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SURFACE VEHICLE RECOMMENDED PRACTICE

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INSTRUMENTAL COLOR DIFFERENCE MEASUREMENT FOR EXTERIOR FINISHES, TEXTILES AND COLORED TRIM

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. Scope—The practice applies to parts and materials used in vehicle manufacture which are intended to be acceptable color matches to a specified color standard. This practice is intended for use with parts or materials which are opaque or nearly so and does not apply to transparent materials. Materials covered by this practice include topcoat paint finishes, interior soft trim, interior and exterior hard trim, and exterior film.

1.1 Purpose—The intent of this practice is to precisely specify procedures for instrumental color difference measurement of colored parts or colored materials incorporated in the manufacture of vehicles. The recommended practice provides a consistent engineering practice for determination of color difference, for numerical communication of color difference, and for determination of acceptance or rejection compared to numerical tolerances. The practice is intended to be used as a specification and means of communication for color part acceptance in a buyer-seller agreement.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 ASTM E 284-81a—Standard Definitions of Terms Relating to Appearance of Materials

2.1.2 Commission International de l'Éclairage, International Lighting Vocabulary, Bureau Central de la CIE, Paris, 1970, 3rd ed., Publications CIE No. 17 [E-1.1.] 1970. CIE publications are available from Dr. Klaus D. Mielenz, Secretary, U.S. National Committee, CIE, Room B-306, Metrology Bldg., National Bureau of Standards, Gaithersburg, MD 20899.

2.1.3 ASTM E 105-58—Probability Sampling of Materials

2.1.4 Commission International de l'Éclairage, Colorimetry, Bureau Central de la CIE, Paris, 1970, Publication CIE No. 15 (E-1.3.1.) 1971.

2.1.5 Commission International de l'Éclairage, Recommendations on Uniform Color Spaces—Color Difference Equations Psychometric Color Terms, Bureau Central de la CIE, Paris, 1978, Supplement No. 2 to CIE Publication No. 15 (E-1.3.1) 1971/(TC-1.3.) 1978.

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2.1.6 Rolf G. Kuehni, "CIELAB Color Difference and LIghtness, Hue and Chroma Components for Objective Color Control", Detroit Colour Council Technical Bulletin No. 1. Available from Detroit Colour Council, c/o Matteson-Ridolfi Co., 14450 King Road, Riverview, MI 48192.

2.1.7 ASTM D 1729-82—Visual Evaluation of Color Differences of Opaque Materials

2.1.8 One source for color performance standards is British Ceramic Research Association Instrument Performance Standards, available from Hemmendinger Color Lab, RD 1, Box 213, Pequest Bend, Belvidere, NJ 07823.

2.1.9 One source for external verification is Color and Appearance Proficiency Testing, service available from Collaborative Testing Services, 8343-A Greensboro Dr., McLean, VA 22102.

2.1.10 F. J. J. Clarke, R. McDonald, B. Rigg. "Modifications to the JPC 79 Colour-difference Formula", J. Soc. Dyers and Colourists, 100, 128-132 (1984).

2.1.11 "Farbtoleranzen Fuer Automobillackierungen, Unilackierungen", DIN 6175, Teil 1. Entwurf Dezember 1984, Beuth Verlag Gumbh, Berlin 30, Federal Republic of Germany.

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 ASTM Committee E-12—ASTM Standards on Color and Appearance Measurement, 1st Edition, 1984

2.2.2 ASTM D 3134-74—Selecting and Defining Color and Gloss Tolerances of Opaque Materials and for Evaluating Conformance

2.2.3 Commission International de l'Éclairage, Colorimetry, Second Edition, Final Draft (April 1983), Publication CIE No. 15.2 (TC-1.3).

2.2.4 Collaborative Testing Services, "Color and Appearance, Report No. 50," 1984. Reports the results of interlaboratory color difference measurements of automobile fabrics.

2.2.5 R. W. Harold, K. Loughrey, T. Mabon, "Benefits of the Sample Averaging Technique," Hunterlab Application Notes, 4 No. 3, March 21, 1985

2.2.6 Wolfgang Budde, "The Gloss Trap in Diffuse Reflectance Measurements," Color Research and Application 5, 73-75 (1980).

2.2.7 Strocka and Brockes, "Comparison of the CIE (1931) 2° and the CIE (1964) 10° Colorimetric Standard Observer with Individual Observers in the Assessment of Metameric Matches," Proc. Intern. Color Meeting, Color 69, Stockholm 1969, Vol. 2, pp 785-793

2.2.8 Brian P. Hake, "Comparison of CIELAB, JPC79 and CMC (2:1) Color Difference Equations Performance on Automotive Exterior Paints and Grained Interior Plastics," Symposium on Color and Appearance Instrumentation, Pittsburgh, April 1985

3. Definitions—Except for terms specifically defined in this document, terminology used in this report follows the definitions reported by ASTM (2.1.1) and the Commission International de l'Éclairage (2.1.2) 1970.

3.1 Product, Lot, Sample, Reading, Measurement:

3.1.1 PRODUCT—A product is the group of all parts or material having the same color, composition and physical form.

3.1.2 LOT—A lot is the customary unit of production of a product comprising one or more individual product units. For example, a lot of plastic parts might comprise 500 individual product units and a lot of paint material might comprise one 5000 gallon batch of paint.

3.1.3 SAMPLE—A sample is an individual product unit chosen from the product lot. The sample or group of samples chosen shall be representative of the color difference properties of the product lot (2.1.3).

3.1.4 READING—A reading is a single instrumental color difference assessment made in one particular location and in one particular orientation within a sample.

3.1.5 MEASUREMENT—A measurement is the estimate of the sample color difference relative to a standard determined from one reading or the mean of multiple readings as specified by the procedure of this recommended practice.

3.2 Standards

3.2.1 OFFICIAL STANDARD—An official standard is a physical standard that is an acceptable match to the concept color. The official standard physically represents the color target for visual and colorimetric evaluation of all products referenced to that official standard. Where feasible, the official standard should have the same composition and construction as the reference and working standards.

