The Transformation of Backing Correction to Substrate Correction

David Q. McDowell

Keywords: Standards, Colorimetric, Characterization, Correction, Data

Abstract

The "Tristimulus Correction Method" for modification of colorimetric data to account for a change in the color of the backing material used behind the print (e.g., black vs white) has been successfully validated since its introduction in 2005. The larger problem that has arisen is the need to adapt color characterization data for changes in paper color. The increased use of optical brightening agents and the popularity of "whiter" papers have resulted in an almost continual change in the "color" of the printing paper commonly used. Shifts of greater than 4 CIE DE2000 units between the paper used to establish color characterization data and the paper used for printing are not uncommon. It was hypothesized that a change in the backing used for measurement represented a change in paper color and was fundamentally no different than a change in the actual color of the paper. Thus backing correction was transformed to substrate correction — the computational steps are the same, only the name has changed. This paper documents the tests conducted by CGATS and the USTAG to TC130 to validate this hypothesis. It also documents additional tests that were conducted to show the impact of the differences between the three current standard illumination conditions (M0, M1, and M2) used for viewing, colorimetric computation, and densitometric computation.

Background

The tristimulus correction method was first formally documented in a 2005 TAGA paper titled "Correcting Measured Colorimetric Data for Differences in Backing Material" (McDowell, 2005). At that time it was envisioned as a way that could be used to circumvent the dilemma raised by the conflicting requirements of the densitometric standards (and early graphic arts colorimetric standards) which required black backing and the color science community which wanted characterization data based on measurements made over white backing. If measurements made over black backing could be adjusted or corrected so that they were very close to measurements of the same samples over white backing (or vice versa) then the backing would no longer be a stumbling block to data interchange, but merely another variable.

The tristimulus correction method was based on the observation that, when the differences in CIE X, Y, and Z between measurements of large data sets made over two backing materials (i.e., black and white) are plotted vs the X, Y, and Z values for measurements made over either material, the best fit result is approximately a straight line. At the lowest value of each tristimulus value, the differences between measurements made over the two backings is at or near zero. The maximum difference in measurement due to backing material characteristics is always at the maximum tristimulus value, which equates to a measurement of the substrate (usually paper) alone. Thus, knowing only the X, Y and Z tristimulus values for substrate alone over both the old and the new backing, the full set of measurement data can be modified to predict what it would have been if it had been measured over the new backing.

In mathematical terms this is:

$$X(n)_2 = X(n)_1 + \left(X(s)_2 - X(s)_1\right) \times \frac{\left(X(n)_1 - X_{MIN}\right)}{\left(X(s)_1 - X_{MIN}\right)}$$

Where

$X(n)_1$ = Measured value of X for sample n on substrate (or backing) 1

$X(n)_2$ = Predicted value of X for sample n on substrate (or backing) 2

$X(s)_1$ = Measured value of X of the substrate over substrate (or backing) 1

$X(s)_2$ = Measured value of X of the substrate over substrate (or backing) 2

X_{MIN} = Minimum value of X which generally corresponds to a 4-color solid, which is patch ID 1286 of the IT8.7/4 data set.

For computation this can be rearranged as follows.

$$X(n)_2 = \left(X(n)_1 \times (1 + C)\right) - \left(C \times X_{MIN}\right)$$

Where

$$C = \frac{X(S)_2 - X(S)_1}{X(S)_1 - X_{MIN}}$$

Corrections for Y and Z of the individual samples are accomplished in a similar manner and CIE L*, a* and b* values are computed from the new tristimulus values.

This application of the tristimulus correction method has worked reasonably well to correct for differences in backing and gives results that are within the noise level of typical measurements made over either backing. It is widely used in the graphic arts industry and is normatively documented in ISO 13655, Graphic technology — Spectral measurement and colorimetric computation for graphic arts images.

Correcting for a Paper Change

It can be generalized that the changes in the "color" of the paper due to a difference in backing was conceptually no different than changes in the color of the paper due to any other effect. It was proposed that the tristimulus correction method could be used to adjust for changes in paper color due to any reason. However, this was a much harder hypothesis to test. In the spring of 2009 the ANSI Committee for Graphic Arts Technology Standards (GCATS) and the US shadow committee for ISO TC 130 (USTAG/ TC130) undertook the task of testing this hypothesis.

At the same time that test of this hypothesis was being developed, the impact of the spectral power distribution of measurement sources was becoming a key issue. The 2009 versions of both ISO 5, *Photography and graphic technology — Density measurements* and ISO 13655, specified four spectral power distributions for sources used for measurement of density and colorimetry. These are:

— M0, Assumed to be tungsten but can be used to identify a source as unknown.

— M1, D50 or a practical equivalent to deal with paper florescence,

— M2, UV cut, and

— M3, UV cut plus polarization.

