THE SECOND C: The Sixth Circle of Hell—Heresy

By Keith Hoover

So far, we have reviewed the tenets of color appearance—Light, Object, and Observer —and outlined the foundation for a digital color management process. As with all complex models, there are misunderstandings (and even intentional misinterpretations) that, if not corrected, undermine their value. These must be addressed. We will eventually cover "redemption," but first comes propitiation, of which repentance is a key component.

The Road to Digital Color

Several brands have digital color processes to manage lab dips. They have seemingly done all the right things—selected feasible color standards, specified illuminants and light sources for match assessment, adopted spectrophotometers, purchased color QC software, and established approval tolerances.[1]

There are many choices available in the market for these key components, many of which are interchangeable. Their products—whether color samples, hardware, or software—are built to established specs or industry requirements. One supplier is selected over another because of reputation, service offerings, or perceived value. So, whether a brand buys a "color widget" from vendor A or vendor B, both deliver the same basic functionality.

But that is not true for color difference tolerances. The standards, instruments, and software provide the data. The tolerance delivers the *decision*. So, while one might approach instruments or software selection as a smorgasbord of sorts, tolerances cannot be mixed and matched.

Several color difference metrics have been devised to quantify differences in L*a*b* or LCH values. However, the Holy Grail has always been to have a single pass/fail number —what we call Delta E, or total color difference. In the late twentieth century, CIE DE_{ab} (called CIE DE in this article) was the total color difference metric used in the textile industry. However, its accuracy was dependent on each color. So, red/green (Da*) or yellow/blue (Db*) tolerances were added to the CIE DE tolerance for each color being analyzed. A different set of tolerances had to be stored with each color standard, so a "single color difference" metric proved elusive.

In 1984, the Colour Measurement Committee of the Society of Dyers and Colourists introduced DE_{CMC}, an improved total color difference metric that addressed the shade-dependent weaknesses of CIE DE. In the last segment, I said, "The CMC equation is the accepted model in the apparel industry because it works." That is based partially on an understanding of the model, but mostly on years of experience SEEING the results. DE_{CMC} is an accurate and reliable metric to assess color acceptability regardless of shade.

The Road to Hell

However, to some, color is "magical." They would rather admire it as a problem than solve it. Especially when the solution impacts their perceived value as a magician.

Everyone who has learned anything about assessing color difference has been taught that we are most sensitive to differences in hue. A color's cast is described by a* and b*, which includes both Hue Angle and Chromaticity. So, Da* and Db* tolerances are not well-suited to monitor Hue Angle difference.

The big innovation in the CMC color difference equation was its claim to automatically adjust the Hue Angle difference tolerance based on where a color falls in color space. No more keeping track of

Da* or Db* tolerances for individual color standards. The equation takes care of that.

But, hey, if one tolerance is good, then two must be better. Since a difference in hue is so important, maybe we should add another tolerance—just to be safe. This appears to summarize the thinking of those who have added a 0.50 DH (Hue Angle difference) tolerance to DE_{CMC} as a specification for digital color approval. In other words, for a sample to pass, it must measure less than the DE_{CMC} tolerance (presumably 1.00) AND less than the DH tolerance (0.50).

The DH Tolerance Fallacy

DE_{CMC} has been used commercially for decades resulting in literally millions of records attesting to its sufficiency[2]. Before we add a second tolerance, evidence should be presented to demonstrate its need. I have yet to see such evidence—or any discrepancy in digital/visual correlation that was not the result of a process or people mistake as outlined in the third installment of this series, "Lab Dips—The First Circle of Hell, Part 1." Nevertheless, let's take a look at how CMC works and what the impact would be of adding a DH tolerance.

The Experiment

A color's hue is important and our perception of Hue Angle difference varies by color. Does DE_{CMC} adequately adjust the tolerance for Hue Angle difference based on a color's shade?

To answer that, we need a set of color standards that have identical Lightness and Chromaticity values but vary in hue to represent all Hue Angles. Lightness and Chromaticity are constant, Hue Angle is the variable. In this case, let's choose 36 standards, all with a Lightness value of 60 and a Chromaticity value of 35 with each varying in Hue Angle by ten degrees (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300,310, 320, 330, 340, 350, 360).

