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Calibration Intervals

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Contents

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References

- ILAC-G24/ OIML -D10, Guidelines for the determination of calibration intervals of measuring instruments (www.ilac.org)
- NCSL RP-1, Establishment and Adjustment of Calibration Intervals (www.ncsli.org)

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Why do we calibrate?

To check the accuracy of a measuring instrument.

To improve the accuracy of a measuring instrument.

To test a new instrument

To have confidence in a measuring instrument's results.

To test an instrument after it has been repaired or modified

To check the operation of an instrument which has had a shock, vibration, or exposure to adverse conditions.

Because many instruments' results drift over time.

To ensure the best results prior to and after a critical measurement.

Because measurements are important! Measurement and measurement-related operations have been estimated to account for between 3% and 6% of the GDP of industrial countries.

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Risks of Not-Calibrating

- Equipment downtime
- Production downtime
- Inaccurate results
- Need for rework
- Loss of money
- Safety concerns

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Calibration intervals- What does ISO/IEC 17025 Require?

6.4.4 The laboratory shall verify that equipment conforms to specified requirements before being placed or returned into service.

6.4.5 The equipment used for measurement shall be capable of achieving the measurement accuracy and/or measurement uncertainty required to provide a valid result.

6.4.6 Measuring equipment shall be calibrated when:

— the measurement accuracy or measurement uncertainty affects the validity of the reported results, and/or

— calibration of the equipment is required to establish the metrological traceability of the reported results.

6.4.7 The laboratory shall establish a calibration programme, which shall be reviewed and adjusted as necessary in order to maintain confidence in the status of calibration.

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Calibration intervals- Additional Requirements

- The accreditation body may have specific requirements.

- The industry may have specific requirements.

- Testing standards may have specific requirements.

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Calibration of equipment: Who is responsible?

It is the responsibility of the laboratory to justify the need for calibration and to determine the calibration intervals.

- If a calibration is not a dominant factor in the result, the laboratory has quantitative evidence that the associated contribution of the calibration contributes little (insignificantly) to the measurement result and the measurement uncertainty.
- If this can be demonstrated, then there is no requirement for this equipment to be calibrated.

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Significance Test

Any number, x, that is one third or less than another, y, will tend to have no significant effect on the outcome of the square root of the sum of their squares:

$$z = \sqrt{x^2 + y^2}$$

***x* = 1.0 and *y* = 3.0**

If, x = 1.0 and y = 3.0, then z = 3.16 if x is included in the expression and 3.0 if it is not. The difference is approximately 5%, a relatively insignificant difference when considering uncertainties.

Any number, x, that is one tenth or less than another, y, will tend to have negligible effect on the outcome of the square root of the sum of their squares.

If, x = 1.0 and y = 10.0, then z = 10.05 if x is included in the expression and 10.0 if it is not. The difference is approximately 0.5%, a negligible difference when considering uncertainties.

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Significance Test- Examples

If the uncertainty of an instrument is:

- Smaller than 1/10 of the largest contributor in the estimation of uncertainty for all tests affected by that instrument → Evidence to increase the period of calibration from one to two years or more.
- Between 1/10 and 1/3 of the largest contributor in the estimation of uncertainty for all tests affected by that instrument → The laboratory must maintain the period of calibration at one year
- Larger than 1/3 of the largest contributor in the estimation of uncertainty for all tests affected by that instrument → Evidence to decrease the period of calibration to less than one year; for example every six months.

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No-Periodic Calibration Required

If the instrument does not make measurements

If the instrument does not make critical measurements

When does this status may be assigned to an item?

If the instrument makes measurements which only provide an indication of operational status but does not provide a numerical value

If the operation of an instrument is unlikely to change

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Re-calibration Interval Analysis- First thoughts

No single best practice for establishing and adjusting calibration intervals that applies to all CABs.

Calibration is concerned with many different types of equipment.

