

# IPC-TM-650 TEST METHODS MANUAL

**1 Scope** Tests performed on presumably identical samples under seemingly identical conditions do not always yield identical results. This is due in part to errors inherent in every measurement. During the development of a new test procedure or use of an existing test procedure, this variability must be understood and precautions taken to ensure that it is controlled to within necessary limits. Performance of this test method will help to estimate measurement error and troubleshoot possible causes. It can provide evidence that a new test procedure is suitable for use when submitted for review, or an existing test procedure is capable of measuring the applicable parameter.

This method provides a simple, easy to use, standard procedure for determining the precision of a test method using the average and range method. It can be used on tests that involve measurements that yield continuous data. The calculations shown in this procedure are streamlined versions; useful for situations where up to five repeated readings are taken on each of up to 10 samples by up to 10 test laboratories, operators or test conditions.

This procedure is not useful for measurements which result in binary data, such as pass-fail or go-no go results, or where more than five repeated measurements or more than ten laboratories or conditions are used. These situations are covered under other methods. (see 6.3)

## 1.1 Definitions

**Accuracy (Bias)** – The difference between an observed measurement and the true (but perhaps unknown) value being measured (see Figure 1).

**Continuous Data** – Numerical data that can take any conceivable value within an observed range and forms a distribution about a mean value.

**Precision** – The closeness to each other of repeated measurements of the same quantity.

**Repeatability** – Variation of a measurement system that is obtained by repeating measurements on the same sample(s) by the same procedure under the same measurement conditions (see Figure 1).

**Reproducibility** – Variation among the averages of measurements made under different measurement conditions such as different operators, equipment, and/or locations (see Figure 1).

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| Number<br><b>1.9</b>                                                      |                      |
| Subject<br><b>Measurement Precision Estimation for Variables Data</b>     |                      |
| Date<br><b>01/03</b>                                                      | Revision<br><b>A</b> |
| Originating Task Group<br><b>Measurement Precision Task Group (7-11a)</b> |                      |