The effect of, and differences in the values measured with, these sources on substrates (papers) containing different levels of optical brightening agents (OBAs) was largely unknown, outside of the paper industry, and mostly anecdotal. Therefore, the decision was made to combine a study of the effects in graphic reproduction of measurement sources on measured color and the ability of the tristimulus correction method to compensate for substrate color differences into a single study.

The driving force for this study was the realization that the current marketplace is pushing the paper manufacturers to provide “whiter” papers (more negative CIE b* value) and that this shift in paper color is large enough in many cases to invalidate the aim characterization data. However, many of the papers with a lower CIE b* value are still are in use. This change in paper color is being exacerbated by the combination of the use of optical brightening agents (OBAs) to achieve the change in paper color and the more stringent requirements on the UV content of viewing and measurement illuminant. With a high level of OBAs present, a change in measurement condition from M0 to M1 (or even between M0 instruments) can result in enough change to invalidate the aim characterization data. A procedure that would allow characterization data to be adjusted for changes in paper color, over a reasonable range, would allow the same set of characterization data to be used with a larger selection of papers.

Some have argued that a change in paper involves much more than a simple change in paper color. Tone value increase (TVI) is tied to paper characteristics as are ink absorption, ink spread, tack, etc. However, in the modern color managed world, the goal is to define a reference and adjust the data in such a way that the color produced for a give set of CMYK input data is consistent regardless of the printing process or parameters used. The assumption is made that if the outer color gamut can be achieved, a match of within gamut colors can also be achieved through the use of appropriate linear or colorimetric transforms of the data.

One caution that must be recognized is that the tristimulus correction method only attempts to predict the colorimetry that would result if the substrate were changed and the basic printing parameters did not change. There have been no studies to show the visual appearance associated with a substrate change. Clearly two substrates of different colors (hues) placed side by side will look different. Even a change as small as 0.5 CIELAB DE2000 is reported to be visually detectable when placed side by side. Unfortunately, the color of the substrate (usually paper) is in effect a 5th color that cannot be corrected and impacts the complete image (and data set) even if the printing is identical. The range of visually acceptable appearance change in substrate color is dependant on at least the application, comparison modality, and observer, and is both beyond the scope of both CIE basic colorimetry and this study and is probably unknown at this time.

To solve the problem of producing multiple samples where the only difference was the substrate it was proposed that the Kodak Approval Proofing system be used to prepare test images. The key factors that influenced the choice of the Kodak Approval Proofing System were:

- It generates a halftone image that is similar to a printed halftone.
- The completed image is created on a donor sheet which is then transferred to a substrate.
- The image transferred is not believed to be modified by the substrate.

These factors allowed CGATS and the USTAG to make the assumption that the only difference between the transferred images was the substrate.

The image selected for use in this experiment was a test form that included images of the ANSI IT8.7/4 (*Graphic technology — Input data for characterization of 4-color process printing — Expanded data set*) target. 15 Kodak Approval donor sheets were prepared sequentially using the same equipment, data file, and donor materials. This allowed the first and last transfer sheets to be measured to verify consistency of the full set. The intermediate sheets were transferred to the 13 different papers listed in Table 1.

	Paper Name	**L***	**a***	**b***
1	Newsprint 3	82.18	2.60	8.12
2	SVS 6	90.92	-0.94	1.11
3	Summerset	93.00	0.84	-3.92
4	PS House 12	93.04	1.56	-6.37
5	Fortune Gloss 13	93.12	0.83	-4.33
6	Gusto 14	93.13	1.15	-6.02
7	Orion 9	93.41	0.69	-3.76
8	Finesse	93.71	1.71	-7.33
9	Sterling 4	93.73	1.15	-4.64
10	Utopia 5	94.28	1.71	-8.02
11	McCoy Gloss 11	94.48	2.13	-8.73
12	McCoy	94.64	-1.32	3.38
13	Centura 8	94.82	1.45	-7.28

Table 1 – *Colorimetry of Papers used (M1, white backing)*

These were then measured with (1) a typical spectrophotometer to represent M0 data, (2) an experimental setup at X-Rite Corporation that simulated M1 measurements, and (3) a UV cut instrument to represent M2 measurements. Spectral radiance factor data were collected at 10 nm intervals for all 1617 patches of the IT8.7/4 target on each of the 13 substrates for each of the three measurement condition. Note that I have used the term spectral radiance factor data rather than the more common spectral reflectance data because many of the samples included a fluorescent component due to the presence of OBAs. Colorimetric data were then computed for all patches using the weighting functions of ISO 13655. This provided an extensive body of data that allowed comparisons between, and across, measurement conditions and substrates.