Each CAB requiring calibration of test equipment and standards:

- establishes its own individual maximum acceptable uncertainty levels and renewal/adjustment policies,
- determines what parameters to calibrate and what tolerances to use,
- sets cost constraints on interval analysis expenditures,
- establishes calibration and testing procedures.

Each of these activities has a direct bearing on which calibration interval analysis method is optimal for a given organization.

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Re-calibration Interval Analysis- First thoughts

Reliability is defined as the probability that the device will remain in-tolerance throughout the established interval.

Devices shall be calibrated at periodic intervals established and maintained to assure acceptable accuracy and reliability.

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Intervals shall be shortened or may be lengthened, by the CAB, when the results of previous calibrations indicate that such action is appropriate in order to maintain acceptable reliability.

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Re-calibration Interval Analysis- Basic Considerations

Choices to a laboratory , **depending on the significance of the contribution of the instrument to the overall uncertainty of the desired test result:**

When instrument performance is very much better than the requirement, the laboratory can reduce the calibration frequency (extend the cycle time).

When performance is at the same level as requirement, the calibration frequency must be increased.

When the laboratory does not know, they must calibrate that equipment once per year.

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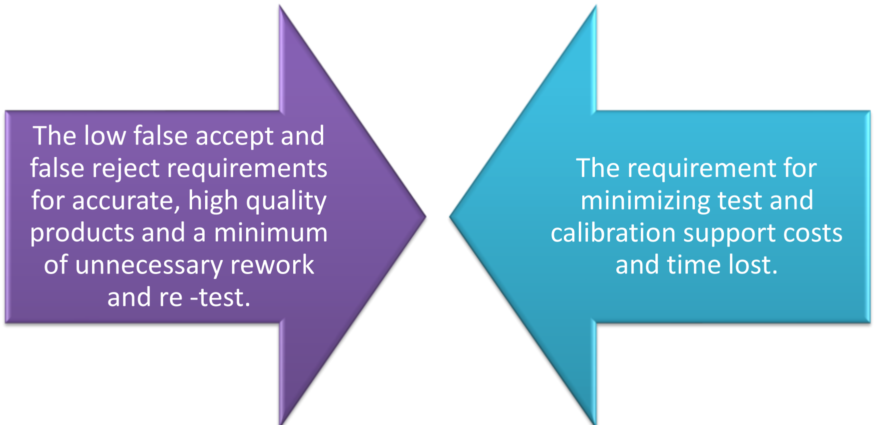
Re-calibration Interval Analysis

Minimizing costs and time lost is a worthwhile goal!



Balance of the benefit of reduced uncertainty against the cost of achieving it.

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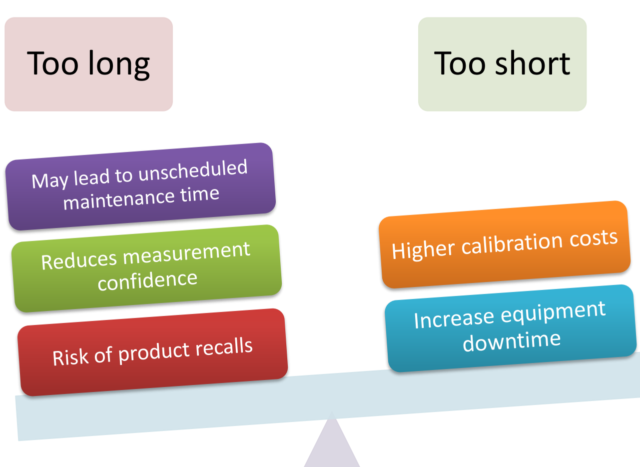
Re-calibration Interval Analysis

Minimizing costs and time lost is a worthwhile goal!



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How do you define the re-calibration interval of your devices?

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Should everyone follow the same interval?

How often do you change your oil?

- Every 5000 km?
- Every 10000 km?
- Every 3 months?
- When the oil looks dirty?
- When the viscosity of the oil changes?
- When you remember?
- When you have time?