Second, we need three batches for comparison to each standard.

Batch 1: Hue Angle difference—one Hue Angle degree less than the standard, identical Lightness and Chromaticity

Batch 2: Chromaticity difference—one point less Chromaticity, identical Hue Angle and Lightness

Batch 3: Lightness difference—one point less Lightness, identical Hue Angle and Chromaticity

With these samples in place, we will be able to see how the CMC model accommodates Hue Angle differences across many shades. We will also see how differences in Lightness, Chromaticity, and Hue Angle impact DE_{CMC}. Finally, we will be able to get some insight on the impact of adding a DH approval tolerance.

This textile series will share technical insights and wisdom of AATCC members. The "Second C" series will focus on color. If you wish to contribute your own technical insights on topics of interest to AATCC members, contact Communications Director, Maria Thiry; thirym@aatcc.org.

That is a lot of color samples—but not to worry. We are exploring digital color tolerances, so we can use digital color software to create virtual standards and batches. Datacolor Tools allows the user to input colors several ways. The simplest is via a connection to a spectrophotometer. Metamerism does not come into play here, so we don't need spectral data. Instead, we can use the Tools function to create color standards and batches by specifying a set of Lightness, Chromaticity, and Hue Angle values for each.

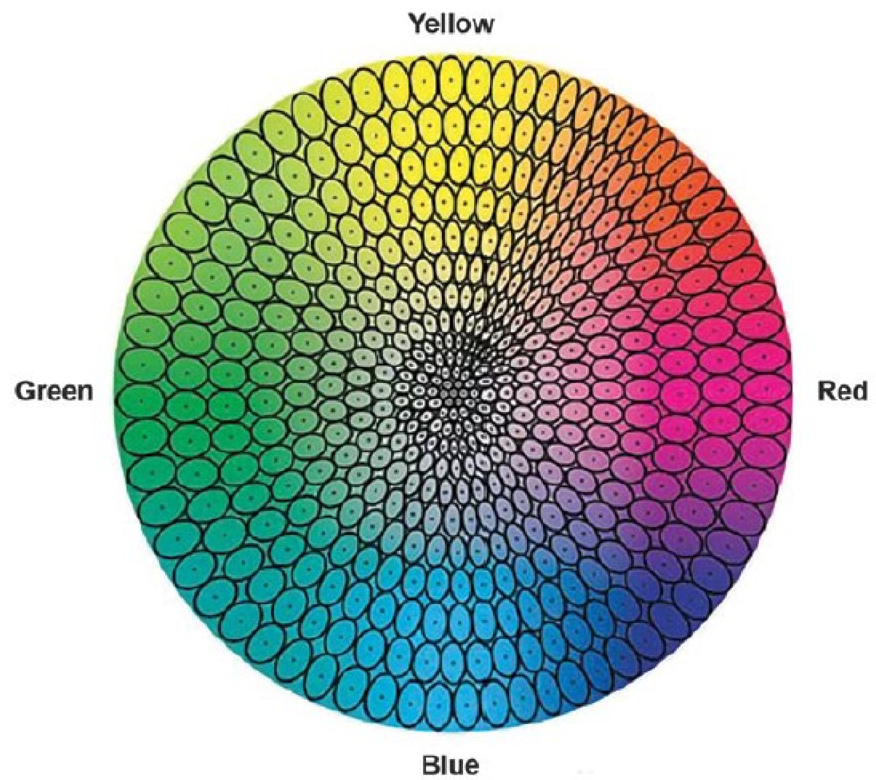

Figure 1: An artist's rendering of what a whole bunch of CMC tolerance ellipses would look like superimposed on a single slice of color space (Lightness as a constant with Chromaticity and Hue and Hue Angle as variables

The Data

Once the virtual samples were created, the color difference numbers were processed in Datacolor Tools using D65/10. Table 1 lists color difference numbers for all standards and batches.

