Designation: E 1345 – 98

# Standard Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements[1]

This standard is issued under the fixed designation E 1345; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## INTRODUCTION

Recent improvements in the precision and bias of color-measuring instruments have been accompanied by more widespread use of numerical color tolerances based on instrumental measurements. As tighter tolerances are specified, they begin to approach the limits of visual perception. In many cases, the instrument user has found it difficult to prepare and measure specimens with adequate repeatability. This practice provides procedures for reducing variability in the mean results of color measurement by the use of multiple measurements, and it indicates how many measurements are required for a specific reduction.

## 1. Scope

1.1 Reduction of the variability associated with average color or color-difference measurements of object-color specimens is achieved by statistical analysis of the results of multiple measurements on a single specimen, or by measurement of multiple specimens, whichever is appropriate.

1.2 This practice provides a means for the determination of the number of measurements required to reduce the variability to a predetermined fraction of the relevant color or color-difference tolerances.

1.3 This practice is general in scope rather than specific as to instrument or material.

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[2]

D 3134 Practice for Establishing Retroreflectance Color and Gloss Tolerances[2]

E 178 Practice for Dealing With Outlying Observations[3]

E 284 Terminology of Appearance[2]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[2]

E 456 Terminology Relating to Quality and Statistics[3]

E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation[2]

2.2 *Other Standard:*

SAE J 1545 Recommended Practice for Instrumental Color Difference Measurement for Exterior Finishes, Textiles and Colored Trim[4]

## 3. Terminology

3.1 Definitions of appearance terms in Terminology E 284 or statistical terms in Terminology E 456 are applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *box and whisker plot*, *n*—a nonparmetric data analysis diagram that illustrates the 25, 50, and 75 % cumulative distribution of values in a data set (the box) and the expected range of values, defined by distance outside the box ends; see *whiskers*, see Fig. 1.

3.2.2 *extreme value*, *n*—a single reading, selected from a series of readings, whose value is farther from the nearer box end than 3.0 times the hinge length.

3.2.2.1 *Discussion*—A box and whiskers plot is normally used to find outliers and extreme values. Such values should be eliminated from a series before calculating the series mean, standard deviation, and confidence intervals.

3.2.3 *hinges*, *n*—the 25 and 75 % cumulative distribution points in a set of readings taken during a measurement.

3.2.3.1 *Discussion*—Hinges represent the values in which 25 % of the readings are less than the lower hinge and 75 % of the readings are less than the upper hinge. See also *hinge length*.

3.2.3.2 *Discussion*—Hinges are sometimes called the lower ($Q_1$) and upper ($Q_1$) quartile values.

[1] This practice is under the jurisdiction of ASTM Committee E-12 on Color and Appearance of Materials and is the direct responsibility of Subcommittee E12.04 on Planning.

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] Available from the Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096.

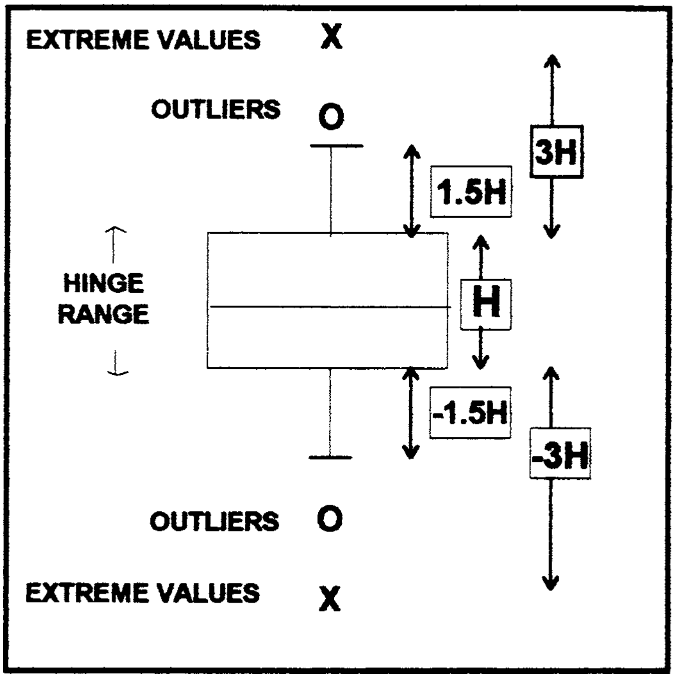


FIG. 1 Schematic Description of a Box and Whisker Plot

3.2.4 *hinge length, H, n*—the range of values between the lower and upper hinges.