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Setting an Initial Calibration Interval

Set an initial calibration interval for every piece of MTE, taking into account:

- The manufacturer's recommendations
- The AB's recommendations
- Your experience with that equipment (If you have similar equipment already in service)
- Recommendations of industry and government-related organizations

Do any of these apply to you?

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Initial calibration intervals: Questions to ask when setting them

How stable is the equipment? Does it have a tendency to wear of drift?

How complex and critical are the measurements that will be made? What is the measurement uncertainty required?

Will the M&TE be used frequently or only rarely? What does the previous calibration data tell you? Are intermediate checks performed?

What are the environmental conditions (such as dust, vibration, and temperature) in which the equipment must operate? What is the extent and severity of use?

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Initial calibration intervals: Questions to ask when setting them

What is the risk of damage or misuse? Are skilled technicians or unskilled technicians using the equipment? Is the measurement automated or manual?

Are there any customer contract obligations regarding calibration intervals?

Are there any regulatory agency obligations regarding calibration intervals?

What are the risks associated with using improperly calibrated equipment? What is the cost of correction and recall measures when the MTE is found to be "out of calibration"?

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Reliability: For how long is a measurement uncertainty estimate valid?

- A calibration, and the corresponding measurement uncertainty, are just a snapshot in time.
- "Our knowledge of the values of the measurable attributes of a calibrated item begins to diminish from the time the item is calibrated. This loss of knowledge of the values of attributes over time is called **uncertainty growth**" (NCSL RP-1)

When does it exceed your out-of-tolerance condition?

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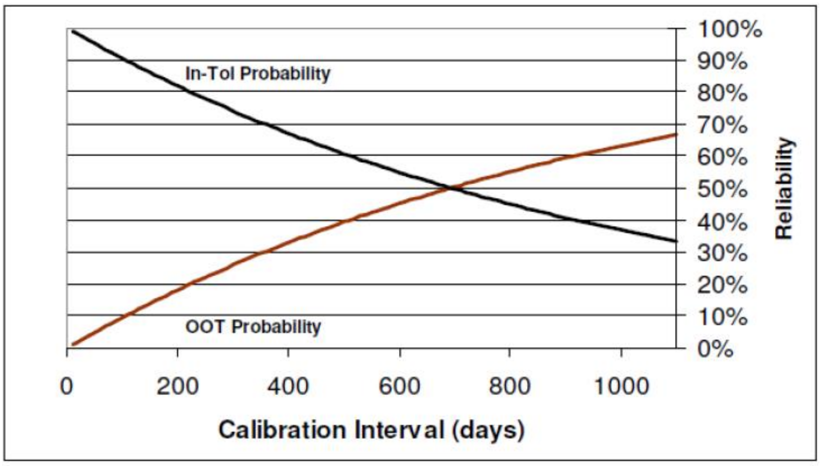
Reliability vs. Time



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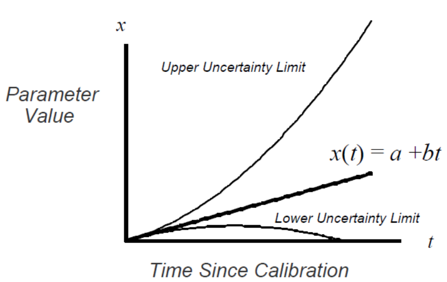
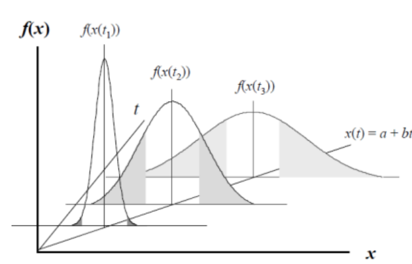
Reliability vs. Time





Uncertainty is generally reported at time of test. As time progresses following calibration, the uncertainty of the standard must also follow some progression, the progression being an increased uncertainty band.