To understand the data in Table 1, let's first look at the columns. The Standard and Batch Names are in columns A and B. Simple enough. Before we move on to columns C through H, it is important to understand that there is a good deal of confusion at brands and mills alike about the delta numbers for Lightness, Chromaticity, and Hue Angle. Doesn't DL mean Lightness difference? Doesn't DC mean Chromaticity difference? And doesn't DH mean Hue Angle difference? Well, it depends.

Those simple "D" designations usually apply to the old CIE model that includes CIE DE. The correct difference metrics for the CMC model are different:

- DL^*/lS_L (Lightness difference, what we will call CMC DL*/SL)
- DC^*_{ab}/cS_C (Chromaticity difference, what we will call CMC DC*/SC)
- DH^*_{ab}/S_H (Hue Angle difference, what we will call CMC DH*/SH)

It is not unusual to see a color difference print-out showing DE_{CMC} and CIE DL, DC, and DH. Although they sound the same, they are not. So, I have included the incorrect (pink fill) and correct (green fill) metrics that describe Lightness, Chromaticity, and Hue Angle differences in columns C through H to show how they differ. Finally, columns I and J compare CIE DE and DE_{CMC} for each color.

The lines are simple to describe. Let's start with lines 2 through 4. First is the Standard Name, which is the same for all three lines. In column B, line 2 is the batch that varies in Hue Angle. Line 3 is the batch that varies in Chromaticity. Line 4 is the batch that varies in Lightness. The rest of the data were described above. So, each set of three lines provide data about one of the 36 colors.

The Results

Hue Angle Difference

Figures 1 and 2 tell the CMC story visually. Figure 1 shows a theoretical "slice" of color space with CMC tolerance ellipses superimposed.[3] Figure 2 shows the exact CMC tolerance ellipses of the 36 color standards used in the experiment.

The data in Table 1 show that the CIE DE value for all 36 samples that varied in Hue Angle was 0.61. When DE_{CMC} was applied, the results ranged from 0.37 to 0.78.[4] Samples with a higher DE_{CMC} are more sensitive to Hue Angle difference (Hue Angles 40 to 70). So, the CMC model was able to identify Hue Angle-sensitive colors and adjust their tolerances.