3.2.2 REFERENCE STANDARD—A reference standard is a physical standard used to calibrate working standards. Reference standards shall have the same composition and construction as the working standards and the composition and construction shall be representative of samples of the product. Reference standards are instrumentally referenced to the official standard.

3.2.3 WORKING STANDARD—A working standard is a physical standard in routine use. Working standards are made of material identical to the reference standard and are instrumentally referenced to the reference standard.

3.3 Instruments

3.3.1 MASTER INSTRUMENT—The master instrument is an instrument that is used to establish the basic references among various levels of standards and among other instruments. This instrument is the normal arbiter in any situation not adequately resolved at a lower level. This instrument should generally be a spectrophotometer and is usually retained by the organization which issues the standards.

3.3.2 SECONDARY INSTRUMENT—A secondary instrument is any other instrument used for color difference measurement of the product by reference to the standards.

4. Basic Color Measurements Specifications

4.1 Standard Observer—The standard observer for colorimetric determination should be the CIE 1964 supplementary standard colorimetric observer (2.1.4) 1971, referred to as the 10° standard observer. If the design of the color measuring instrument used precludes use of the 10° standard observer, the CIE 1931 standard colorimetric observer (2.1.4), referred to as the 2° standard observer, may be used. See Appendix B1.1.

4.2 Standard Illuminant—The standard illuminant for colorimetric determination should be CIE standard illuminant D65 [CIE No. 15 (E-1.3.1.) 1971]. If the design of the color measuring instrument used precludes use of CIE standard illuminant D65, CIE standard illuminant (2.1.4) may be used. No other illuminant may be used. See Appendix B1.1.

4.3 Uniform Color Space—The uniform color space for determination of color difference shall be the CIE 1976 ($L^*a^*b^*$) space (2.1.5). This space may be abbreviated, CIELAB. The conversion to CIELAB coordinates for colors with tristimulus value ratios (X/X_n, Y/Y_n, Z/Z_n) less than or equal to 0.01 shall follow the equations in the appendix to the CIELAB specification (2.1.5).

4.4 Color Difference—The color difference between sample and standard shall be determined by three component color difference scales. The three component color difference scales shall be lightness difference (DL^*), CIE 1976 a, b chroma difference (DC^*_{ab}) and CIE 1976 a, b hue difference (DH^*_{ab}) (2.1.5 and 2.1.6). The abbreviations DL^*, DC^*, DH^* respectively are recommended .[1]

4.5 Color Difference Tolerance—Tolerances for color difference assessment shall be specified by upper and lower tolerances on each of the color difference scales; DL^*, DC^*, DH^*. A sample is rated acceptable by the color difference assessment if its measured color difference values relative to the color standard are within the specified tolerances for DL^*, DC^* and DH^*. A sample is rated unacceptable by the color difference assessment if its measured color difference values relative to the color standard are outside the specified tolerances for DL^*, DC^*, DH^* on one or more of the color difference scales.

4.5.1 TOLERANCE APPLICATION—Often there will be some difference in color values between a reference standard and the official standard and between a working standard and a reference standard (see 6.1.2). The color tolerances as applied to each level of standards should be adjusted to account for these differences. For example, if the DL^* tolerances were ±2 and the reference standard measured +1 L^* unit higher than the official standard, the DL^* tolerances as referenced to that reference standard should be adjusted to +1 and –3 DL^* units. See Figure 1.

1. Capital D indicates a differential colorimetric value (sometimes referred to as a delta, Greek symbol Δ).

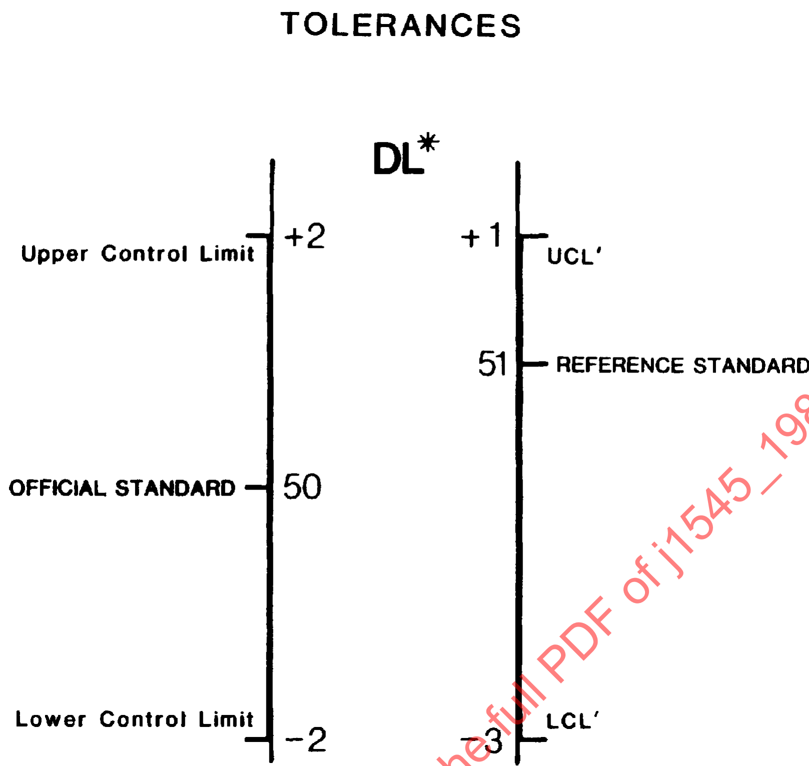


FIGURE 1—EXAMPLE OF THE MODIFICATION OF THE UPPER AND LOWER TOLERANCES OF A REFERENCE STANDARD TO ALLOW FOR THE COLOR DIFFERENCE OF THE REFERENCE STANDARD RELATIVE TO THE OFFICIAL STANDARD.