Source: Managing Calibration Intervals, Donald W. Wyatt, Howard T. Castrup, NCSL Annual Workshop & Symposium, 1991

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Risks!

- Risk mitigation is a goal of calibration intervals.
- An appropriate recall cycle reduces the risk associated with using a measurement standard that is out of tolerance.

Short calibration cycles:

Little risk of calibrating a customer's piece of equipment with a standard that is "out of tolerance".

The risk of over calibrating and spending too much of the calibration budget on maintaining such a high reliability.

Lengthy calibration intervals:

Higher risk of using a calibration standard that is "out of tolerance".

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Periodic System Evaluation

Just as periodic calibration is necessary to verify the accuracy of devices, periodic evaluation of a calibration interval analysis system is necessary to verify its effectiveness.

- Such evaluations are possible only if predetermined criteria of performance have been established.
- One such criterion involves comparing observed (recorded) measurement reliabilities against measurement reliability targets.

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Models on the determination of calibration intervals

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Models on the determination of calibration intervals

All models include:

- an initial choice of the calibration interval, and a review of this interval using statistical methods.
- Establishment of a validity period during which the instrument can be used without concern for major uncertainties in measurement output.

Most calibration systems also allow for shortening calibration intervals if errors larger than allowed are detected. Similarly, calibration periods are lengthened if instruments are well behaved within close limits of the original calibration as instruments are returned for recalibration.

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Reliability

Reliability :	the probability that a device or parameter will remain in-tolerance throughout the established interval.
Observed reliability (for a device or parameter):	the fraction of items or parameters that are found to be in-tolerance when tested, calibrated or otherwise inspected.
Reliability Target:	the percentage of items in use that are in-tolerance during use (between calibrations)

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Calibration Interval Objectives

Establishment of calibration intervals that ensure that measurement decision risks are under control.

The cost per interval is held to a minimum.

Find an interval of time between calibrations that results in holding the reliability target to a minimum acceptable level.

- Statistical Methods
- Algorithmic Methods

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Fixed Intervals (every 6, 12, ..., months)

- Easy to implement
- Easy to remember
- Easy to schedule
- Easy record keeping
- Requires little expertise for staff

- “Out-of-calibration” equipment may be in use
- Test reports/products may need to be recalled
- Equipment may be calibrated too often=extra cost

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Automatic Adjustment (Staircase- “Simple Response Method” in RP-1)

ILAC-G24: Each time an instrument is calibrated, the subsequent interval is extended if it is found to be within the MPE required for measurement, or reduced if found to be outside this MPE

- Intervals based on data
- Easy to implement
- Requires little expertise for staff

- Interval adjustments are responses to single calibration events
- Unbalanced workload- difficult to track deadlines
- “Out-of-calibration” equipment may be in use
- Test reports/products may need to be recalled
- Equipment may be calibrated too often=extra cost

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In-Use Time

ILAC-G24: Calibration intervals are expressed in hours of use instead of calendar time

- Tracks equipment in-use time
- Number of calibrations varies directly with length of time in use
- Requires little expertise for staff
- Some instruments drift over time

- Cannot be used with all instruments
- Unbalanced workload- difficult to track deadlines
- "Out-of-calibration" equipment may be in use
- Cost of timers can be high
- Test reports/products may need to be recalled
- Equipment may be calibrated too often=extra cost

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Borrowed Intervals

Organizations must be similar with respect to calibration procedures, usage and handling of equipment, as well as environment.