Standard Name	Batch Name	CIE DL	CMC DL*/SL	CIE DC	CMC DC*/SC	CIE DH	CMC DH*/SH	CIE DE	DE CMC
L=60 C=35 H=360	L=60 C=35 H=359	0.00	0.00	0.00	0.00	-0.61	-0.41	0.61	**0.41**
	L=60 C=34 H=360	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=360	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=10	L=60 C=35 H=9	0.00	0.00	0.00	0.00	-0.61	-0.44	0.61	**0.44**
	L=60 C=34 H=10	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=10	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=20	L=60 C=35 H=19	0.00	0.00	0.00	0.00	-0.61	-0.48	0.61	**0.48**
	L=60 C=34 H=20	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=20	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=30	L=60 C=35 H=29	0.00	0.00	0.00	0.00	-0.61	-0.53	0.61	**0.53**
	L=60 C=34 H=30	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=30	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=40	L=60 C=35 H=39	0.00	0.00	0.00	0.00	-0.61	-0.61	0.61	**0.61**
	L=60 C=34 H=40	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=40	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=50	L=60 C=35 H=49	0.00	0.00	0.00	0.00	-0.61	-0.71	0.61	**0.71**
	L=60 C=34 H=50	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=50	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=60	L=60 C=35 H=59	0.00	0.00	0.00	0.00	-0.61	-0.71	0.61	**0.71**
	L=60 C=34 H=60	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=60	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=70	L=60 C=35 H=69	0.00	0.00	0.00	0.00	-0.61	-0.61	0.61	**0.61**
	L=60 C=34 H=70	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=70	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=80	L=60 C=35 H=79	0.00	0.00	0.00	0.00	-0.61	-0.53	0.61	**0.53**
	L=60 C=34 H=80	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=80	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=90	L=60 C=35 H=89	0.00	0.00	0.00	0.00	-0.61	-0.48	0.61	**0.48**
	L=60 C=34 H=90	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=90	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=100	L=35 C=60 H=99	0.00	0.00	0.00	0.00	-0.61	-0.44	0.61	**0.44**
	L=60 C=34 H=100	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=100	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=110	L=60 C=35 H=109	0.00	0.00	0.00	0.00	-0.61	-0.41	0.61	**0.41**
	L=60 C=34 H=110	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=110	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=120	L=60 C=35 H=119	0.00	0.00	0.00	0.00	-0.61	-0.39	0.61	**0.39**
	L=60 C=34 H=120	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=120	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=130	L=60 C=35 H=129	0.00	0.00	0.00	0.00	-0.61	-0.38	0.61	**0.38**
	L=60 C=34 H=130	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=130	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=140	L=60 C=35 H=139	0.00	0.00	0.00	0.00	-0.61	-0.37	0.61	**0.37**
	L=60 C=34 H=140	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=140	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=150	L=60 C=35 H=149	0.00	0.00	0.00	0.00	-0.61	-0.37	0.61	**0.37**
	L=60 C=34 H=150	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=150	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=160	L=60 C=35 H=159	0.00	0.00	0.00	0.00	-0.61	-0.38	0.61	**0.38**
	L=60 C=34 H=160	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=160	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=170	L=60 C=35 H=169	0.00	0.00	0.00	0.00	-0.61	-0.38	0.61	**0.38**
	L=60 C=34 H=170	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=170	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=180	L=60 C=35 H=179	0.00	0.00	0.00	0.00	-0.61	-0.37	0.61	**0.37**
	L=60 C=34 H=180	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=180	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=190	L=60 C=35 H=189	0.00	0.00	0.00	0.00	-0.61	-0.37	0.61	**0.37**
	L=60 C=34 H=190	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=190	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=200	L=60 C=35 H=199	0.00	0.00	0.00	0.00	-0.61	-0.37	0.61	**0.37**
	L=60 C=34 H=200	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=200	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=210	L=60 C=35 H=209	0.00	0.00	0.00	0.00	-0.61	-0.38	0.61	**0.38**
	L=60 C=34 H=210	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=210	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=220	L=60 C=35 H=219	0.00	0.00	0.00	0.00	-0.61	-0.38	0.61	**0.38**
	L=60 C=34 H=220	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=220	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=230	L=60 C=35 H=229	0.00	0.00	0.00	0.00	-0.61	-0.39	0.61	**0.39**
	L=60 C=34 H=230	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=230	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=240	L=60 C=35 H=239	0.00	0.00	0.00	0.00	-0.61	-0.41	0.61	**0.41**
	L=60 C=34 H=240	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=240	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=250	L=60 C=35 H=249	0.00	0.00	0.00	0.00	-0.61	-0.42	0.61	**0.42**
	L=60 C=34 H=250	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=250	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=260	L=60 C=35 H=259	0.00	0.00	0.00	0.00	-0.61	-0.44	0.61	**0.44**
	L=60 C=34 H=260	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=260	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=270	L=60 C=35 H=269	0.00	0.00	0.00	0.00	-0.61	-0.47	0.61	**0.47**
	L=60 C=34 H=270	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=270	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=280	L=60 C=35 H=279	0.00	0.00	0.00	0.00	-0.61	-0.50	0.61	**0.50**
	L=60 C=34 H=280	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=280	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=290	L=60 C=35 H=289	0.00	0.00	0.00	0.00	-0.61	-0.48	0.61	**0.48**
	L=60 C=34 H=290	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=290	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=300	L=60 C=35 H=299	0.00	0.00	0.00	0.00	-0.61	-0.45	0.61	**0.45**
	L=60 C=34 H=300	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=34 H=300	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=310	L=60 C=35 H=309	0.00	0.00	0.00	0.00	-0.61	-0.43	0.61	**0.43**
	L=60 C=34 H=310	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=310	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=320	L=60 C=35 H=319	0.00	0.00	0.00	0.00	-0.61	-0.41	0.61	**0.41**
	L=60 C=34 H=320	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=34 H=320	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=330	L=60 C=35 H=329	0.00	0.00	0.00	0.00	-0.61	-0.40	0.61	**0.40**
	L=60 C=34 H=330	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=330	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=340	L=60 C=35 H=339	0.00	0.00	0.00	0.00	-0.61	-0.39	0.61	**0.39**
	L=60 C=34 H=340	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=34 H=340	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42
L=60 C=35 H=350	L=60 C=35 H=349	0.00	0.00	0.00	0.00	-0.61	-0.39	0.61	**0.39**
	L=60 C=34 H=350	0.00	0.00	-1.00	-0.46	0.00	0.00	1.00	0.46
	L=59 C=35 H=350	-1.00	-0.42	0.00	0.00	0.00	0.00	1.00	0.42