4.6 Color Measuring Instrument—The instrument used for color difference measurement shall be either a spectrophotometer or a tristimulus colorimeter. The instrument geometry, unless otherwise specified under Section 7, shall conform to one of the four sets of illuminating and viewing conditions specified by the CIE (2.1.4). The instrument geometries are identified by the convention: illuminating geometry/viewing geometry. The four allowed instrument geometries with their abbreviations are 45°/normal (45/0), normal/45 degrees (0/45), diffuse/normal (d/0) and normal/diffuse (0/d). If a diffuse geometry (d/0 or 0/d) instrument is used, the specular component of reflectance shall be included in the measurement. The angle between the sample normal and the illuminating beam in 0/d geometry and the angle between the sample normal and the viewing beam in d/0 geometry shall not exceed 10°.

4.6.1 EFFECT OF INSTRUMENT DESIGN ON COLOR DIFFERENCE MEASUREMENT—Instruments of differing designs and especially of differing illuminating and viewing geometries do not necessarily result in equivalent color difference values for all sample differences. The result depends on sample characteristics and instrument design. For this reason, the color difference tolerances for a product may need to have different values with different instrument designs.

4.6.2 EFFECT OF APPEARANCE ON COLOR DIFFERENCE MEASUREMENT—Appearance characteristics other than color may influence color difference measurement. Examples of these characteristics include gloss, texture, luster, transparency, pile height, and other surface characteristics. For this reason, it is necessary to assure that the sample and standard have similar appearance characteristics.

4.7 Sample-Color Difference Measurement Variability—The variability of sample-color difference measurements depend on the variability within the color sample and the variability of the color measurement instrument. In order for the color difference acceptability decision to be valid, the standard errors of the mean estimates of the DL^*, DC^*, and DH^* values must be small fractions of their respective DL^*, DC^*, and DH^* tolerances. Sample color difference acceptability decisions made under this document shall require that the standard error of the mean estimate for each color difference scale be less than the greater of 0.2 scale units or 0.1 times the tolerance range. The tolerance range is the upper tolerance minus the lower tolerance.

4.7.1 DETERMINATION OF THE STANDARD DEVIATION OF SAMPLE COLOR DIFFERENCE MEASUREMENT—For each product measured under this document, the standard deviations of the sample color difference measurement must be determined once. The sample shall be a representative sample of the product. The color difference measurements shall conform to the measurement practices appropriate for the color sample as specified in Section 7. The standard deviations for DL^*, DC^*, and DH^* measurements shall be determined from at least 10 color difference readings of randomly selected areas of the sample. The sample-color difference measurement standard deviations are represented by S_{DL*}, S_{DC*} and S_{DH*}. The defining equation for standard deviation is shown in Equation 1:

$$S = \left[\frac{\sum_i (X_i - \bar{X})^2}{N - 1}\right]^{0.5} \qquad \text{(Eq. 1)}$$

where:

S is the standard deviation
N is the number of sample readings
$\bar{X}$ is the mean of N sample readings
X_i is an individual sample reading for the i^{th} reading

4.7.2 STANDARD ERROR OF THE MEAN ESTIMATE—The standard error of the mean estimate (S_e) is equal to the standard deviation divided by the square root of the number of sample readings (N). See Equation 2.

$$S_e = S/(N)^{0.5} \qquad \text{(Eq. 2)}$$

where:

N is the sampling number. The standard error of the mean esimate is a measure of the uncertainty in the estimate of the mean of multiple sample readings.

4.7.3 STANDARD ERROR OF THE MEAN ESTIMATE WITH A SINGLE MEASUREMENT—If the standard errors of the estimates ($S_{eDL}*$, $S_{eDC}*$, $S_{eDH}*$) with one sample reading do not exceed the greater of 0.2 scale units or 0.1 times their respective tolerance ranges, then a single color difference measurement is valid under this practice. In this case, N=1, and the standard error of the estimate is equal to the standard deviation. See Equation 3.

$$S_e = S \quad \text{if} \quad N = 1 \qquad \text{(Eq. 3)}$$

Samples taken from future lots of the same product and measured with the same instrument and procedures shall require one sample reading.

4.7.4 STANDARD ERROR OF THE MEAN ESTIMATE WITH MULTIPLE MEASUREMENTS—If the standard errors of the mean estimates with a single measurement exceed the greater of 0.2 scale units or 0.1 times the tolerance range, then multiple measurements are required. Averaging multiple measurements in varying areas of the sample can reduce the standard error of the mean to acceptable levels.

The sampling number required to meet the standard error of the mean estimate criterion is determined by rearranging Equation 2. See Equation 4:

$$N = (S / S_{e,g})^2 \quad \text{(Eq. 4)}$$

For each color difference scale, determine the sampling number by substituting the sample-color difference measurement standard deviation (S) and the standard error of the mean estimate goal ($S_{e,g}$) into Equation 4. The standard error of the estimate goal is the greater of 0.2 scale units or 0.1 times the tolerance range. Round each sampling number to the next larger integer value. The product sampling number shall be the largest of the sampling numbers for the DL^*, DC^*, and DH^* color difference measurement scales. Samples taken from future lots of the same product and measured with the same instrument and procedures shall require that all sample color difference measurements be the mean of N readings in varying sample areas.

4.7.5 ADDITIONAL INFORMATION—Appendix A, provides additional information on sample color difference measurement variability including the rationale for this procedure and an example calculation.

4.8 Report—The user shall report the standard observer, standard illuminant, instrument geometry, the standard error of the mean estimate and the sampling number employed in instrumental color difference measurements made under this document.

5. Tolerance Determination

5.1 General Tolerance Concepts—A tolerance is the permissible variation of an object in some characteristic. Tolerances are agreed upon between buyer and seller and could be part of the purchasing contract. In reference to this document, color tolerances of automotive materials are separately expressed in terms of the three perceptual variables; hue, chroma, and lightness. (See 4.5.) The reference material is the agreed-upon standard material.

Tolerances are normally the sum of the variability in the material manufacturing process and the method used to assess the tolerance. For colored materials, especially materials that need to match or harmonize, the overriding factor for tolerances is the degree of mismatch that can be visually tolerated in the application. Tolerances are, therefore, usually set by visual methods.