3.2.4.1 *Discussion*—The hinge length is sometimes called the box width or the interquartile range $Q_3$ to $Q_1$.

3.2.5 *outlier*, *n*—a single reading, selected from a series of readings, whose value is further from the nearer box end then 1.5 times the hinge length; see see 3.2.2.1.

3.2.6 *sampling number, N, n*—number of multiple measurements, or number of multiple specimens, required to reduce the variability of color or color-difference measurement to a desired level.

3.2.7 *standard deviation of color or color-difference measurement, s*—standard deviation of the color scale or color-difference-scale value, $x_i$, being considered:

$$s = [\{\Sigma(x_i - x_{avg})^2\}/(n - 1)]^{0.5} \quad (1)$$

where:

$x_{avg}$ = $(\Sigma x_i)/n$, and
$n$ = the number of replicate measurements made.

3.2.8 *standard deviation of instrument,* $s_i$, *n*—standard deviation of a color-scale or color-difference-scale value due to instrument variability alone:

$$s_i = [\{\Sigma(x_i - x_{avg})^2\}/(n - 1)]^{0.5} \quad (2)$$

3.2.9 *standard error of the estimated mean,* $s_e$, *n*—standard deviation of color or color-difference measurement divided by the square root of the sampling number:

$$s_e = s/(N^{0.5}) \quad (3)$$

3.2.10 *standard error goal,* $s_{e,g}$, *n*—level to which the standard error of the estimated mean is to be reduced.

3.2.11 *tolerance*, *n*—the upper tolerance limit minus the lower tolerance limit; the total allowable range of the color-scale or color-difference-scale value considered.

TABLE 1 Appropriate and Inappropriate Color Coordinates for Use in This Practice

| Color Coordinates | Appropriate | Inappropriate |
|---|---|---|
| CIE *Yxy* | | √ |
| CIE *LCH* | √ | |
| CIE *LAB* | √ | |
| CIE LUV | √ | |
| CIE L*u′v′* | | √ |

3.2.12 *whiskers*, *n*—lines extending out from the box ends to the largest and smallest observations lying within 1.5 times the hinge length, measured from the box ends.

## 4. Summary of Practice

4.1 This practice assumes that, for the material under consideration and a specified set of color scales, relevant color or color-difference tolerances have been established (see Practice D 3134).

4.2 For convenience, the numerical example in the Appendix uses CIELAB *LCH* (lightness, chroma, hue) color difference scales $\Delta L^*$, $\Delta C^*_{ab}$, and $\Delta H^*_{ab}$ (see Test Method D 2244 and Practice E 308), but this is not meant to be restrictive.

NOTE 1—Some coordinates, such as CIE *x, y, Y*, do not follow the theories of this standard due to excessive colinearity. While it has not been tested, this same colinearity problem may also be observed in 1960 *u, v* and 1976 *u`, v`* coordinates. Table 1 provides a listing of the appropriate and inappropriate color coordinates for use with this practice.

4.3 The successive steps in the procedure are as follows:

4.3.1 Determine the standard deviation of instrument.

4.3.1.1 Screen the measurement data for outliers and extreme values.

4.3.2 Determine the standard deviation of color or color-difference measurement.

4.3.2.1 Screen the measurement data for outliers and extreme values.

4.3.3 Determine the standard error of the estimated mean for a sampling number of one.

4.3.4 Determine the final sampling number that reduces the standard error of the estimated mean to less than the standard error goal for each scale value.

4.3.5 Determine the final standard error goal values.

NOTE 2—When the standard error of the estimated mean for a sampling number of one is larger than a specified fraction of the tolerance or a specified multiple of the standard deviation of instrument for any of the three color-difference-scale values, a sampling number greater than one is required.

4.4 *Screening for and Elimination of Outliers and Extreme Values in Measured Data*:

4.4.1 *Box and whisker test*—This test is best carried out by computer. Many programs for the box and whisker technique are available.[5]

4.4.1.1 Order the readings from lowest to highest value. The reading whose value is half way between the minimum and maximum values is the median. Fig. 1 illustrates the following steps.

[5] See for example, Schaefer, R. L. and Anderson, R. B., *The Student Edition of Minitab*, Addison-Wesley, New York, 1989.