If a 0.50 DH tolerance were applied using the CIE DH metric, then all 36 samples that varied by Hue Angle would fail, since they all came in with a CIE DH of 0.61. If the CMC DH*/SH tolerance of 0.50 were applied, then 7 of the 36 samples would fail even though their DE_{CMC} values only ranged from 0.50 to 0.71. It is interesting to note that Datacolor Tools builds in a "Warn" function for all batches with DE_{CMC} values between 0.75 and 1.00. So, the addition of a DH tolerance (whether CIE or CMC DH*/SH) creates unnecessary failures (see Figure 3).

Chromaticity and Lightness Differences

The CIE DC value for all samples that varied in Chromaticity by one point was 1.00, translating to a CIE DE of 1.00. DE_{CMC} tolerance shot. However, the CMC DC*/SC value for those same samples was less than half, or 0.46.

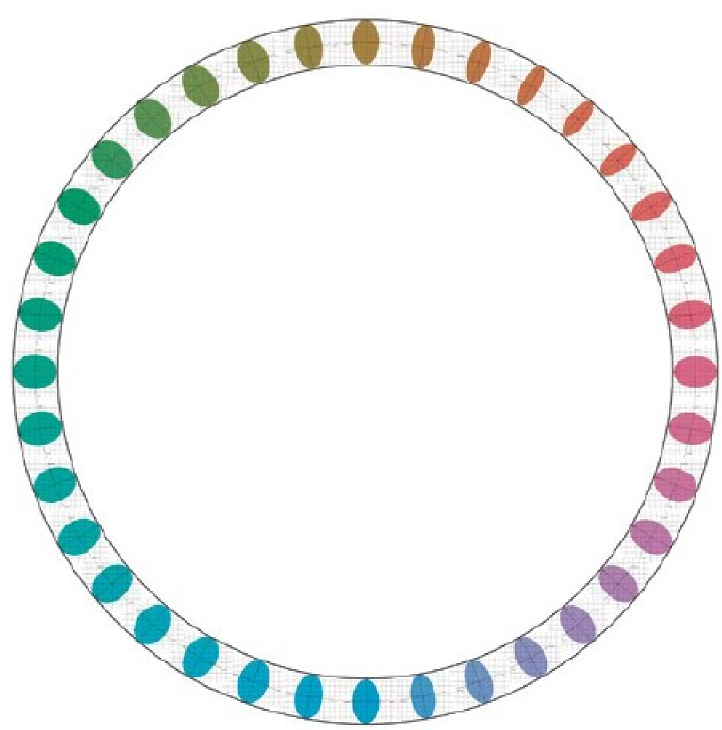

Figure 2: CMC Tolerance Ellipses for the 36 Colors. The ovals around the perimeter of the circle are the actual CMC tolerance ellipses created in Datacolor Tools for all 36 standards used in the experiment. The color of each oval is the precise color of that virtual standard created in Datacolor Envision. The ovals are equally (and accurately) spaced around the circle according to their respective Hue Angles. The Chromaticity axes (the length) of all are equal, but the Hue axis (the fatness) of each ellipse varies based on its sensitivity to acceptable differences in hue.