5.2 Procedures for Visual Determination of Tolerances—Visual tolerances shall be set up by preparing and judging color samples differing in defined ways.

Since tolerances are expressed relatively in terms of differences and are likely to change only slowly across color space, tolerance experience developed for one color may be applied to other colored materials of similar construction having similar hue, chroma, and lightness.

The viewing situation has an important influence on color tolerances. Therefore, the viewing conditions should simulate the end use application. Appearance and width of the line separating the two color fields to be compared shall be similar to the appearance and width of the line separating the colored fields in the final application.

Color samples should be selected which exhibit increasing visual distances from the standard in the hue, chroma, and lightness variables. The differences represented by pairs of standard and sample are visually assessed by a panel of observers. The visual conditions of assessment shall generally conform to ASTM D 1729-82 (2.1.7).

Tolerances shall be set based on the visual judgements and the measured and calculated hue, chroma, lightness differences between pairs of samples.

6. Standards and Instruments

6.1 Standards Procedures—Standards are used for colorimetric control of the product and to maintain the validity of the test procedure.

6.1.1 STANDARDS—The composition and construction of reference standards, working standards, and the product to be colorimetrically controlled with these standards shall be identical. Normally, the official standard will also have identical composition and construction to the reference standards, working standards and product. In those cases where an official standard in the material of the product is not developed, it is permissible to calibrate the reference standard to an official standard of the same color in another similar product form. For example, an ABS molded part reference standard could be calibrated to a polypropylene molded part official standard. See Figure 2.

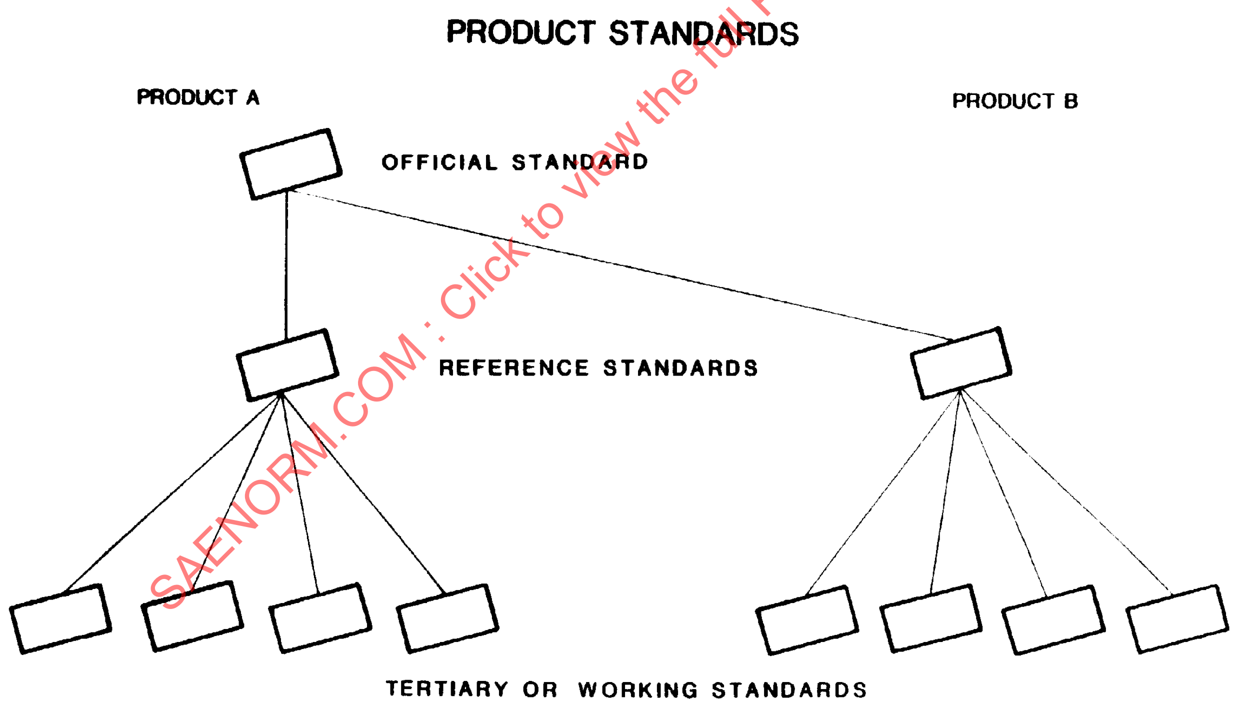


FIGURE 2—NETWORK SHOWING THE RELATIONSHIPS BETWEEN OFFICIAL, REFERENCE, AND WORKING STANDARDS. FOR PRODUCT A, THE OFFICIAL REFERENCE AND WORKING STANDARDS HAVE THE SAME COMPOSITION AND CONSTRUCTION AS THE PRODUCT. AN OFFICIAL STANDARD WAS NOT PREPARED FOR PRODUCT B. IN THIS CASE, THE REFERENCE AND WORKING STANDARDS HAVE THE SAME COMPOSITION AND CONSTRUCTION AS THE PRODUCT.

6.1.2 STANDARDIZATION PROCEDURE—A quantity of reference standards is prepared and instrumentally referenced to the official standard. See 4.5.1. At this point, the official standard should be labelled, dated, and placed in storage. Proper storage requires that the standards are stored so as to preserve their color by minimizing the influence of factors such as light, temperature, and contamination. A quantity of reference standards should be retained by both the customer and the supplier. These, also, should be labelled, dated, and placed in storage. One of these reference standards at a time should be designated as the current reference standard and this standard should be used until it is deemed unreliable for this purpose. At such time, it should be discarded and a fresh reference standard employed. Unreliability would generally be determined by reference to other reserved reference standards or, ultimately, to the official standard.

