A guide to Understanding Color Tolerancing
Dear Customer:

For over a decade, X-Rite has manufactured quality control instruments for the printing, photo finishing, medical and industrial x-ray processing industries. Our commitment to these markets has given us worldwide recognition and leadership.

To remain competitive, we have devoted both dollars and time to the research and development of new advances in color measurement instruments.

A few notable developments are due to the growing demand for consistent color quality. In nearly every industry where a consumer’s buying decision is greatly influenced by a product’s appearance, there is a vital need to accurately communicate and control color.

This increased consumer discrimination has led us to the development of colorimeters and spectrophotometers: color measurement tools that provide accurate, predictable data on the color attributes of a product.

As a result, our instruments let you objectively communicate specific color and color differences to management and production personnel as well as to your customers.

The purpose of this guide is to define and illustrate the various color tolerancing methods used in many industries including graphic arts, paint and coatings, plastics, metallics, and textiles. It explains how the different color tolerancing methods relate to each other – and how the CMC tolerancing method most closely matches the visual acceptability response of the human eye.

Thank you for considering X-Rite products. We look forward to working in partnership with you.

Sincerely,

Ted Thompson
President & Chief Executive Officer

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<table>
<thead>
<tr>
<th>Table of Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpreting Color Differences</td>
<td>1</td>
</tr>
<tr>
<td>Limitation of the Human Eye</td>
<td>2</td>
</tr>
<tr>
<td>Color Tolerancing Methods</td>
<td>2</td>
</tr>
<tr>
<td>CIELAB Color Tolerancing</td>
<td>3</td>
</tr>
<tr>
<td>CIELCH Color Tolerancing</td>
<td>4</td>
</tr>
<tr>
<td>CMC Color Tolerancing</td>
<td>5 &amp; 6</td>
</tr>
<tr>
<td>Using Color Tolerancing</td>
<td>7</td>
</tr>
<tr>
<td>Color Control Software</td>
<td>7</td>
</tr>
<tr>
<td>X-Rite Color Measurement Instruments</td>
<td>8</td>
</tr>
</tbody>
</table>
Interpreting color from different perspectives

Since the introduction of color measurement instrumentation, there has been a international goal to describe color differences with numerical value. This guide briefly explains the most common color tolerancing methods used today. Each of these methods is internationally recognized and has its own numerical color order system supported by a specific glossary of color terminology.

Each person accepts or rejects color matches based on their own color perception skills. In any industry this can lead to confusion and frustration between customers, suppliers, vendors, production, and management. To aid in color decisions, color acceptability limits can be determined.

Acceptability limits are numerical values at which the perceived color differences are no longer acceptable.

These numerical values are used as guidelines or tolerance limits to aid in controlling color in the process, to ensure color consistency within a production run, and to minimize lot to lot variability.

Are these acceptable color matches?
Why you can’t always count on your eyes

The human eye has some inherent limitations when distinguishing color differences. In addition to color memory loss, eye fatigue, color blindness, and viewing conditions the eye does not detect differences in hue (red, yellow, green, blue, etc.), chroma (saturation), or lightness/darkness equally. In fact, the average observer will see hue differences first, chroma or saturation differences second, and lightness/darkness differences last.

As a result, the tolerance that we have for an acceptable color match is bounded by a three dimensional boundary with varying limits for lightness/darkness, hue and chroma.

Methods that improve color interpretation

Since the development of color measurement instruments there has been an evolution of mathematical formulae attempting to create tolerancing methods that best correlate to the eye’s sensitivity.

The first internationally accepted method, developed by the Commission International de l’Eclairage (CIE), was L*a*b* color tolerancing. (Also known as CIELAB).

Some years later the CIE adopted revisions to the L*a*b* calculations which led to L*C*H* color tolerancing. (Also know as CIELCH).

The newest of the accepted tolerancing methods, developed by the Colour Measurement Committee of the Society of Dyes & Colourists in Great Britain, is known as CMC tolerancing.

The following pages describe these three color tolerancing procedures.
The CIELAB calculations were one of the first attempts to develop a uniform color space. One unit of color difference for a green color was similar to one unit of color difference for a red and blue and so on.

$L^*a^*b^*$ values are calculated from the tristimulus values $(X,Y,Z)$ which are the backbone of all color mathematical models. The location of a color, in the CIELAB color space, is defined by a three dimensional cartesian (rectangular) coordinate system.

