3.6.12])*.

**quality capable process**

A process is quality capable if it is able to fully comply with the specified requirements.

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**quality characteristic**

Inherent characteristic of a product, a process or system related to a requirement [ISO 22514-1]

*EDITORIAL NOTE: For the term "inherent", see also the editorial note for the term "product characteristic".*

**quality control chart**

Quality control chart (Shewhart chart) for monitoring a parameter of the probability distribution of a characteristic with the purpose of determining whether the value of the parameter deviates from a given value.

**quantitative characteristic**

Characteristic whose values are allocated to a scale with defined distances. [DIN 55350-12]

*EDITORIAL NOTE: All physical quantities are quantitative characteristics, for example length, volume, angle, weight, mass, temperature, tension, current, time, speed.*

**quantity**

Property of a phenomenon, a body or a substance wherein the property has a value which can be expressed by a number and a reference [VIM]

**quantity type**

Aspect which is common with comparable quantities [VIM]

**quantity value**

Numerical value and reference, which together specify a quantity quantitatively [VIM]

**random cause**

Cause of the variation which is constantly inherent in a process [ISO 22514-1]

**random sample**

Sample, which has been selected randomly [ISO 3534-1]

**range**

Greatest minus smallest single value: $R = x_{max} - x_{min}$

**reaction plan**

Reaction plan Action or series of steps prescribed in a control plan in the event abnormal or nonconforming events are detected. [IATF 16949]

**resulting process distribution**

Time-dependent distribution model that reflects the instantaneous distribution of the characteristic under consideration, and the changes of its location, dispersion and shape parameters during the time interval of process observation. According to [ISO 22514-2].

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**requirements**

Requirement or expectation that or which is stipulated, commonly provided or mandatory

[ISO 9000]

**sample**

Subset of a population which consists of one or more selection units.

[ISO 3534-1]

*EDITORIAL NOTE: In contrast to the population a sample is a real and therefore finite number of "things" or events. Examples of this are the set of*

- *vehicles that passed through the highway tunnel near Leonberg on a specific day,*
- *results observed when rolling one die 10 times,*
- *results obtained when conducting 25 measurements against a standard of length,*
- *50 parts made while testing a machine's capacity.*

*By the way, the German term for "sample" ("Stichprobe") originates from the practice of "piercing" grain sacks and cotton bales during quality inspection. A sample consists of one or several units that were "drawn" from a real or fictitious population according to the random principle. The number of these elements is called the sample size. The properties of the sample are supposed to represent the population. Random sampling presupposes that each element of the population is given the same chance (same probability) to be picked for the sample. In general, it is rarely possible to apply the random principle in a nearly ideal manner (flipping a coin, roulette, drawing the lottery numbers). The idea is especially problematic with regard to fictitious populations; "drawing" the sample is only possible in a figurative sense.*

**sample mean**

Average, arithmetic mean. Sum of random variables in a random sample divided by the number of terms in the sum. [ISO 3534-1]

**sample size**

Number of sampling units in a sample [DIN 55350-14]

**sampling unit**

One of the individual parts into which a population is divided. [ISO 3534-1]

**Shewhart control chart**

Control chart with Shewhart control limits intended primarily to distinguish between the variation in the plotted measure due to random causes and that due to special causes. [ISO 3534-2]

**sorting inspection**

This is a 100% inspection and means that objects/units/items are inspected (visually or using technical means) with respect to defined characteristics and sepa-rated according to the individual results (e.g. conforming / nonconforming).

**specification**

Document that specifies requirements

*NOTE: A specification may refer to activities (for example process document, process specification and test specification), or products (for example, product specification, performance specification and drawing).*

[ISO 9000]

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**specification interval**

Area between the limits maximum value and minimum value [ISO 22514-1]

*EDITORIAL NOTE: The limits are also referred to as specification limits.*

**specification limit**

Limiting value stated for a characteristic [ISO 3534-2]

**stable process; process in a state of statistical control**

Process which (with regard to its variation) is only subject to random causes

*NOTE 1: A stable process will behave in general as if the samples are random samples at any time with simple sampling from the same population.*

*NOTE 4: In some processes, the expected value of the characteristic can change, or the standard deviation can be increased. The reasons may be, for example, tool wear or the reduction of the concentration in a solution. A progressive change in the expected value or the standard deviation of such a process is considered as systematic and not as a random cause. These are then the results of sampling, not simple random samples from the same population.*

[ISO 21747]

*EDITORIAL NOTE: The English original version of this term is identically defined in ISO 3534-2 (2006) and ISO 21747 (2006); DIN ISO 21747 contains the older German translation (2007); DIN ISO 3534-2 contains the newer German translation (2013) and uses only the term "process in a state of statistical control".*

**stable process**

Process which is only subject to random variation causes

*NOTE 2: A stable process behaves in general as if samples drawn from the process are at any time simple random samples from the same population.*

[ISO 22514-1]

*EDITORIAL NOTE: The definition of the term from the original English version ISO 3534-2 (2006) was adopted in modified form in the English version ISO 22514-1 (2014); The German version DIN ISO 22514-1 (2016) uses only the term "stable process".*

**statistic**

Completely specified function of random variables

*NATIONAL FOOTNOTE: Statistics characterize properties of a frequency distribution*

[ISO 3534-1]

**standard deviation of a sample**

Square root of the variance: $s = \sqrt{s^2}$

**Statistical Process Control**

Statistical quality control for processes

*EDITORIAL NOTE: SPC is a standard method for visualizing and controlling processes, based on measurements of random samples. The goal of SPC is to ensure that the planned process output is achieved and that corresponding customer requirements are fulfilled.*

*SPC is always linked to the (manual or software supported) use of quality control charts with the the goal of achieving, maintaining and improving stable and capable processes. This is done by recording process or product data, drawing conclusions from this data and reacting to undesirable data with appropriate actions.*

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**statistical quality control**

Part of quality control where statistical procedures are applied.