Similarly, a quantity of working standards are prepared and instrumentally referenced to the current reference standard. One of these working standards is designated the current working standard and the remainder are labelled, dated, and placed in storage. Working standards are used routinely by the instrument operator to compare samples of the product to the established standard. It is from a working standard that the color tolerances are applied to judge the acceptability or unacceptability of a sample. When a working standard is judged unreliable, by reference to the current reference standard, it should be discarded and a fresh working standard substituted.

The reliability of reference standards and working standards should be evaluated on a scheduled basis. If the current measurement of the standard varies from its assigned values in DL^*, DC^*, or DH^* by more than the greater of 0.2 scale units or 0.1 times the tolerance range, then the standard should be discarded.

6.2 Instrument Procedures—One instrument is designated as the master instrument. Its primary purpose is to provide the instrumental reference between the official standard and any reference standard. An additional purpose is to serve as a "referee" instrument in the event of any dispute or question concerning any lower level standard or any secondary instrument. The master instrument shall employ the 10 degrees standard observer and illuminant D65 when metamerism may be present between the official standard and the reference standard.

Secondary instruments are used for routine measurement and control of finished product. They also serve to determine the relationship between reference and working standards as well as to determine the reliability of a particular reference or working standard. The network of instruments and standards is illustrated in Figure 3.

6.3 System Maintenance—A color control program is a complex scheme involving product, instruments, standards, procedures, and personnel. Any measurement is only an approximation of the exactly current state of the material and the instrument being used. Care should be used in both the setup of the program and the necessary maintenance of the program to insure consistent and reliable results. Proper attention to certain areas, including the use of unbiased external resources, should be considered to insure the integrity of any color control program. The intent of this section is to recommend certain practices that should insure this integrity.

6.3.1 INSTRUMENT VERIFICATION PROCEDURE—Instrument performance standards which are independent of the product standards should be used to periodically verify the performance of master and secondary instruments. Instrument performance standards are available from the instrument manufacturer or from an independent source (2.1.8)

6.3.2 EXTERNAL VERIFICATION SERVICE—Outside resources are useful in the verification process (2.1.9). They provide an unbiased reference as to the performance of both the instruments and personnel involved in the program.

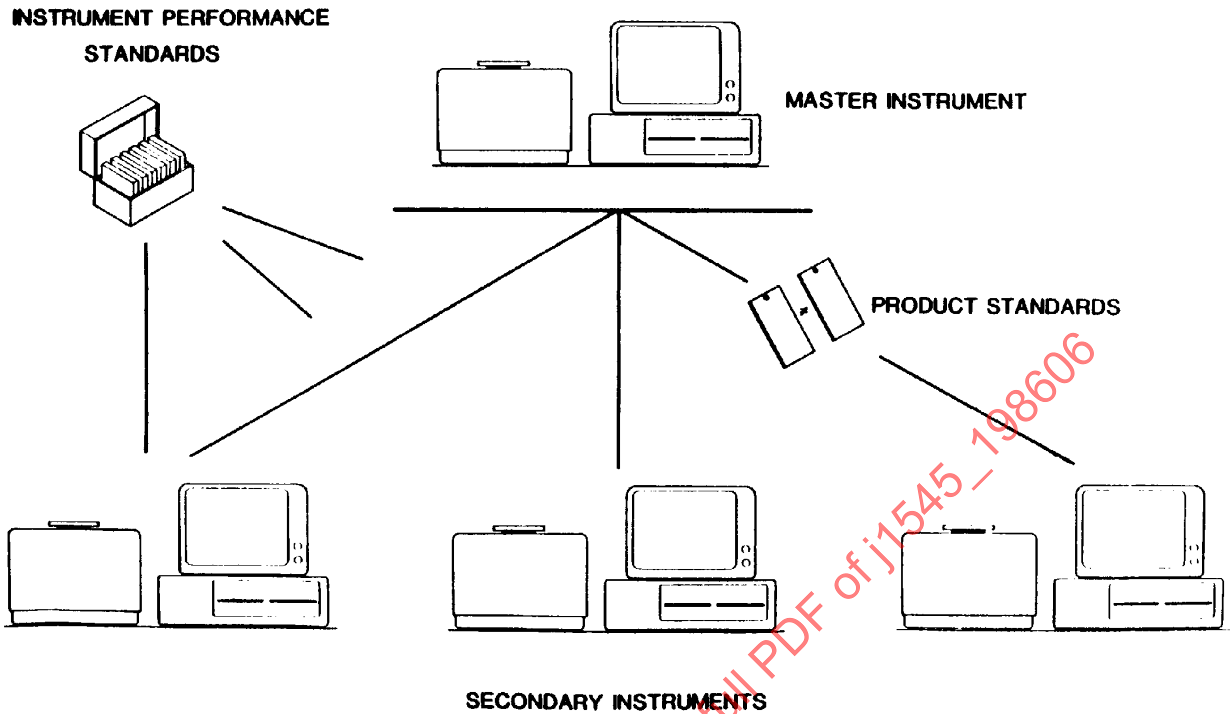


FIGURE 3—NETWORK SHOWING THE RELATIONSHIPS BETWEEN MASTER AND SECONDARY INSTRUMENTS AND INSTRUMENT PERFORMANCE AND PRODUCT STANDARDS.

7. Measurement Practices

7.1 Exterior Finishes

7.1.1 SCOPE—The practice described in this section refers to high-gloss exterior paints and decorative films.

7.1.2 INSTRUMENT—The instrument used in measuring high-gloss exterior finishes shall conform to the requirement of 4.6. When a single illuminating/viewing geometry is used to measure finishes containing oriented flake type pigments, it is possible that the sample and standard will not match for other measurement geometries. Visually the observed effect is that sample may match standard at some viewing angle and not match at others. For these applications, multiple geometry measurements will provide better control of geometric differences. See B.1.3.

7.1.3 SAMPLE PREPARATION—Samples of exterior finishes should be prepared using appropriate substrate, primer and film thickness as specified for the end use of the product. For other than production parts, sample size should be at least 3 x 5 in (75 x 125 mm). Samples must be clean and free from scratches and other defects in the area to be measured. The sample should be similar to the standard in gloss and texture.