The Papers Used

The 13 papers used (Table 1) were selected based on availability and represented a reasonable spread across papers typically used in the publication market. Newsprint was the exception and it was included to provide an extreme case. Figure 1 shows the spectral radiance factor curves for all 13 papers measured under

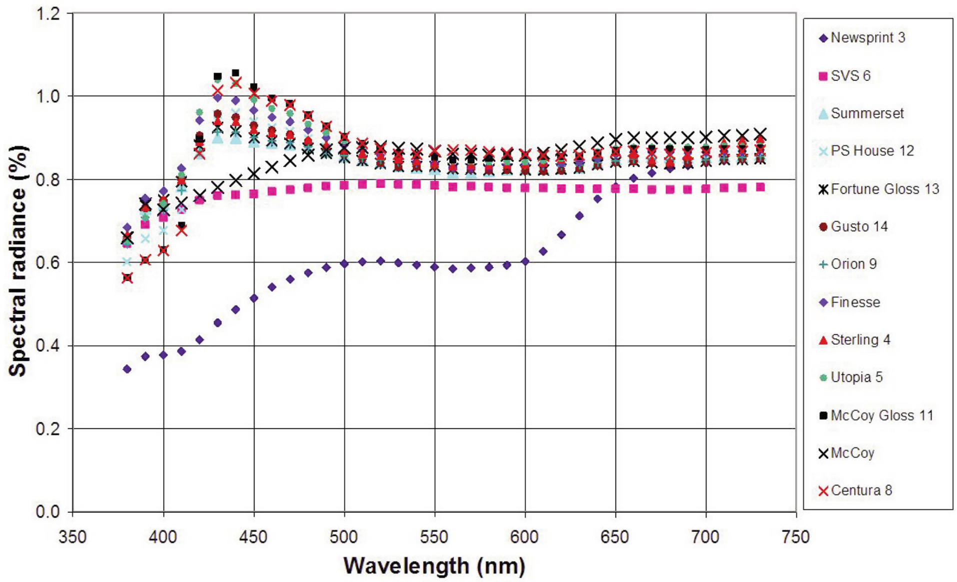

Figure 1 — Spectral radiance of papers used, M1 white backing

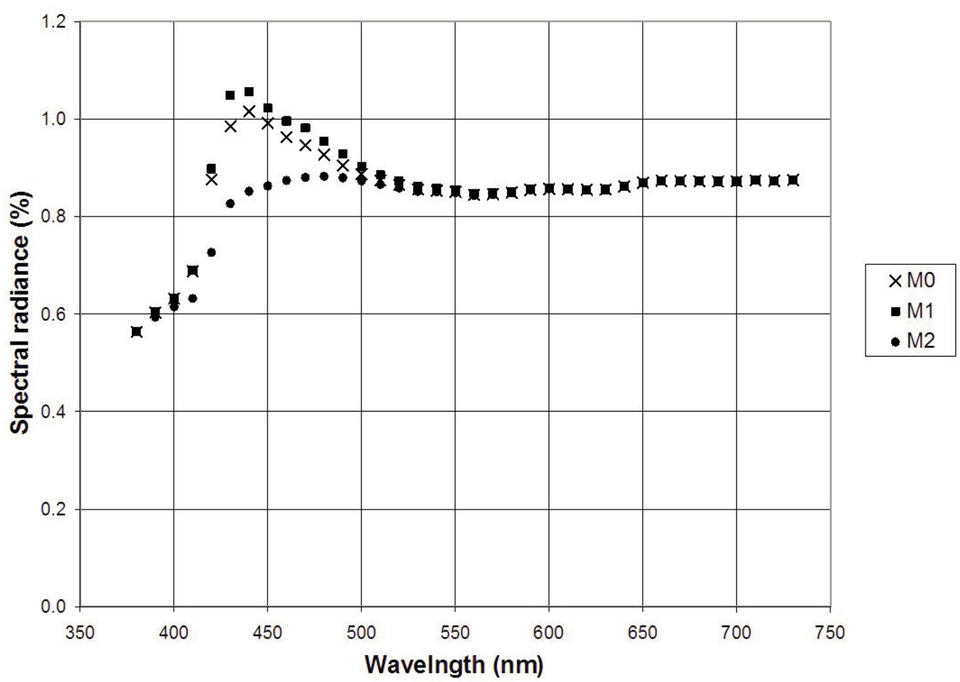

Figure 2 — Spectral radiance of McCoy Gloss, M0, M1. M2 white backing.

M1, over white, conditions. McCoy Gloss is the paper showing the greatest OBA effect. Figure 2 shows the spectral radiance factor curves for McCoy Gloss under all three measurement conditions. From these plots it can be seen that the M0 instrument used had a significant amount of UV. McCoy was reported to be the same paper as McCoy Gloss but without any OBA content. Figure 3 shows the spectral radiance factor curves for McCoy under all three measurement conditions. You will note that, except for an unexplained data anomaly at 390 nm, all three curves fall essentially on top of one another.