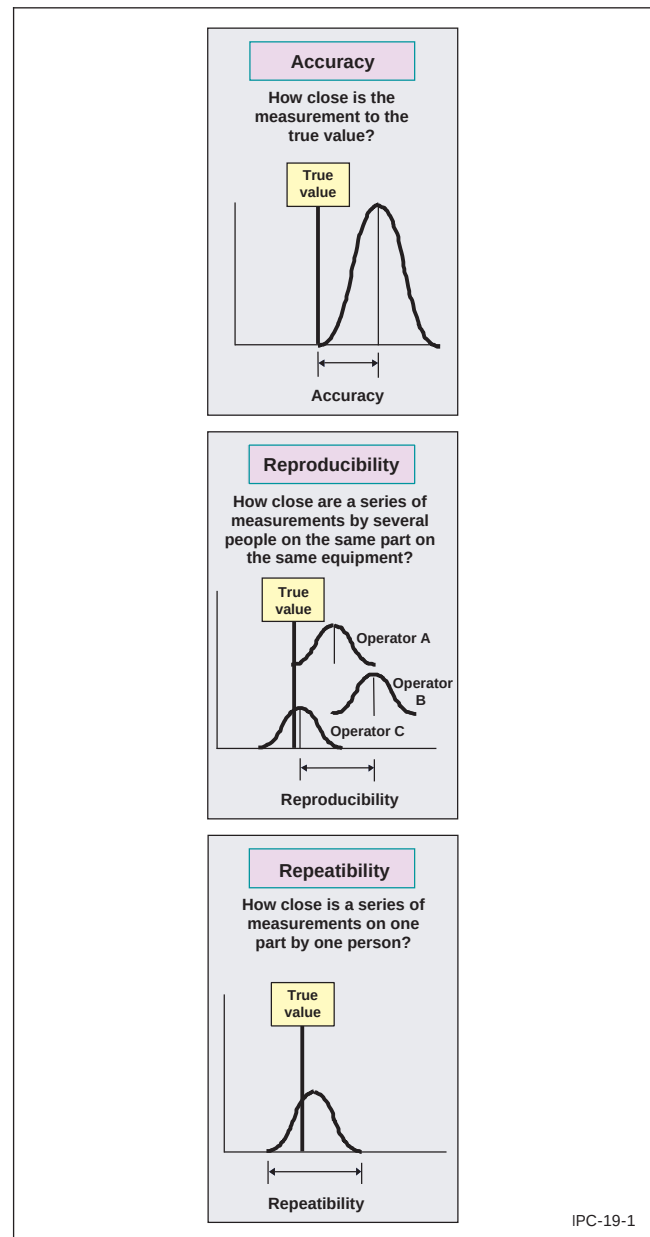


Figure 1 Measurement Repeatability and Reproducibility

**Resolution** – The size of the smallest increment on the measurement instrument under examination. This value is frequently used in the advertising literature to classify the instrument.

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**2 Applicable Documents** The applicable document will be the test procedure under evaluation.

**3 Test Specimens** The test specimens used will be as specified in the test procedure under investigation.

The number and types of test materials to be used will depend on the range of levels in the class of materials to be tested. If it is known that precision is worse at one end of the range, evaluations could be limited to that end of the range. In general, evaluations should be performed on all combinations of materials, levels, test set-ups, and test conditions. If resources are limited, begin the study with those combinations deemed to be the most critical, or where measurement error is likely to be greatest.

The number of samples will also depend on the difficulty involved in obtaining, processing, and distributing the test specimens, the difficulty, length of time required for, and expense of performing the test, and other prior known information.

This test method will assume that measurements can be repeated on the same sample. For situations where this is not possible or the sample is consumed during the test, see 6.3.

**4 Apparatus** The apparatus used will be as specified by the test procedure under investigation.

The resolution of the measurement apparatus should be sufficient to achieve the desired accuracy of the measurement. For example, if you were to measure mass, and expect to measure it to 1 gm, the balance should be able to measure to at least 0.1 gm.

## 5 Procedure

**5.1 Planning the Evaluation** Keep the evaluation as simple as possible to obtain estimates of within and between tester variability that are free of unintended secondary effects. A particular test condition could be different combinations of laboratories, operators, equipment, etc.

Be sure the procedure under evaluation is complete and describes the test parameters as well as recommended techniques for controlling variability. Include known best practices and draw extensively on the experience of test users.

The method used in this procedure allows for up to ten test conditions. Solicit participants from among the community of facilities with the proper test equipment, competent operators and familiarity with the test. In order to obtain representative

precision estimates, do not select only from a small group of users who are considered exceptionally qualified. Be sure to specify any special calibration procedures or material preparation requirements.

The analysis method used in this procedure allows up to five repeated measurements per sample. The test samples should be carefully prepared in order to be as consistent and homogeneous as possible. Try to limit the lots of raw materials and processing facilities used. Randomize the samples prior to dividing into test groups. Prepare more than the material required to ensure adequate amount is available for the study in case of lost or damaged specimens, errors, test set-up, etc.

Carefully package and label the samples. Assign serial numbers, if possible. Identify the version of the test procedure and specify care and handling procedures. Provide a data sheet, and describe any documentation required. Require a test log, and insist that all observations of any unusual events be recorded.

**5.2 Conducting the Evaluation** Ensure the samples are inspected on receipt. Send replacement units if damaged or tests are performed improperly. Follow the documented test procedure carefully to ensure no unusual variation is introduced.

Inspect the data sheets when returned. Review the test logs for unusual events. Review the measurements for level and consistency. Question unusual data points. Incorrect readings and typographical errors must be corrected prior to analysis.

**5.3 Analyzing the Data** Analysis may be performed on the Measurement Precision data sheet or on other applicable software. A Measurement Precision Calculator has been prepared to perform the calculations using the equations shown below (see 6.5).

This evaluation technique is called the Average and Range Method and partitions the total measurement precision ( $S_{R\&I}$ ) into two portions: the with-in test condition variation, called repeatability ( $S_r$ ) and between test condition variation, called reproducibility ( $S_R$ ). The method does this by calculating an estimate of the standard deviation of the measurement repeatability by using the range of the repeated measurements with-in each test condition, and by calculating an estimate of the standard deviation of the reproducibility by using the range between different test condition averages.