7.1.4 SAMPLE PRESENTATION—Sample and standard should be oriented in the same direction. When making multiple measurements, care must be taken to avoid the edges of the panel because of the tendency for excessive film build in these areas. The number of measurements required shall be determined as described in 4.7.

7.2 Textiles

7.2.1 SCOPE—The practice described in this section refers to colored fibrous materials. These products include but are not limited to body cloth, headlining cloth, carpet, webbing, straps, and flocking.

7.2.2 INSTRUMENT—The instrument used for textile measurements shall conform to one of the four sets of illuminating and viewing geometries specified in 4.6.

7.2.3 SAMPLE PREPARATION—Textile samples must be prepared before presentation to an instrument. Samples must be clean and free from lint, creases, and other distortions. A lint roller or brush should be used to clean the samples. Pile fabrics and carpet must be oriented in the natural direction of pile lay. Once the direction is identified, a lint roller or brush should be used to orient the pile.

Textile samples and standards should be similar in luster, texture, and physical form. For multicolored pattern textiles, the individual components of the pattern should be visually similar to those of the standard. Figure 4 shows two samples that are visually different but numerically the same. Color difference readings between these two samples would be meaningless.

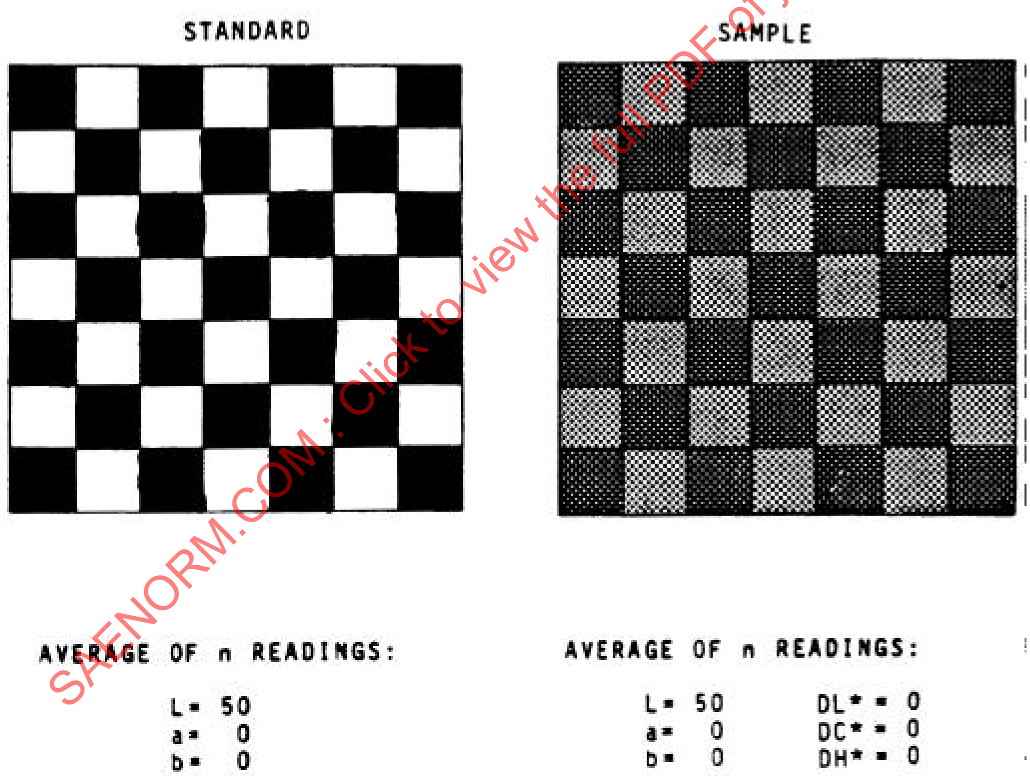


FIGURE 4—HYPOTHETICAL EXAMPLE OF A MULTICOLOR SAMPLE AND STANDARD. WHILE THE MEAN COLOR DIFFERENCE SCALE READINGS ARE WITHIN TOLERANCE, THE SAMPLE IS UNACCEPTABLE BECAUSE THE INDIVIDUAL COMPONENTS OF THE PATTERN DO NOT VISUALLY MATCH THE INDIVIDUAL COMPONENTS OF THE STANDARD PATTERN.

The size of textile samples should be approximately 200 x 250 mm (8 x 10 in). If this is not possible, as may be the case for webbing and straps, a 250 mm (10 in) length of the standard width should be used.

7.2.4 SAMPLE PRESENTATION—Multiple readings are required to account for variation in color and to minimize the influence of directionality. Accordingly, the determinations of standard deviation (4.7.1) and sampling number (4.7.4) are modified for textile samples. The standard deviation is determined from 12 sample readings with each reading in a different position and with the 12 readings evenly apportioned to sample orientations of 0°, 90°, 180°, and 270° in relation to an arbitrarily selected reference direction on the sample. In order to minimize the influence of directionality for all illuminating/viewing geometries, equal numbers of each of the four directional orientations must be used. Therefore, the allowed sampling numbers for textiles are 4, 8, 12, 16, etc. The textile sampling number shall be the sampling number (4.7.4) raised to the next larger multiple of four. The textile sample measurement shall comprise the specified number of readings in N different positions with N/4 of the readings in each of the four orientations. Figure 5 illustrates the positions and orientations of the readings for a textile sample with a sampling number of four.