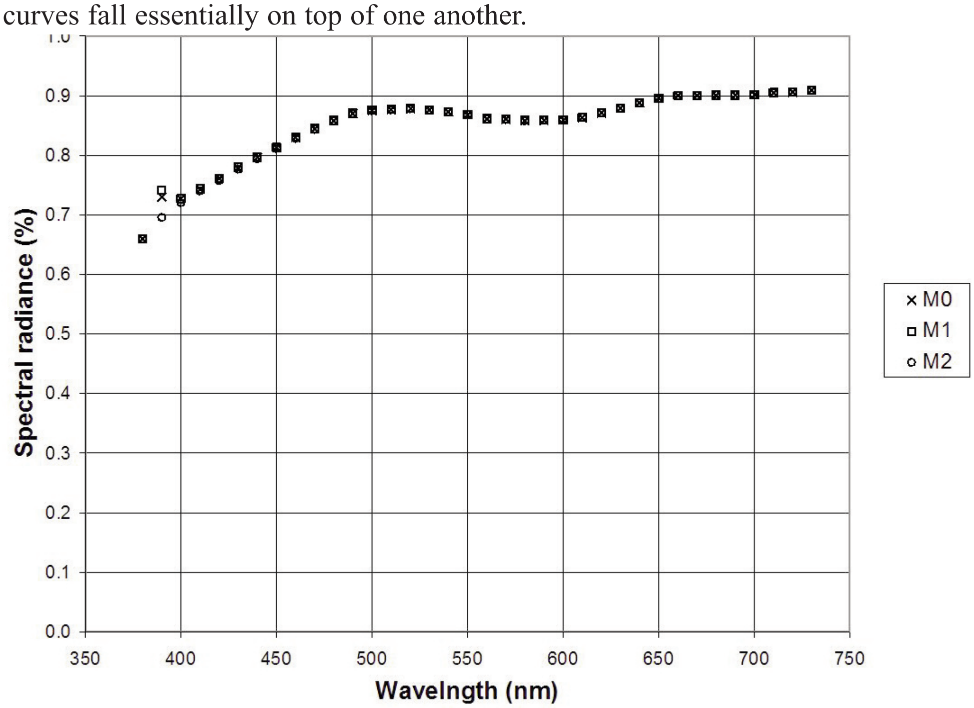

Figure 3 *— Spectral radiance of McCoy (M0, M1 and M2 white backing)*

Summary of Initial Tests

The initial data analysis focused on using characterization data measured on one substrate to predict what the characterization data would be if the identical printing were done on a different substrate of the 13 substrates involved in the experiment. The tristimulus correction method was used to make these predictions with the only new information being the measured value of the second substrate. Because measured data was available for the characterization data being predicted, the computed data could then be compared with the actual measured data.

There are 29 sets of identical CMYK printing values (duplicate patches) that occur twice in the IT8.7/4 target and ideally when printed have exactly the same color. These occur in different physical locations within the target (and therefore the printed sheet). The differences in the measured colorimetric values between pairs provides an estimate of the combined within-sheet paper variation, within-sheet imaging variation, and measurement variation.

Figure 4 shows a cumulative probability plot of the color differences (CIE DE2000) of the pooled redundant patches from all 13 substrate samples (377 pairs). The M1 measurements were used for these data.

