

M1 Simulation by Varying Printing and Proofing Substrates

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Keywords: ICC, printing, proofing, simulation, OBA, color, workflow

Abstract

ICC color management can match color, pixel by pixel, from the source color space to the destination color space. The degree of color match is limited by the repeatability of the device and color management constraints between the source and destination. This research outlines a method whereby printing and proofing can be simulated visually and quantitatively. Major findings indicate that (1) the simulation error at the device level is about 1 ΔE_{00} at the 95th percentile of the sample distribution; (2) the error at the color management workflow level, except special causes, is about 2 ΔE_{00} at the 95th percentile of the sample distribution; (3) gamut clipping, due to CIE-b* difference or CIE-L* difference, is a special cause that contributes to proof-to-print mismatch. Avoiding gamut clipping by choosing the proofing substrate close to the white points of the printing paper, but with more “head room,” is a key finding in this study. In addition, we need no fewer than two proofing stocks to choose from. This is because the OBA difference between a proof and a print is an indication of the criticalness of the M1 lighting, i.e., the match becomes more metameric when the OBA difference is high.

Introduction

Characterized Reference Printing Condition (CRPC) and its derived ICC profile often serve as the default source color space in a color-managed proofing workflow. The standard proof serves as a proxy for printed color. Printers are asked to print to match the color appearance of the proof.

The market does not want to standardize paper color. As print buyers choose ‘whiter’ papers, the ‘white’ appearance of the paper is often the result of adding optical brightening agent (OBA) in the papermaking process. Consequently, color-managed proofs, made on non-brightened substrates, no longer match OBA-brightened print.

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CGATS.21, Printing from digital data across multiple technologies, establishes principles for the use of color characterization data as the definition of printing by specifying a number of characterized reference printing conditions. It also specifies that colorimetry should be measured according to ISO 13655 M1 with white backing. If the printing substrate has a color that differs from the characterized reference printing condition selected, the substrate correction method, as defined in ISO 13655, shall be used to adjust the data before proofing and printing.

Given that color measurement and color viewing conform to M1, this research sets out to answer the following two questions:

- What are the effect of the white point and the OBA amount of a substrate on print-to-proof color match, and
- What are the recommended practices in achieving proof-to-print color match when both printing and proofing substrates varying in OBA amounts?

Literature Review

Recognizing that OBA affects printing conformance and printed color appearance, Chung and Tian studied optical brightening agents correction methods, also known as the SCCA (Advanced Materials Research, 2011). Later, Chung conducted a follow-up study on printing conformance to substrate-corrected dataset (TAGA Proceedings, 2013). Chung also tested a method to achieve proof and print visual match under the influence of OBA whereby the source ICC profile is built from the substrate-corrected dataset. Four commercial proofing solution providers were invited to participate in the study (IARIGAI, 2013).

RIT conducted a psychometric experiment to study the perceptibility of color difference of color pairs, caused by OBA difference in paper substrates, and its relationship with quantitative measurement metrics (TAGA, 2015). The research utilized a four-level visual ranking scale, from no difference (0), just noticeable difference or JND (1), more than JND (2), to noticeable difference (3), to rank 27 color pairs with each pair prepared by the same colorants on two different substrates, one having OBA and the other did not. In addition to ΔE metrics, the research specifies the metric, OBA or the OBA amount in a substrate, per ISO/FDIS 15397 (2013), as the difference between two measurements, M1 and M2 (Eq. 1). In addition, ΔOBA is defined as the difference in OBA between a proofing substrate and a printing paper (Eq. 2).

$$OBA = b^*_{M2} - b^*_{M1} \quad \text{Eq. (1)}$$

$$\Delta OBA = OBA_{\text{Proof}} - OBA_{\text{Print}} \quad \text{Eq. (2)}$$

The psychometric study, conducted by RIT, placed samples in edge contact and provided two anchor pairs (one with no difference and the other with noticeable difference). The results show that fluorescent agents and printed color affect the OBA metric, but its CIE-L* stays the same. The study concludes that there is a linear relationship between visual difference and ΔE_{00} metric. Since ΔOBA is the main contributor of ΔE_{00} , the study also concludes that there is a linear relationship between visual difference and ΔOBA .

Methodology

In a color proofing workflow, color difference between proof and print can come from different substrates, including OBA amount, colorants, and ICC color management (look-up table size, mapping, and rounding error). This research devises a M1 color-managed workflow, as outlined below, to test the viability of proof-to-print color match by simulating a pictorial color (SCID) image visually and quantitatively.