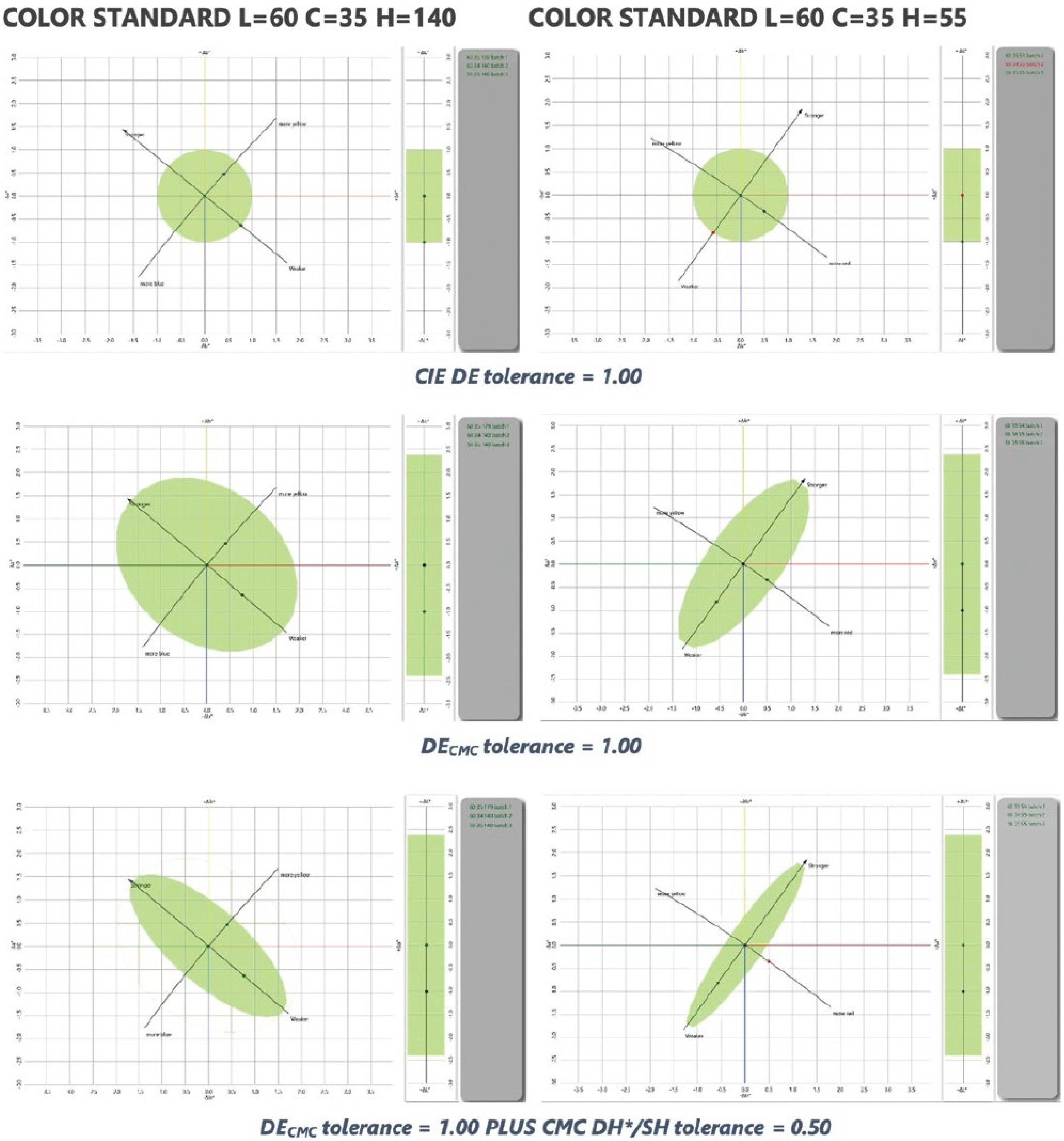

Figure 3: The top row shows that the CIE DE tolerance is identical for both colors (as well as the 34 others). Lightness, Chromaticity, and Hue Angle differences are all treated the same. The middle row shows that DE_{CMC} expands the Hue Angle tolerance for colors showing the least sensitivity to variations in hue (left) and tightens it for those with the highest sensitivity to variations in hue (right). It also expands the Lightness and Chromaticity tolerances for all 36 colors in the experiment. The bottom row shows the impact of adding a CMC DH/SH tolerance of 0.50 to the DE_{CMC} tolerance of 1.00. The girth of the CMC ellipse (Hue Angle difference) is cut in half regardless of the color standard's sensitivity to variations in hue.*

The CIE DL value for all samples that varied in Lightness by one point was 1.00, translating to a CIE DE of 1.00. Again, DE_{CMC} tolerance shot. However, the CMC DL*/SL value for those same samples was less than half, or 0.42. Remember, using the 2:1 l:c ratio dilutes the impact of Lightness differences.