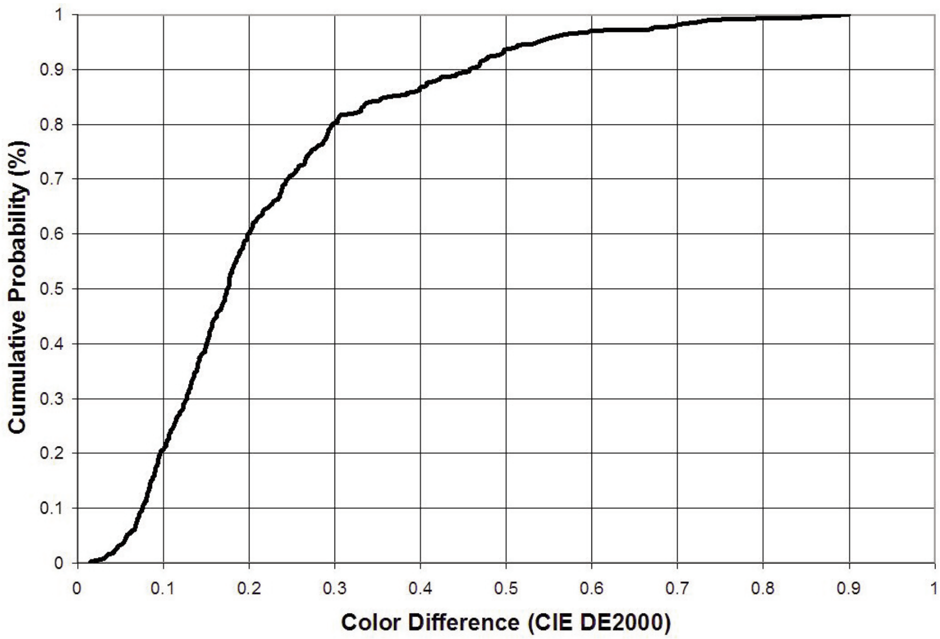

Figure 4 *— Cumulative probability of color differences, all redundant patches*

Figures 5 through 7 show typical results achieved when using characterization data measured on one substrate to predict what the characterization data would be if the identical printing were done on a different substrate of the 13 substrates involved in the experiment. The plots shown all used the data for Fortune Gloss as the reference data set to predict the characterization data that would have been obtained if a different substrate had been used. The three cumulative probabilities shown represent: the actual CIE DE2000 color difference between the Fortune Gloss data set and the data set being predicted (Reference); the CIE DE2000 color difference between the predicted data set and the measured values of that data set (Predicted); and an estimate of uncertainty based on the analysis of the duplicate patches, as described above and shown in Figure 1 (Dups).

Newsprint was included in these tests to represent an extreme case. However, in the real world of ink on paper printing it would probably not be an appropriate candidate for prediction from a characterization data set based on a grade 1 coated stock. The basic premise of the tristimulus correction method is that the solids and outer gamut of the characterization data set can be achieved on the substrate for which the prediction is being made. While in this experiment, which uses a transfer proofing system, that is probably a realistic assumption. However, it is not a realistic assumption for traditional printing.

Figure 8 is similar to Figures 5 through 7 except in this case McCoy was used to predict McCoy Gloss. This pair was chosen because McCoy and McCoy Gloss are reported to be essentially the same paper except for the addition of OBAs in McCoy Gloss.