- Easy to implement
- Hard work is already done
- Possibly requires little expertise for staff

- Depends on which method you borrow
- How do you know when intervals change?
- Must have similar risk tolerance

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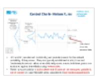
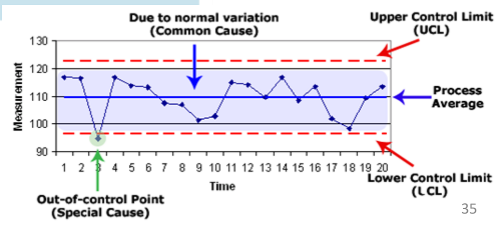
Control Charts

- Calibration intervals are flexible
- Can help to predict out of control situations=time to recalibrate

- More work
- Unbalanced workload





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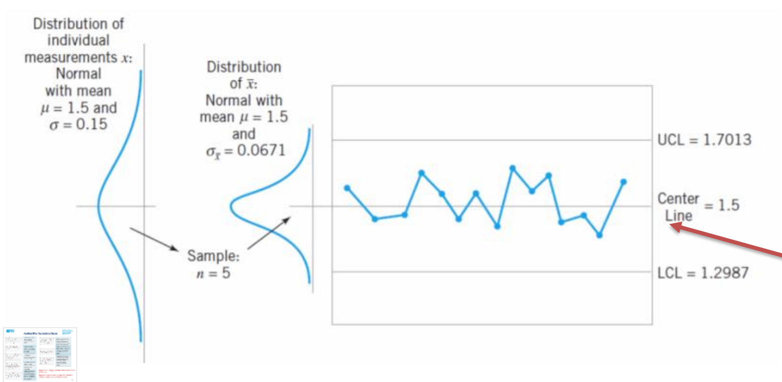
Control Charts- Nelson Rules



Calculated from the process data

- UCL and LCL are derived statistically, and provide bounds for the natural variability of the process. They are typically established at ±3σ (Standard Deviation) above and below an established process mean; individual points are evaluated against these limits using Nelson rules.
- These rules are used as a tool to determine if some of the measured variable is out of control i.e. unpredictable versus consistent. ('non-random conditions')

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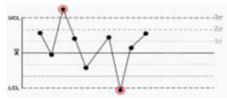
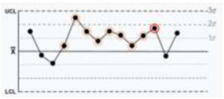
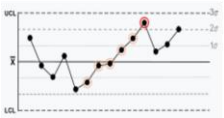
Control Charts- Nelson Rules



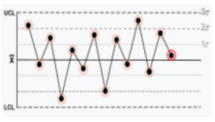
1.One point is more than 3 standard deviations from the mean.



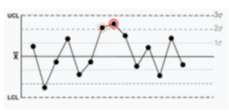
2.Nine (or more) points in a row are on the same side of the mean.



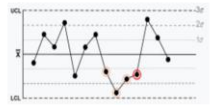
3.Six (or more) points in a row are continually increasing (or decreasing).



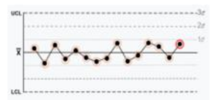
4.Fourteen (or more) points in a row alternate in direction, increasing then decreasing.



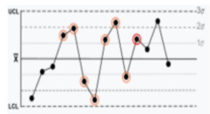
5.Two (or three) out of three points in a row are more than 2 standard deviations from the mean in the same direction.



6.Four (or five) out of five points in a row are more than 1 standard deviation from the mean in the same direction.



7.Fifteen points in a row are all within 1 standard deviation of the mean on either side of the mean.



8.Eight points in a row exist, but none within 1 standard deviation of the mean, and the points are in both directions from the mean.

http://www.itl.nist.gov/div898/handbook/pmc/section3/pmc3.htm

http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/control-chart.html

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Calibration Management Software

- Easy to implement

- Cost
- Requires some expertise
- Removes “thought process”

http://www.capterra.com/calibration-management-software/

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Methods for the determination of calibration intervals

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Statistical Methods

- Employ sophisticated statistical techniques to mathematically model in-tolerance probability vs. time elapsed since calibration.
- Attempt to predict a calibration interval that corresponds to a specific end-of-period in-tolerance percentage.
- They require considerable calibration history for analysis and are often difficult to implement.