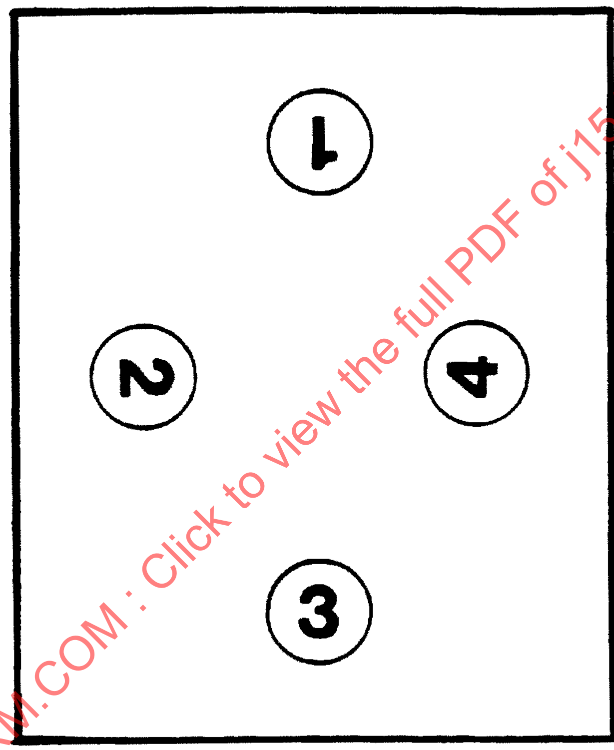


FIGURE 5—FOR TEXTILE SAMPLE MEASUREMENT, A MINIMUM MEASUREMENT IS THE MEAN OF FOUR READINGS WITH EACH READING TAKEN WITH A DIFFERENT SAMPLE AREA AND SAMPLE ORIENTATION AS ILLUSTRATED.

If the sample is translucent, several layers of material may be required to obtain a valid measurement. To determine whether an additional layer is necessary, two readings, one with a white substrate, and one with a neutral black substrate with reflectance values less than 5% shall be taken. If the DL^*, DC^*, and DH^* values of the two readings are all less than the greater of 0.2 scale units or 0.1 times each tolerance range, an additional layer of material will not be required. The backing for all textile color measurements shall be a neutral black with reflectance values less than 5%. The measurement shall be made at the plane of the sample port and without any cover glass.

7.3 Colored Trim

7.3.1 SCOPE—The practice described in this section refers to materials which are pigmented and generally have low gloss. These include painted low-gloss and semi-gloss parts, leather, coated fabrics, unsupported low-gloss film, and color-impregnated plastics.

7.3.2 INSTRUMENT—The instrument used for colored trim measurements shall conform to one of the four sets of illuminating and viewing geometries specified in 4.6.

7.3.3 SAMPLE PREPARATION—Samples must be clean and free from scratches and other distortions. Samples should be similar to the standard in gloss and surface texture.

When measuring multicolor patterned materials and parts, the individual color components should be similar in pattern and general color. Multicolor parts must not be compared in measurement to solid color parts.

7.3.4 SAMPLE PRESENTATION—For materials of a directional nature, sample and standard should be oriented in the same direction. Materials and parts described in this section are presumed to be essentially opaque. If some light transmission is likely, use a neutral black sample backing with reflectance values less than 5%.

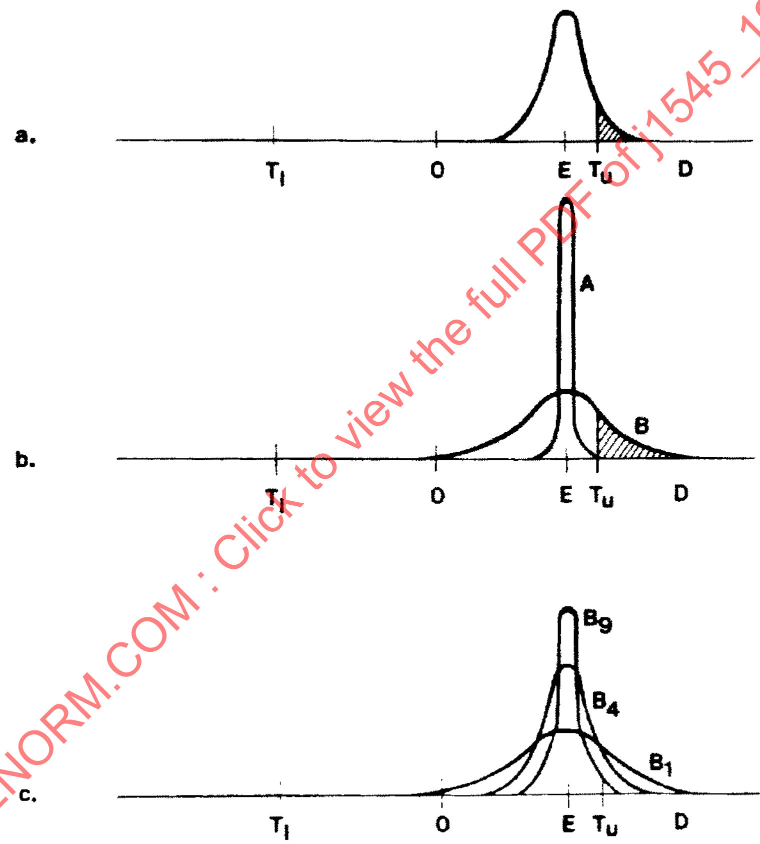
Sampling of solid color parts and multicolor parts shall conform to the guidelines in 4.7.

PREPARED BY THE SAE COLOR DIFFERENCE SUBCOMMITTEE OF THE
SAE NONMETALLIC MATERIALS COMMITTEE

APPENDIX A

SAMPLE COLOR MEASUREMENT VARIABILITY

A.1 ***Rationale***—When a sample color difference measurement is made, the color difference values obtained are estimates of the sample color difference values. Because of variability within the sample and because of instrument variability, repeat sample color difference readings will form a distribution of values. A single reading, therefore, is a sample from this distribution and the uncertainty of the reading is related to the standard deviation of repeat sample readings. In Figure A1(a), notice that for a sample mean estimate value there is a distribution of possible sample estimate values. In this example, notice that while the sample estimate has an acceptable value, because of the uncertainty of the estimate there is some probability (cross-hatched area of Figure A1(a) that a single sample color difference reading is unacceptable.



a. Distribution of sample readings. The shaded area represents the probability that a sample reading is outside the tolerance.

b. Two sample reading distributions with low (A) and high (B) standard deviations.

c. Distributions of sample measurement estimates with one reading (B1), the mean of four readings (B4), and the mean of nine readings (B9).