Summary of Findings

Lightness, Chromaticity, and Hue Angle "difference" metrics are not determined by merely subtracting the value in the batch from the value in the standard. A one-point difference in Lightness, Chromaticity, and Hue Angle between a standard and a batch did not lead to a CMC DL*/SL, CMC DC*/SC or CMC DH*/SH value of 1.00 in any case. A weighting function is applied based on the location of the color in CIE color space. And, as shown in Table 1, DE_{CMC} will never be *less than* any of the three other delta metrics.

This experiment demonstrates that the CMC model clearly adjusts approval tolerances based on a color standard's Hue Angle. Adding an arbitrary CMC DH*/SH tolerance of 0.50 would cut the width of the CMC tolerance ellipse in half across the board, thus reducing the number and variety of acceptable matches for every single color in color space. If hue were the only issue in color difference and if the CMC model did not adjust for it, then a supplementary CMC DH*/SH tolerance might make sense.

But there is more to color than Hue Angle. As shown in Figure 3, the CMC model scores Chromaticity and Lightness differences much differently than its CIE predecessor. This experiment investigated Hue Angle by keeping Lightness and Chromaticity constant. But Hue Angle is not always the biggest issue. Several colors in the experiment were marginally more sensitive to a change in Chromaticity or Lightness than a change in Hue Angle.

Hue Angle takes on less importance and Chromaticity more importance in achromatic shades. Consider a light, dull color standard (L=80, C=2, H=55) and a dark, dull color standard (L=15, C=2, H=280). Additional work in Datacolor Tools not included in Table 1 indicates that a batch for either color standard that varies by only one point in Chromaticity yields a 1.31 CMC DC*/SC and DE_{CMC}. However, a batch for either color that varies by 10 Hue Angle degrees yields a 0.48 CMC DH*/SH and DE_{CMC}.

The big conclusion here is that equations calculating total color difference are quite complex—a lot of very smart people considered a lot of variables when building them. Think twice before throwing in another tolerance just in case.

The Road to Redemption

When change is required, many focus on what they need to start doing. However, if your company specifies a DH tolerance in addition to a DE_{CMC} tolerance, then you need to focus on what to STOP doing.

DE_{CMC} 2:1 is a sufficient tolerance for color approval. And I mean color approval, not filtering out stuff to visually review. Or stuff to think about. So, rescind the DH tolerance requirement *lest a worse thing happen to thee.*

Unfortunately, a DH tolerance is not the only or least harmful heresy in color management. In the next installment, we will look at using approved lab dips as production standards and my favorite, quadrant color approval.

References

1. Technically, these are metrics and tolerences. For clarity, they will be combined into the term "tolerance" in this article.
2. Natific's Color Warehouse (CWH) has captured spectral data and color difference numbers for all production lots at CAP mills since 2008. CAP mills are required to maintain runcards corresponding with the data for a given period of time.
3. https://www.xrite.com/blog/tolerancing-part-3
4. The highest DE_{CMC} value came from the "L=60 C=35 H=55" standard and "L=60 C=35 H=54" pair, which fell outside of the samples shown in Table 1.

Keith Hoover, president of Black Swan Textiles, (**www.blackswantextiles.com**), implements manufacturing-centric digital processes for color and fabric development. He has implemented digital color management programs for Ralph Lauren, Target, Lands' End, JCPenney, and Under Armour, ultimately leading to a process that eliminated lab dips altogether. At Under Armour, Hoover championed the UA Lighthouse, driving digitalization and advanced manufacturing processes to explore local-for-local sourcing. He has worked hands-on in mills worldwide and is a frequent AATCC presenter.