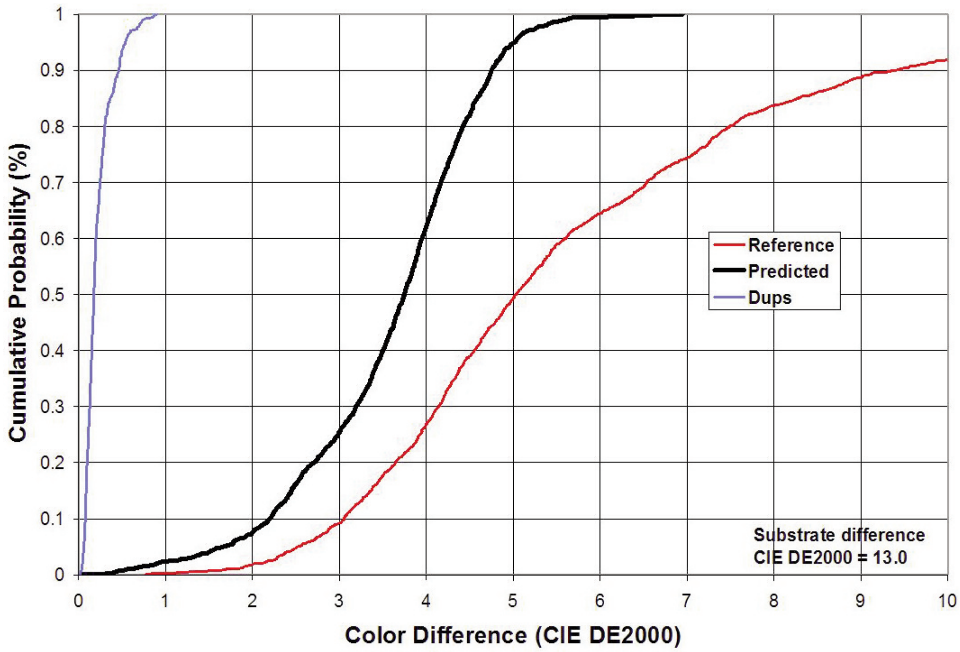

Figure 5 — Newsprint predicted from Fortune Gloss

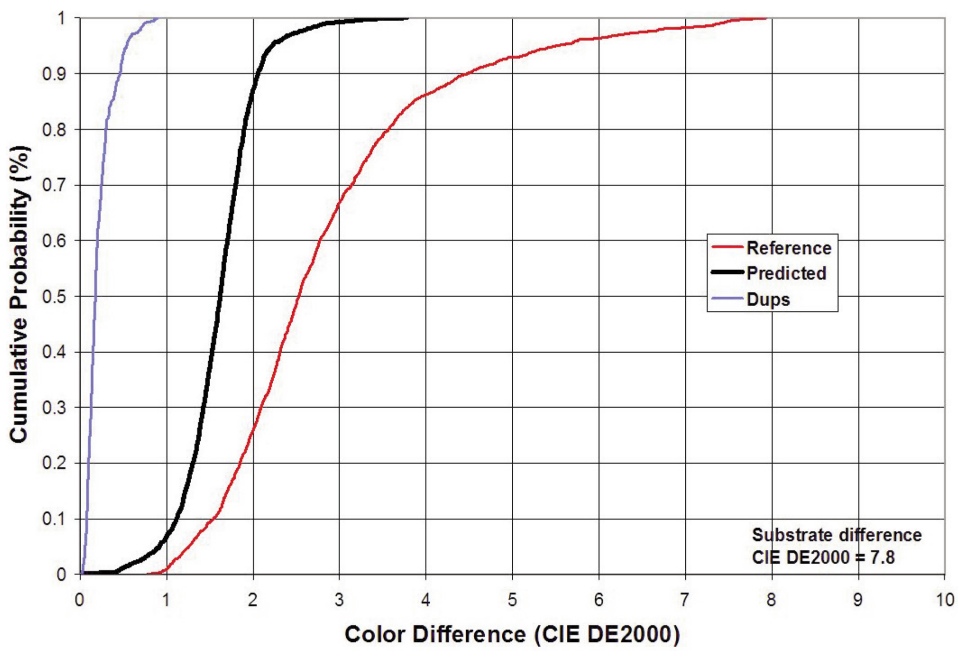

Figure 6 — McCoy predicted from Fortune Gloss

While using the predicted data set is not as good as creating a new data set, in all cases it is a significant improvement over using the data set based on the reference (incorrect) substrate. Within the limits of this test, it can be concluded that the tristimulus correction method provides a reasonable estimate of a new characterization data