NOTE: A special area of statistical quality control is statistical process control.

[DIN 55350-11]

**target value**

Preferred value or reference value of characteristic which is specified in a specification

[ISO 3534-2]

(specified) **tolerance**

Difference between maximum value and minimum value [ISO 3534-2]

**tolerance interval:** see **specification interval**

*EDITORIAL NOTE 1: The specification of a tolerance consists of a number and a unit of measurement, e.g. 0.01 mm. The term tolerance interval or specification interval refers to the range between the minimum value and the maximum value. Apart from the limited resolution of the measuring process, the tolerance interval contains an infinite number of values.*

*EDITORIAL NOTE 2: Colloquially, phrases such as "exceeding tolerance" or "adhering to tolerance" are often used. This usually means that a measured value of a characteristic lies within or outside the tolerance interval.*

*EDITORIAL NOTE 3: Since according to the standard a specification is a document, the term specification interval is strictly speaking wrong. What is meant is the (specified) tolerance interval defined in the specification for a characteristic.*

**tolerance zone** see **specification interval**

**tolerance zone**

Area of permitted values between lower and upper limiting value. [DIN 55350-12]

**upper specification limit**

Limit indicating the upper limiting value [ISO 3534-2]

**variance of a sample**

The deviations of the individual values from the arithmetic mean are summarized and the sum is devided by the number of values reduced by one: $s^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (x_i - \bar{x})^2$

**variation**

Difference between values of a characteristic [ISO 22514-1]

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# Literature


Corporate directives, only internally available

[CD 02981] CD 02981 Information Governance

[CD 00301] CDQ 0301 Management of Characteristics

[CD 00501] CDQ 0501 Identification and Traceability

[CD 00503] CDQ 0503 Rework and Repair

[CDQ 0509] CDQ 0509 Concessions

Booklet Series “Quality Management in the Bosch Group”, Technical Statistics

[Booklet 1] Booklet No. 1, Basics Concepts of Technical Statistics, Continuous Characteristics

[Booklet 2] Booklet No. 2, Basics Concepts of Technical Statistics, Discrete Characteristics

[Booklet 3] Booklet No. 3, Basics Concepts of Techn. Statistics, Evaluation of Measurement Series

[Booklet 8] Booklet No. 8, Measurement Uncertainty

[Booklet 9] Booklet No. 9, Machine and Capability Capability

[Booklet 10] Booklet No. 10, Capability of Measurement and Test Processes

[AIAG PPAP] AIAG Core Tools, Production Part Approval Process (PPAP)

[AIAG SPC] AIAG Core Tools, Statistical Process Control (SPC)

[AQDEF] Advanced Quality Data Exchange Format of the Automotive Industry, Q-DAS GmbH, Weinheim, Germany

[IATF 16949] IATF 16949, Automotive Quality Management System Standard — Quality management system requirements for automotive production and relevant service parts organizations

[DIN 1319-1] Basic concepts in metrology, Part 1: General concepts (under revision)

[DIN 55350-11] DIN 55350-11, Concepts for quality management — Part 11: Supplement to DIN EN ISO 9000

[DIN 55350-12] DIN 55350-12, Concepts in the field of quality and statistics — Concepts relating to characteristics

[DIN 55350-14] DIN 55350-14, Concepts in the field of quality and statistics — Concepts of sampling

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

[ISO 3534-2] DIN ISO 3534-2, Statistics — Vocabulary and symbols — Part 2: Applied Statistics

[ISO 7870-2] Control charts — Part 2: Shewhart control charts

[ISO 7870-5] Control charts — Part 5: Specialized control charts

[ISO 7870-6] Control charts — Part 6: EWMA control charts

[ISO 7870-8] Control charts — Part 8: Charting techniques for short runs and small mixed batches

[ISO 9001] DIN EN ISO 9001, Quality management systems — Requirements

[ISO 11462-1] Guidelines for implementation of statistical process control (SPC) — Part 1: Elements of SPC

[ISO 11462-2] Guidelines for implementation of statistical process control (SPC) — Part 2: Catalogue of tools and techniques


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[ISO 22514] DIN ISO 22514-2, Statistical methods in process management — Capability and performance — Part 2: Process performance capability and process capability statistics of time-dependent process models

[Schulze] Dietrich/Schulze: Statistical Procedures for Machine and Process Qualification, Hanser-Verlag

[Shew 1931] Economic Control of Quality of Manufactured Product, D. Van Nostrand Comp., 1931

[Shew 1939] Statistical Method from the Viewpoint of Quality Control, Washington, The Graduate School, The Deptartment of Agriculture, 1939

[VDA-4] VDA Volume 4, Securing the quality in the process landscape, methods, economic process design and process control

[VIM] International Dictionary of Metrology (VIM), German-English version ISO/IEC Guide 99:2007, published by DIN German Institute for Standardization, Beuth Verlag Berlin Vienna Zurich

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