For normally distributed parameters, these two standard deviations are combined to estimate the total measurement precision by taking the square root of the sum of the squares.

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This method is summarized by equations (1) through (3) below.

$$S_{R\&r} = (S_R^2 + S_r^2)^{1/2} \quad (1)$$

where,

$$S_r = \bar{R} \times K_1 / 5.15$$

$$S_R = \left[ (R_{\bar{x}} \times K_2)^2 - \left( \frac{28.1 \times S_r^2}{n \times k} \right) \right]^{1/2} / 5.15 \quad (2)$$

and where

$$\bar{R} = \frac{\sum_{i=1}^m \sum_{j=1}^n R_{ij}}{m \times n} \quad (3)$$

$R_{ij}$  = Range of repeated readings for test condition i and sample j

m = number of test conditions

n = number of samples

$R_{\bar{x}}$  = Range of operator averages - the maximum Test condition average, minus the minimum test condition average.

k = number of repeated readings

The K factors,  $K_1$ ,  $K_2$ , and  $K_3$  are noted in Table 1 below.

**Table 1 K Factors**

| K Factors |       |            |       |         |       |
|-----------|-------|------------|-------|---------|-------|
| Readings  | $K_1$ | Conditions | $K_2$ | Samples | $K_3$ |
| 2         | 4.57  | 2          | 3.65  | 2       | 3.65  |
| 3         | 3.04  | 3          | 2.70  | 3       | 2.70  |
| 4         | 2.50  | 4          | 2.30  | 4       | 2.30  |
| 5         | 2.21  | 5          | 2.08  | 5       | 2.08  |
| 6         | 2.03  | 6          | 1.93  | 6       | 1.93  |
| 7         | 1.90  | 7          | 1.82  | 7       | 1.82  |
| 8         | 1.81  | 8          | 1.74  | 8       | 1.74  |
| 9         | 1.73  | 9          | 1.67  | 9       | 1.67  |
| 10        | 1.67  | 10         | 1.62  | 10      | 1.62  |

**5.4 Evaluating Process Capability of Measurement System** The estimated standard deviation of the total measurement precision,  $S_{R\&r}$ , can be used to evaluate the capability of the measurement process. This capability assessment is performed by comparing the estimated measurement precision to the specification tolerances and to total product variation.

**5.4.1 Capability Assessment 1 – Gage Repeatability and Reproducibility (GRR)** The precision-to-tolerance ratio,

GRR, shows what percent of the specification window is consumed by measurement uncertainty, and is defined as:

$$GRR = \frac{5.15 \times S_{R\&r}}{USL - LSL} \times 100 \quad (4)$$

where,

USL = upper specification limit and

LSL = lower specification limit

This equation is defined for situations where both specification limits exist. It would not be evaluated where only an upper or lower limit exists. A factor of 5.15 is used to calculate the 99% confidence interval on the total measurement precision. Another commonly used factor is 6 used to represent a 99.975% confidence interval.

**5.4.2 Capability Assessment 2 – Precision to Variation Ratio (PV)** The precision-to-variation ratio shows what percentage of the total observed product variation can be attributed to measurement uncertainty. It is calculated as follows:

$$PV = \frac{S_{R\&r}^2}{S_T^2} \times 100 \quad (5)$$

Where

$$S_T^2 = S_{R\&r}^2 + S_p^2 \quad (6)$$

And where

$$S_p = R_p \times K_3 \quad (7)$$

$R_p$  = The range between the maximum and minimum part measurement averages.  $K_3$  is noted in Table 1, above.

**5.4.3 Measurement Tolerance** The measurement tolerance defines a confidence half interval around the measured value using the estimated measurement precision.

$$TOL = 2.57 \times S_{R\&r} \quad (8)$$

The factor 2.57 is used to give the 99% confidence half interval. Thus there is a 99% chance that the true (but unknown) value of the parameter being measured will fall within  $\pm TOL$  of the measured value.

**5.5 Preparing Analysis Conclusions** Goals for measurement precision should be established before the study begins. The goals should be established using knowledge of the anticipated levels of product variability (or process capability), specifications, customer needs and the possible impact of dispositioning test samples improperly (see 6.4).