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Algorithmic (Reactive) Methods

Utilize simple to complex decision algorithms to adjust calibration intervals in response to in-tolerance or out-of-tolerance conditions observed during calibration.

Consist of instructions to lengthen or shorten calibration intervals in response to current or recent observations.

Wide acceptance due to their simplicity and low cost of implementation.

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Algorithmic (Reactive) Methods –Main Drawbacks

- Interval changes are in response to small numbers (usually one or two) of observed in-tolerance or out-of-tolerance conditions. Any given in-tolerance or out-of tolerance condition is a random occurrence.
- Make no attempt to model underlying uncertainty growth mechanisms.
- Cannot be readily tailored to prescribed reliability targets that are commensurate with quality objectives. The level of reliability attainable with a given algorithmic method can be discovered only by trial and error or by simulation.
- Interval changes are ordinarily computed manually by calibrating technicians, rather than established via automated methods. Accordingly, operating costs can be high.

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Examples

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Example 1- Using the 3 most recent calibration data

Concept: Instrument's calibration history reveals something about how the instrument might be expected to perform in the future.

- If an instrument's calibration record indicates a history of remaining in tolerance it is expected that the instrument might have a higher likelihood of remaining in tolerance.
- If it has performed poorly, it may have a higher probability of being found to be out of tolerance.
- If an adjustment was performed, the instrument should have a higher probability of remaining in tolerance.

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Example 1- Using the 3 most recent calibration data

Algorithm- Reactive method:

Calibration interval adjustments are made in response to data from recent calibrations without any attempt to model or "predict" measurement reliability behaviour over time.

- Calibration intervals are calculated based on the condition received at calibration along with a historical weighting.
- The most recent calibration has the highest weighting and the previous two calibrations each have lower weightings.
- Algorithm: ***NI = CI x (W1 x X +W2 x Y +W3 x Z)***

  NI = the new calculated interval
  CI = the old calibration interval
  W1, W2, W3 = the weighting for the most recent and the previous two calibrations
  X, Y, Z = the multiplier for the as found condition at the most recent and the previous two calibrations

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Example 1- Using the 3 most recent calibration data

Each multiplier and each weighting can be varied to meet the reliability outcome desired by the laboratory. For example:

	Status	Value
A	"In Tolerance"	1
B	"Out of Tolerance" < 1x the tolerance band	0.8
C	"Out of Tolerance" > 1x the tolerance band but < 2x the tolerance band	0.6
D	"Out of Tolerance" > 2x the tolerance band but < 4x the tolerance band	0.4
E	"Out of Tolerance" > 4x the tolerance band but < 6x the tolerance band	0.3

Weightings	Cal sequence	Value
W1	Most recent calibration	0.8
W2	Most Previous Calibration	0.2
W3	Previous Calibration	0.1

Source: Allen Bare, "Simplified Calibration Interval Analysis", NCSL International Workshop and Symposium, 2006

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Example 1- Using the 3 most recent calibration data

Requirements:

- Calibration maintenance database
- Record of in or out of tolerance data
- Capability to track the degree to which the results were out of tolerance
- Fields available to indicate the condition received over each of the past three calibrations.

Attention to:

- Certain items may be required to have a maximum cycle not greater than some "x" months.
- Instruments with a poor calibration history
- Ensure that calibration cycles do not decrease beyond the minimum permitted cycle

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Example 2- Calibration Intervals from Variables Data

Concept: determining calibration intervals for parameters whose values change with time elapsed since calibration.

- Employs as-left and as-found variables data taken during calibration..
- Parameter values are assumed to be normally distributed with mean $y(t)$ and variance σ^2.
- $y(t)$ and σ^2 are estimated by regression analysis with polynomial models of arbitrary degree.
- Calibration intervals that satisfy in-tolerance criteria or maximum allowable uncertainties are determined

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Example 2- Calibration Intervals from Variables Data

Model: $y(t) = y_0 + \delta(t)$

- t is the time elapsed since calibration,
- y_0 is the value of y measured at time t = 0, and
- $\delta(t)$ is the deviation in parameter value as a function of t.