- a) Select a CRPC or a reference dataset.
- b) Select three printing and three proofing conditions (varying in OBA amount).
- c) Study the relationship between white point and OBA amount of these substrates
- d) Select a SCID image.
- e) Simulate the SCID image, as printed, in relation to CRPC.
- f) Simulate the SCID image, as printed and proofed, visually.
- g) Simulate the SCID image, as printed and proofed, quantitatively.
- h) Simulate device error.

Color management resources include the SCCA calculator (Excel), i1 Profiler, Adobe Photoshop, CHROMiX ColorThink, and a host Macintosh computer with a calibrated monitor. Unless otherwise noted, all measurements are M1. A step-by-step procedure to simulate a color-managed image visually and quantitatively is described below:

- 1) Select a reference dataset (CGATS21-2-CRPC6) and ICC profile
The ICC profile, GRACoL2013_CRPC6.icc, downloaded from the ICC web site, has a white point ($95L^*/1a^*/-4b^*$).
- 2) Select three printing papers varying in OBA. Calculate the substrate-corrected datasets and build the substrate-corrected ICC profiles. The three papers, varying in OBA, were selected from 13 papers in the CGATS 2010 database (Table 1).
 - a) sccaL_McCoy.icc: WP: 94.6/-1.3/3.4; OBA: 0.14
 - b) sccaM_Sterling.icc: WP: 93.7/1.2/-4.6; OBA: 4.8
 - c) sccaH_McCoy Gloss.icc: WP: 94.5/2.1/-8.7; OBA: 8.7

CGATS 2010 Database	M1			M2			OBA
	LAB_L	LAB_A	LAB_B	LAB_L	LAB_A	LAB_B	
CGATS CRPC6	95	1	-4	---	---	---	---
sccaL_McCoy	94.64	-1.32	3.38	94.61	-1.34	3.52	0.14
sccaM_Sterling	93.73	1.15	-4.64	93.54	-0.21	0.15	4.78
sccaH_McCoy Glo	94.48	2.13	-8.73	94.05	-0.16	-0.03	8.70

Table 1. Printing papers varying in their OBA amounts

3) Select three proofing papers and their ICC profiles

Mr. Bruce Bayne, Alder Technology, Inc., provided three proofing ICC profiles with varying OBA in this study (Table 2).

- a) pfl_Epson205: Epson Standard Proofing Paper (WP: 93/0/-1.3; OBA: 0.7)
- b) pfM_EPPP: Epson Proofing Paper Production (WP: 94.5/1.1/-4.8; OBA: 5.7)
- c) pfH_Outre: Mid-States FSC 7S Paper (WP: 95/1.7/-10; OBA: 9.7)

Substrate	M1			M2			OBA
	LAB_L	LAB_A	LAB_B	LAB_L	LAB_A	LAB_B	
pfl_Epson205	93.38	-0.13	-1.28	93.35	-0.31	-0.55	0.73
pfM_EPPP	94.54	1.13	-4.75	94.31	-0.41	1.00	5.75
pfH_Outre	95.45	1.69	-9.86	95.03	-0.92	-0.12	9.74

Table 2. Proofing substrates varying in their OBA amounts

4) Select a SCID image

- a) Select a pictorial reference image (ISO 12640, N4A, 300 ppi, untagged CMYK) and re-size it to 3” wide, including white borders, and save as Scene.tif in Photoshop. The 3” wide hi-res image is for visual comparison.
- b) Re-sample the above image into 5 ppi. The pixelated (15x12 or 180 pixels) image, representing colors of interest, is for quantitative comparison (Figure 1).
- c) Save the image as Scene_Pix.tif.



Figure 1. A hi-res pictorial image (left) and a pixelated image (right)

- 5) Simulate the SCID image, as printed, in relation to CRPC
 - a) Step 6a, as shown below, can be used to compare the SCID images, as printed, in relation to the CRPC visually.
 - b) Step 7a, as shown below, can be used to compare the SCID images, as printed, in relation to the CRPC quantitatively.

- 6) Simulate the SCID image, as printed and proofed, visually
 - a) Simulate the SCID image, as printed, visually
 - i. Open the SCID image, Scene.tif, in Adobe Photoshop.
 - ii. Assign a printer ICC profile, CRPC6 or sccaX, where X = L, M, or H, to the image.
 - iii. Convert the image to Adobe RGB space using absolute colorimetric rendering.
 - iv. Save as Scenes_sccaX_adobe.tif.
 - b) Simulate the SCID image, as proofed, visually
 - i. Use i1 Profiler to build 9 device link profiles using the absolute colorimetric rendering intent, medium table size, TAC 320, and no purity preservation (Figure 2).