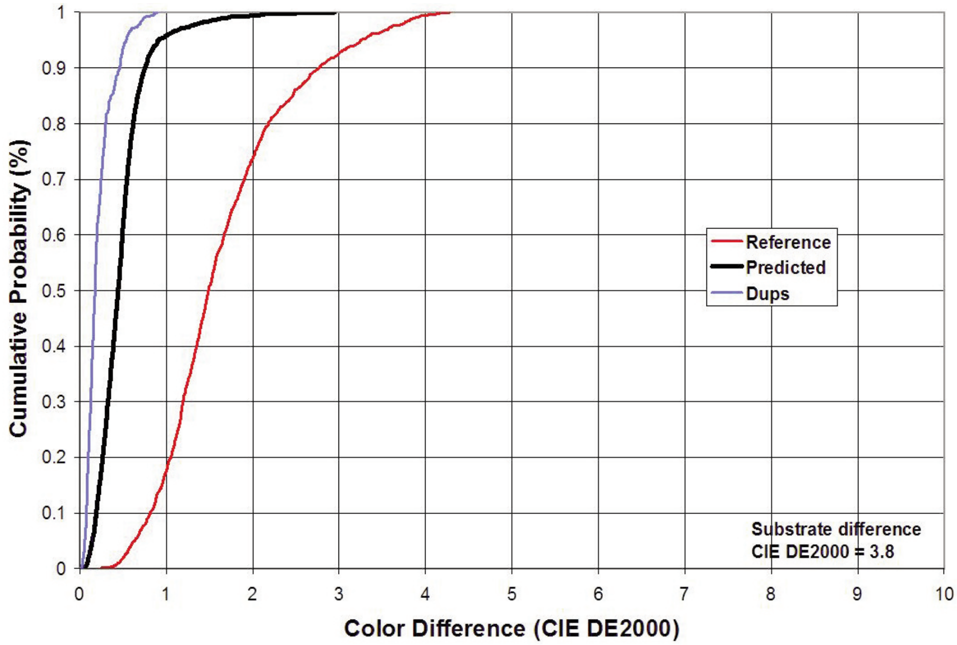

Figure 7 *— McCoy Gloss predicted from Fortune Gloss*

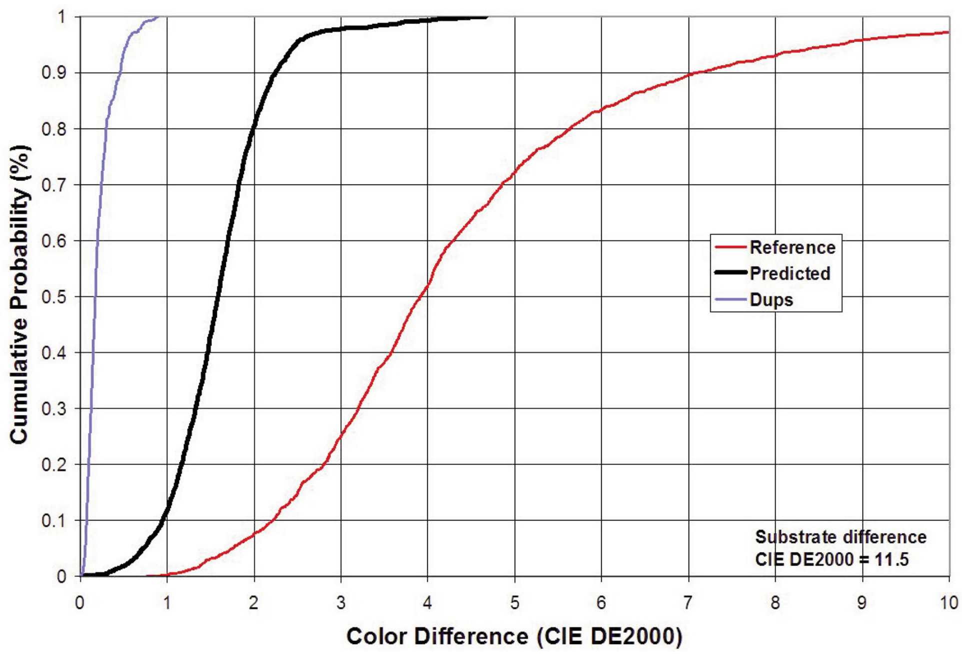

Figure 8 *— McCoy Gloss predicted from McCoy*

set based on an existing data set where the only change is the color of the substrate used and the only new information provided is the measurement of the unprinted new substrate.

Predicting M1 Data from M0 Data or M2 Data

Another possibility considered was the situation where reference characterization data was available based on M0 measurements and data based on M1 measurements were desired. The assumption is that M1 measurements of the unprinted substrate may be more readily available than a complete re-measurement of the data set. Because McCoy Gloss had the greatest OBA effect it was used as an extreme case to evaluate the prediction of M1 characterization data from M0 characterization data. Since the UV content of the illumination in an M0 instrument is unspecified, I have chosen to show the full range of possibilities — both a typical M0 and an M2 (UV cut) instrument were used as the starting point for calculation. The results of these predictions are shown in Figure 9. I have not included the uncertainty prediction based on the duplicate patches because the color difference between the M1 measured characterization data and the M1 characterization data predicted from the M0 measured characterization data are essentially of the same magnitude as the uncertainty predicted from the duplicate patches. Again, reasonable predictions.

Using Spectral Data

One suggestion that was considered was the possibility of using spectral data rather than tristimulus data to predict the changes introduced by a change in paper color. The computational procedure used was similar to that of the tristimulus correction method except that corrected data was prepared at each wavelength and colorimetric data was computed from the corrected spectral radiance factor data. Figure 10 shows the results of using spectral data to predict M1 measurements of characterization data on McCoy Gloss from similar data on McCoy. The results of predictions using tristimulus data (Figure 8) is also shown. The conclusion is that use of spectral data did not produce a significant improvement in the prediction of colorimetric data compared to the use of tristimulus data. However, where spectral data is available and is intended for use in subsequent computations or transforms the use of such a spectral correction method is appropriate and encouraged.

Conclusions

Based on these tests, and their limitations, the tristimulus correction method does a reasonable job of predicting the color characterization data, based on the IT8.7/4 target, for images printed on a substrate having a different color than the substrate on which a reference characterization data set is based. The quality of the predictions seemed independent of the type of paper and OBA levels present but does seem to be dependant on the magnitude of the difference in substrate color.

The use of spectral data rather that tristimulus data in the calculation step does not appear to provide significant improvement in the prediction.

