



Designation: E1345 – 24

Standard Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements¹

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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.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

¹ This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.04 on Color and Appearance Analysis.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

D3134 Practice for Establishing Color and Gloss Tolerances

E178 Practice for Dealing With Outlying Observations

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E456 Terminology Relating to Quality and Statistics

2.2 Other Standard:

SAE J 1545 Recommended Practice for Instrumental Color Difference Measurement for Exterior Finishes, Textiles and Colored Trim³

3. Terminology

3.1 Definitions of appearance terms in Terminology E284 or statistical terms in Terminology E456 are applicable to this practice.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *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.

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

$$s = \left[\frac{\sum (x_i - x_{av})^2}{(n - 1)} \right]^{0.5} \quad (1)$$

³ Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, <http://www.sae.org>.

where:

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

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

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

3.2.4 *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:

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

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

3.2.6 *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.

4. Summary of Practice

4.1 The successive steps in the procedure are as follows:

4.1.1 Determine the standard deviation of instrument.

4.1.1.1 Screen the measurement data for outliers and extreme values.

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

4.1.2.1 Screen the measurement data for outliers and extreme values.

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

4.1.4 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.

4.1.5 Determine the final standard error goal values.

5. Significance and Use

5.1 This practice should be used whenever measured color-scale or color-difference-scale values are to be compared to an established tolerance. In this way it can be demonstrated quantitatively that the sampling and measurement procedures are adequate to allow an unambiguous decision as to whether or not the mean results are within tolerance.

5.2 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 D3134).

5.3 For convenience, the numerical example in the Appendix uses CIELAB *LCH* (lightness, chroma, hue) color difference scales ΔL^* , ΔC^*_{ab} , and ΔH^*_{ab} (see Practice D2244 and Practice E308), 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 collinearity. While it has not been tested, this same collinearity 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.

5.4 This practice is based on portions of SAE J 1545, as it applies to painted or plastic automotive parts. It is generally applicable to object colors in various materials. Textured

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 Luv		✓

materials, such as textiles, may require special consideration (see SAE J 1545 and STP 15D Manual on Presentation of Data and Control Chart Analysis⁴).

6. Procedure

6.1 Determine the standard deviation of instrument, s_i , by carrying out the appropriate color measurement at least 10 times ($n = 10$) when using a stable product standard as the specimen, without removing or disturbing the specimen between measurements. Calculate s_i by the use of Eq 2. This determination should be carried out for each color scale used and for each product with a new color; however, s_i is unlikely to change appreciably over relatively extended periods.

6.1.1 Screen the measurement data for outliers and extreme values. Practice E178 has procedures for outlier identification and testing. If any outliers or extreme values are found, consider whether they should be dropped or retained in calculations. Drop readings not considered to be part of the desired dataset to be used to evaluate the required number of measurements.

6.2 Select maximum allowable values of the standard error of the estimated mean, as a fraction of the tolerance and as a multiple of the standard deviation of instrument. In the absence of specified values of these quantities, use those recommended in SAE J 1545: 0.1 times the tolerance and $2s_i$. These values are used in Appendix X1.

NOTE 2—This practice assumes that all measurements are subject to the central limit theorem of mathematical statistics, so that as the number of replicate or repeat measurements becomes large, the distribution of values is described by the standard normal distribution. It has been shown,^{5,6} however, that averages of large numbers of measurements of a verification standard on a properly maintained spectrophotometer are not approximated by the standard normal distribution. As a result, tests anchored to s_i may exhibit a significance or a power dependence different from that which is expected.

6.3 Determine the standard deviation of color or color-difference measurement, s , by making the appropriate measurement at least 10 times ($n = 10$), as follows:

6.3.1 To assess the variability within a single specimen, measure the same specimen at ten or more randomly selected different areas of the specimen.

6.3.1.1 Screen the measurement data for outliers and extreme values following 6.1.1.

⁴ Available from ASTM International Headquarters 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁵ Marcus, R. T., and Billmeyer, F. W., Jr., "Statistical Study of Color-Measuring Instruments," *Applied Optics*, Vol 13, 1974, pp. 1519–1530.

⁶ Billmeyer, F. W., Jr., and Alessi, P. J., "Assessment of Color-Measuring Instruments," *Color Research and Application*, Vol 1, 1981, pp. 99–102.