Predicted value:

$$\hat{y}(t) = y_0 + \hat{\delta}(t) \qquad u_y \cong \sqrt{\mathrm{var}[\hat{y}(t)]} \qquad \mathrm{var}[\hat{y}(t)] = u_0^2 + \mathrm{var}[\hat{\delta}(t)]$$

Regression Analysis

δ_i the difference between the as found and as left values, t_i the respective time difference

$$\hat{\delta}_i = b_1 t_i + b_2 t_i^2 + \cdots + b_m t_i^m$$

Source: Howard Castrup, "Calibration Intervals from Variables Data", NCSLI Workshop & Symposium , 2005

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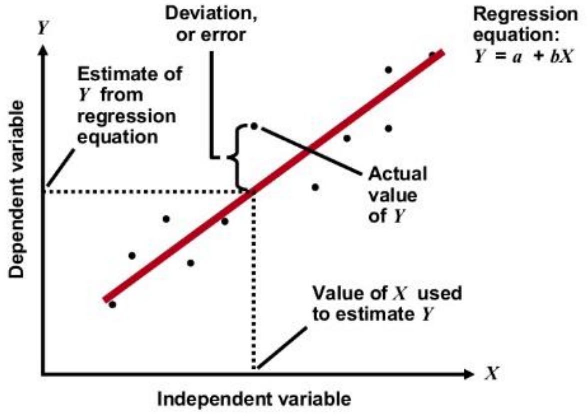
Linear regression



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Example 2- Calibration Intervals from Variables Data

- Lower and upper tolerance limits: $-L_1$ and $+L_2$.
- Solve $\hat{y}(t) = y_0 + \hat{\delta}(t)$ for the time t required for $\hat{y}(t)$ to cross either $-L_1$ or $+L_2$.

Alternatively:

Reliability Target Method: the calibration interval is established as the time corresponding to the point where the confidence that the parameter is in-tolerance drops to some minimum acceptable level, given by $1-\alpha$. α: usually something like 0.05, 0.01, etc.

Uncertainty Target Method: the calibration interval is established as the time required for the uncertainty in $\hat{y}(t)$ to reach a maximum acceptable value.

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Example 3- Estimate the drift by linear regression

Methodology:

Develop a method for estimating the drift based on the determination of a relationship between **Time** and the **Response** of the instrument. In this example, linear regression (first order).

Consists of:

a) The selection of appropriate regression analysis to ensure the credibility of the measurement

b) The use of appropriate assessment of compliance with the specification in order to decide to lengthen or shorten a calibration cycle.

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Example 3- Estimate the drift by linear regression

Linear Relationship:

Y=a+bx

- Where :
  - Y: is the response value (predicted output or reading of the instrument)
  - x : is the regressor (elapsed time)
- The concept of regression analysis deals with finding the best relationship between Y and x, quantifying the strength of this relationship. Furthermore, it is necessary to use methods that allow the prediction of the response values, given the values of the predictor x.

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Example 3- Estimate the drift by linear regression

n successive calibration processes of the same instrument,

n pairs $(x_1,_1),\ldots,(x_n,y_n)$

Y=a+bx

$$b = \frac{\sum_{i=1}^{n}(x_i - \overline{x})\,(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \quad \mathrm{a} = \overline{y} - b\overline{x}$$

- $\overline{x}$ and $\overline{y}$ are the means of $\{x_i\}$ and $\{y_i\}$ respectively.