The Lightness value ($L^*$) indicates how light or dark the color is. The $a^*$ value indicates the position on the red-green axis, $b^*$ is the position on the yellow-blue axis. Once the $L^*a^*b^*$ position of a standard color is determined a rectangular tolerance “box” can be drawn around the standard.

Visual acceptability is more in the shape of an ellipse. Therefore, there are some places in $L^*a^*b^*$ color space where setting a rectangular tolerance box around your color standard may cause problems. A rectangular tolerance around the ellipse can give good numbers for unacceptable color. If the tolerance rectangle is made small enough to fit within visual acceptability it would be possible to get bad numbers for acceptable color.
L*C*H* color difference calculations are derived from the L*a*b* values. The mathematics convert the rectangular coordinate system to a cylindrical polar coordinate system.

The “L*” value is the same as in L*a*b* color space and represents the lightness plane on which the color resides. The “C*” value is calculated vector distance from the center of color space to the measured color (P1).

Larger C* values indicate higher chroma or saturation. Chroma is sometimes referred to as “cleaness” or “dirtiness.” \( \Delta H^* \) is the calculated hue difference between two colors.

Using the L*C*H* polar coordinate system to set up tolerancing allows a tolerance “box” to be rotated in orientation to the hue angle. This more closely matches human perception of color which reduces the chance of disagreement between human observer and instrumental readings or values.
CMC is not a new color space but rather a tolerancing system. CMC tolerancing is a modification of CIELAB which provided better agreement between visual assessment and instrumentally measured color difference.

As explained previously, visual color perception is elliptical. Calculation mathematically defines an ellipsoid arc around the standard color with semi-axis corresponding to hue, chroma, and lightness. The ellipsoid represents the volume of acceptance and automatically varies in size depending on the position of the color in color space.

Figure A shows the variation of the ellipse sizes throughout L*a*b* color space. The ellipses in the orange area of color space are longer and narrower than the broad and rounder ones in the green area. The shape of the ellipses also changes as the color increases in chroma.
Color Tolerancing

The CMC equation also allows the user to vary the overall size of the ellipse to better match what is considered acceptable. The eye generally has greater acceptance for shifts in the lightness (l) dimension than in the chromaticity (c) (hue and chroma) dimension. This tolerance ratio (l:c) is considered to be 2:1.

The CMC equation allows for the ratio between lightness and chromaticity (l:c) to be adjusted to better match acceptability. The textile industry has adopted a ratio of 2:1 while the plastics industry is recommending 1.37:1.

Figure B shows the CMC calculated ellipsoid with a l:c ratio of 2:1 as it would appear around a color standard. The lightness (l) attribute is weighted twice as heavily as the hue and chroma (c) attribute. The dotted line shows the effect of changing the l:c ratio to 1.4:1.

In commercial situations, the amount of color difference that is considered acceptable is accounted for by applying a single commercial factor (cf) to all dimensions of the ellipsoid. By varying the commercial factor – cf (ΔE cmc) the ellipsoid can be made as large or small as necessary to match visual acceptability.

Though no color tolerancing system is perfect the CMC equation best represents color differences as we see them, and is becoming a recognized standard in many industries.
Using Color Tolerances

The ability to set up a color tolerance around a color standard allows for:

1. Rapid determination of color acceptability.

2. Analysis of process color data over time, looking for trends and potential problems.

3. Reporting to customers quality information that will build their confidence in product quality.

Color Control Software

Shown at the right are color tolerancing display screens from QA-Master™, a software program designed for use with X-Rite color measurement instruments.
Whatever your color measurement needs, X-Rite has designed a wide range of instruments to satisfy all requirements.

Clockwise from upper right corner:

- **SP 68** Sphere Spectrophotometer
  - Plastic, Paint,
  - Textiles - any surface

- **938** 0/45 SpectroDensitometer
  - Graphic Arts

- **968** 0/45 Spectrophotometer
  - General Purpose QC

- **918** 0/45 Colorimeter

- **948** 0/45 SpectroColorimeter

- **CDM** 0/45 Color Difference Meter
  - Low Cost Colorimeter

- **MA58** Multi-Angle
  - Spectrophotometer
  - Metallic Paints