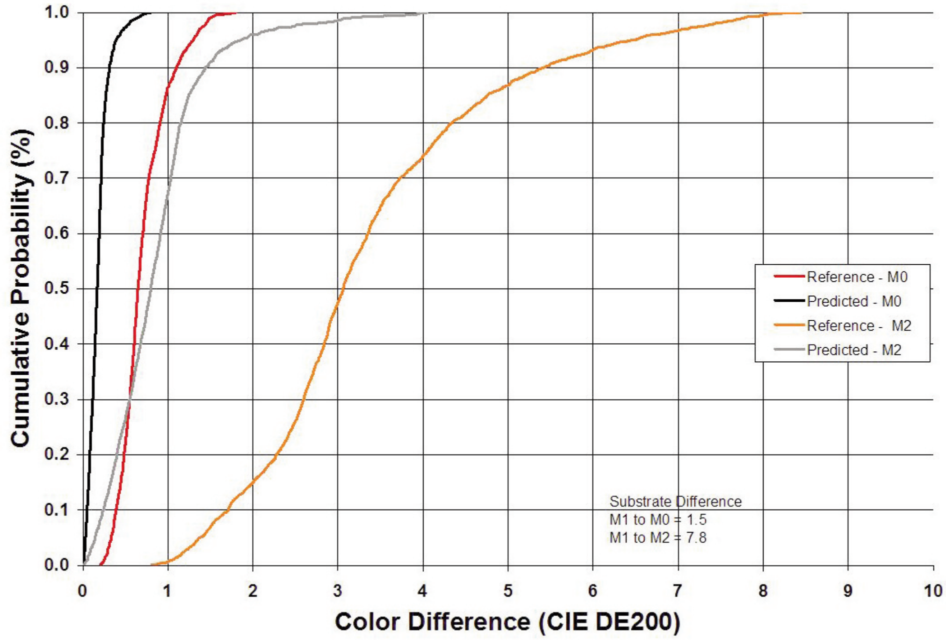

Figure 9 — *McCoy Gloss, M1 predicted from M0 and M2 data*

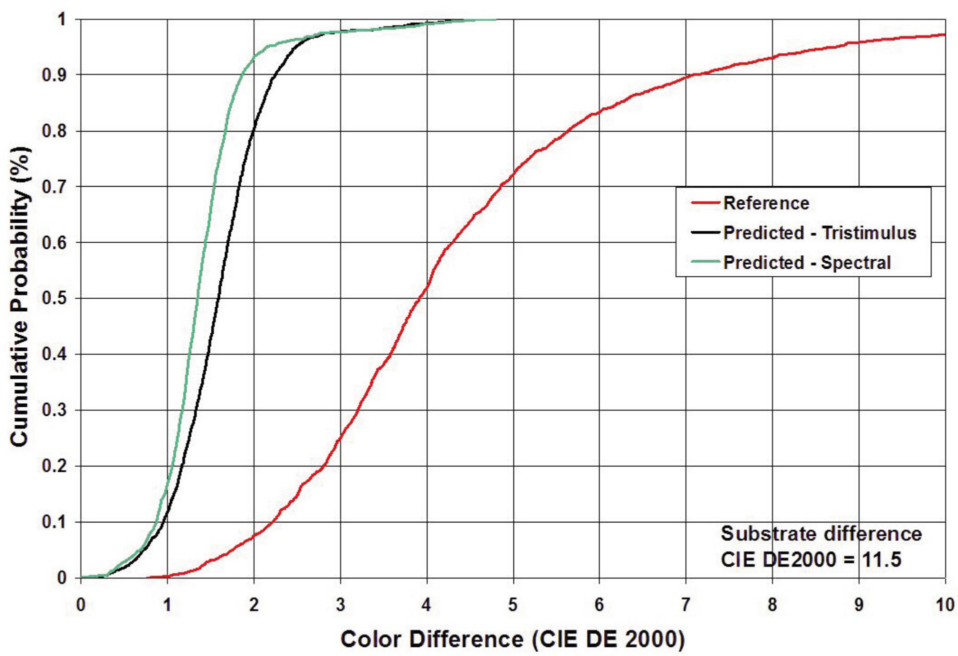

Figure 10 — *McCoy Gloss predicted from McCoy – Spectral computation*

The prediction of characterization data for the M1 measurement condition from characterization data for the same substrate based on M0 or M2 measurements appears to be of the same degree of accuracy as the prediction of data for one substrate based on another substrate.

Applicability

The tristimulus correction method is included in ISO/DIS 15339-1 as the recommended procedure for correcting aim characterization data where the substrate used for printing has different CIELAB values than the reference aim characterization data. It is also used in a number of industry printing certification activities where the reference characterization data and the actual substrate used are not in agreement.

It should be noted that the results of the substrate relative transformations available through the ICC color management architecture are identical to the tristimulus correction method when the minimum values of X, Y and Z are set to 0. The key difference is that when using the ICC substrate relative transforms the image content data is transformed by the color management system and the target aims are not directly available.

The use of the tristimulus correction method to create new aim data allows the process aims to be accessible for process control applications. For example, although the ink used is the same, the color of the solid ink printed on paper changes because only black ink absorbs light at all wavelengths. This results in different colorimetric aims for the solids and two color solid overprints on substrates that differ in color. (Chung, 2011) In addition, for halftone images the substrate itself acts much like a fifth color in the determination of the apparent color of any finite area of the image. Where no tints, or only tints of very low halftone value, are present the color of the image is largely determined by the color of the paper.

Additional Data

The CDROM of the TAGA Proceedings contains three files that include the spectral radiance factor data for all 13 papers measured. These are:

— USTAGN3558 Substrate Experiment M0 Measurement data.xls

— USTAGN3559 Substrate Experiment M1 Measurement data.xls

— USTAGN3560 Substrate Experiment M2 Measurement data.xls

Each file represents a single measurement condition, M0, M1 or M2 over a white backing. The M0 and M2 instruments used comply with the conditions as specified in ISO 13655. The M1 measurement condition represents an early prototype of an instrument intended to meet the requirements of ISO 13655 M1, option 2, which allows use of a computational technique based on adjustment of the radiant power in the spectral region below 400 nm. These data are provided to allow others to experiment with these data to further enhance the effective establishment and adjustment of printing aims within our industry.

Acknowledgements

This work was a collaborative effort of many individuals and companies involved in the ANSI CGATS and USTAG TC130 committees. It is reported here to share this work beyond the standards community although the data and results are available in various ANSI CGATS and USTAG TC130 documents.

Literature Cited

McDowell, David Q., Chung, Robert, Kong, Lingjun.

2005 “Correcting Measured Colorimetric Data for Differences in Backing Material”, TAGA Proceedings, 2005, pp 302-309

Chung, Robert,

2011 “Substrate Correction in ISO 12647-2,” TAGA Proceedings, 2011, pp. 24-47