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Example 3- Estimate the drift by linear regression

- Prediction:

$$\hat{Y} = \alpha + \beta x + \epsilon$$

- α and β are the unknown parameters to estimate using the parameters a and b of the previous linear regression line by constructing a confidence interval and
- ϵ is a random variable assumed to be normally distributed and have mean μ=0 and standard deviation σ=σ(ϵ).
- The 95% confidence interval for α and β have the form:

$$\beta = b \pm t_{0.025} \times SE(b) \quad SE(b) = \frac{s}{\sqrt{SS_{xx}}} \quad SE(\mathrm{a}) = s \times \sqrt{\frac{1}{n} + \frac{\overline{x}^2}{SS_{xx}}}$$
$$\alpha = \mathrm{a} \pm t_{0.025} \times SE(a)$$

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Example 3- Estimate the drift by linear regression

- The prediction of the mean response Y_{new} at a future calibration time (x_{new}) at a 95% confidence level:

$$\alpha + \beta x_{new} = a + b x_{new} + t_{0.025} \mathrm{x} SE(Y_{new}),$$

$$SE(Y_{new}) = s \times \sqrt{1 + \frac{1}{n} + \frac{(x_{new} - \overline{x})^2}{SS_{xx}}}$$

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Example 3- Estimate the drift by linear regression

Assessment of compliance with target values (specification)

$$E_n = \frac{\varepsilon_{drift}}{\sqrt{U^2(\varepsilon_{calib}) + U^2(\varepsilon_{specs}) + SE(Y_i)^2}}$$

- ϵ_{drift} : the deviation between two consecutive calibrations
- $U(\varepsilon_{calib})$: the extended uncertainty of the calibration lab.
- $U(\varepsilon_{specs})$: the extended uncertainty according to the instrument specification
- $SE(Y_i)$:the prediction uncertainty with a 95% confidence level.

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Example 3- Estimate the drift by linear regression

Calibration Interval adjustment

- The interval must be lengthened when the drift between two successive calibrations results to $|E_n|<1$. The recommended calibration interval increase is 20%.
- The interval can be shortened if the drift for three successive calibrations results to $|E_n|> 1$ The recommended calibration interval decrease is 20%.

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Recommended Practices

- Calibration at (planned) periodic intervals to ensure acceptable accuracy and reliability
- Shorten intervals when results of previous calibrations suggest it
- May lengthen intervals on basis of demonstrated performance
- Documented procedure for assigning and adjusting calibration intervals
- Fully documented recall system

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Recommended Practices: How to Establish Calibration Interval

Make an initial choice, considering influencing factors and existing knowledge:

- Accuracy sought and consequences of error
- Manufacturer’s recommendations
- Accommodation and environment
- Purpose and usage
- Maintenance and servicing
- Trends from previous calibrations
- Frequency of checks

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Recommended Practices: How to Establish Calibration Interval

Monitor and review, adjust as necessary

- automatic or staircase method for individual item
- control chart (enables predictions)
- adjust based upon performance of a group of similar items
- in-service checks of critical parameters

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Establishment of calibration intervals Accreditation Body Guidance

ITEM	TYPE	CALIBRATION	INTERVAL (months)	SOURCE
Standard Weights	Reference: Class E1 and E2	External	6	UKAS Lab24
	Reference: Class F1, F2, M1	External	12	UKAS Lab24
	Working: Class E1 and E2 (internal calibration)	Internal	Max 24, depending upon frequency of use)	UKAS Lab24
	Working: Class F1, F2, M1	Internal	12	UKAS Lab24
Weighing Machines	Laboratory balances, platform scales	• External • In house-zero and single/multi-point check	• 12 • Daily before use	UKAS Lab24
	Spring Balances	In house-Check with working masses at suitable points	Daily before use	UKAS Lab24
Pressure Gauges	Piston pressure gauges		60	DKD-R 6-1
	Bourdon tube pressure gauges, class > 0.6		24	DKD-R 6-1
	Electrical pressure gauges > 0.5 % of measurement span		24	DKD-R 6-1
	Pressure transmitters with electrical output > 0.5 % of measurement span		24	DKD-R 6-1
	Bourdon tube pressure gauges, class ≤ 0.6		12	DKD-R 6-1

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Thank you for your attention!

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