FIGURE A1—THE INFLUENCE OF SAMPLE READING VARIABILITY ON COLOR ACCEPTABILITY DECISIONS. THE SYMBOLS ARE LOWER TOLERANCE (T_l), UPPER TOLERANCE (T_u), COLOR DIFFERENCE SCALE (D), ZERO POINT OF THE SCALE (O), AND SAMPLE COLOR DIFFERENCE MEAN ESTIMATE (E).

Not all sample-color difference measurements will have the same uncertainty. In Figure A1(b), two sample estimate distributions with identical mean estimate values but varying uncertainties, as observed by the breadth of their distributions, are shown. For uncertainty distribution A there is a much higher probability that a single sample reading is acceptable than for uncertainty distribution B. This despite the fact that both distributions give identical mean estimates. Clearly, we would prefer to have low sample measurement uncertainty. However, it is not possible to obtain errorless estimates. As a practical compromise, there will be infrequent, incorrect decisions (conditions where the mean estimate is within the tolerance but individual estimates are outside the tolerance or the inverse condition) if the uncertainty of the estimate is a small fraction of the range of the tolerance values. The uncertainty of measurement is defined by the standard error of the mean estimate. The requirement is that the standard error of the mean estimate not exceed the greater of 0.2 scale units or 0.1 times the tolerance range.

How do we proceed if the standard error of the mean estimate exceeds the goal value? The mean of multiple sample readings has lower uncertainty than a single reading. By increasing the number of sample readings included in the measurement, the standard error of the mean estimate can be reduced to an acceptable level. Figure A1(c) shows uncertainty distributions for a single reading (B1), the mean of four readings (B4), and the mean of nine readings (B9). The procedure determines the minimum sampling number which will reduce the standard error of the mean estimate to an acceptable level.

A.2 Hypothetical Example—The standard error of the mean estimate and sampling number are determined for a red molded trim plastic. A representative sample is selected. Ten readings of DL^*, DC^*, and DH^* are made according to the procedures reported in 7.3.. Each reading is made on a separate area of the sample. Table A1 indicates the ten individual sample readings and the calculated means and standard deviations for the DL^*, DC^*, and DH^* readings.

TABLE A1—EXAMPLE CALCULATION OF THE MEANS AND STANDARD DEVIATIONS FOR DL^*, DC^*, AND DH^* SAMPLE MEASUREMENTS

Reading	Color Difference Scales DL^*	Color Difference Scales DC^*	Color Difference Scales DH^*
1	–1.42	0.79	–0.18
2	–0.12	0.14	–0.02
3	–0.62	0.65	0.25
4	–1.13	0.89	0.22
5	–0.71	0.68	0.04
6	–0.22	0.21	0.30
7	–0.47	0.30	–0.01
8	–0.77	1.25	0.19
9	–0.18	0.91	0.21
10	–0.09	0.55	0.21
Mean	–0.57	0.64	0.12
Std. Dev.	0.45	0.35	0.15

The standard errors of the estimates and product sampling numbers are determined as follows (refer to Table A2):

a. Calculate the standard deviations of sample color difference readings for DL^*, DC^*, and DH^* (line 1). Taken from Table A1.
b. Calculate the tolerance range, the upper tolerance minus the lower tolerance (lines 2, 3, 4).
c. Multiply the tolerance range by 0.1 (line 5).
d. The goal for standard error of the mean estimate is the larger of 0.2 units or 0.1 times the tolerance range (line 6).
e. Compare the standard deviation for each color difference scale to its corresponding goal for standard error of the mean estimate. In this case, the standard deviations for the DL^* and DC^* scales exceed their goals and, therefore, multiple readings are required. Proceed to determine the sampling number.
f. Calculate the sampling number for each color scale (line 7). See Equation A1.

$$N = (S / S_{e,g})^2 \quad \text{(Eq. A1)}$$

g. Round the sample averaging numbers to the next larger integer values (line 8).
h. The product sampling number (N_p) is the largest of the individual sampling numbers (line 9).
i. Calculate the standard error of the mean estimate for each color difference scale with the product sample averaging number. See Equation A2.

$$S_e = S / (N_p)^{0.5} \quad \text{(Eq. A2)}$$

Color difference assessments made under this document for all future lots of this product shall be based on the mean of four readings of DL^*, DC^*, and DH^*, with each reading taken from a different area of the sample. The standard error of the mean estimate for each color difference scale and the product sampling number shall be reported with the color difference measurements.

TABLE A2—EXAMPLE CALCULATION OF THE STANDARD ERROR OF THE MEAN ESTIMATE AND THE PRODUCT SAMPLING NUMBER

Line	Quantity	Symbol	Color Difference Scales DL^*	Color Difference Scales DC^*	Color Difference Scales DH^*
1	Standard Deviation	S	0.45	0.35	0.15
2	Upper Tolerance		+2.0	+1.0	+0.5
3	Lower Tolerance		–2.0	–1.0	–0.5
4	Tolerance Range		4.0	2.0	1.0
5	0.1 x Tolerance Range		0.4	0.2	0.1
6	Goal for Standard Error of the Mean Estimate	Se, g	0.4	0.2	0.2
7	Sampling Number	N	1.27	3.06	0.56
8	Round to the Next Larger Integer	N	2	4	1
9	Product Sample Averaging Number	Np	4	4	4
10	Standard Error of the Mean Estimate	Se	0.23	0.18	0.08

A.3 Practical Means to Reduce the Product Sampling Number—It is advantageous to reduce the product sampling number in order to reduce the expense of testing. Users should be aware that the product sampling number may be reduced by increasing the product tolerance range or by decreasing either the sample's color variability or the instrument's measurement variability. A negotiated increase in the color tolerance range to values greater than 2.0 will reduce the number of readings required. For samples which do not intentionally have a multicolor pattern, improvement in the color uniformity of the sample will reduce the within sample variability and reduce the product sample averaging number.