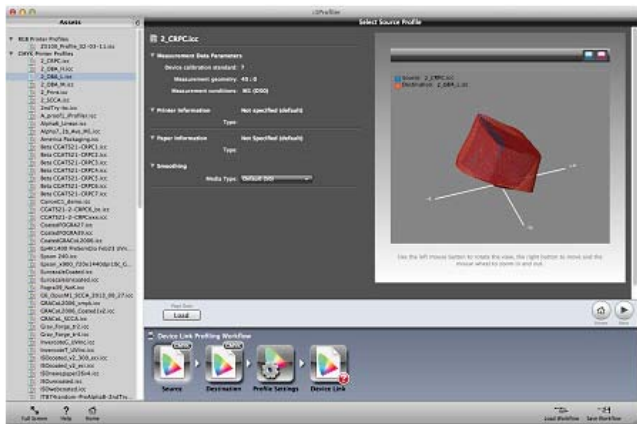


Figure 2. Creating a device link profile in i1 Profiler

- ii. Open the SCID image, Scenes.tif, in Adobe Photoshop.
- iii. Convert the image via a device link profile, DL(sccaX-pfY).icc.
- iv. Assign the proofer profile, pfY.icc, to the converted image.
- v. Convert the above image from pfY space to Adobe RGB space using absolute colorimetric rendering.
- vi. Save as Scenes_sccaX-pfY_adobe.tif.
- c) Place the simulated print (step 6a), and the simulated proof (step 6b) in edge contact in Microsoft PowerPoint. Add legends, and a neutral background.

7) Simulate the SCID image, as printed and proofed, quantitatively

- a) Simulate the SCID image, as printed, quantitatively
 - i. Open the Scene_Pix.tif (step 4c) in ColorThink.
 - ii. Assign a printer profile, sccaX.icc, in absolute colorimetric rendering intent.
 - iii. Custom sample the image (15x12=180) and save the list as a Scene_List(sccaX).txt (Figure 3).

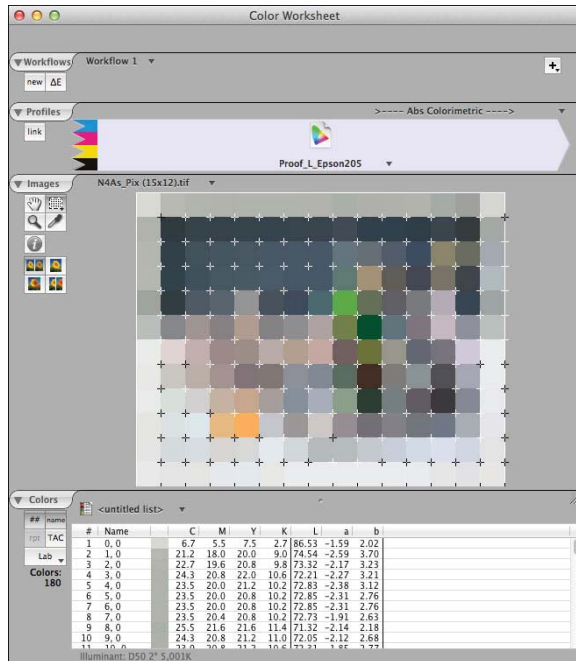


Figure 3. Creating a color list in CHROMiX ColorThink

- b) Simulate the SCID image, as proofed, quantitatively
 - i. Open the SCID image, Scene_Pix.tif (Step 4c), in Adobe Photoshop.
 - ii. Convert the image via a device link profile, DL(sccaX-pfY).icc (step 6b).
 - iii. Assign the proofer profile, pfY.icc, to the converted image.
 - iv. Save it as Scene_Pix(sccaX-pfY).tif.
 - v. Open the Scene_Pix(sccaX-pfY).tif in ColorThink. Sample the pixels (15 x 12=180), using the pfY.icc, in absolute colorimetric rendering.
 - vi. Save the list as a Scene_List(sccaX-pfY).txt.
- c) Compare color difference (ΔE_{00}) between the color list from a pictorial print, and the color list from a color-managed proof.

- 8) Simulate device errors
 - a) Open a CIELAB list (step 7a) in ColorThink.
 - b) Assign a printer or proofer profile, sccaX.icc or pfY.icc, in absolute colorimetric rendering intent.
 - c) Assign the same printer or proofer profile, again in absolute colorimetric rendering intent.
 - d) Custom sample the image (15x12=180) and save the list as a RoundTrip.txt.
 - e) Compare color difference (ΔE_{00}) between the two color-lists in step (a) and step (d).

Results

1) Device error

Device error is estimated by the round-trip error of the device ICC profiles. By assigning a printer or proofer ICC profile twice (step 8), we can compare the color difference between the initial and the round-trip color list. Overall, the device error is 1 ΔE_{00} at the 95th percentile of the sample distribution (Figure 4).

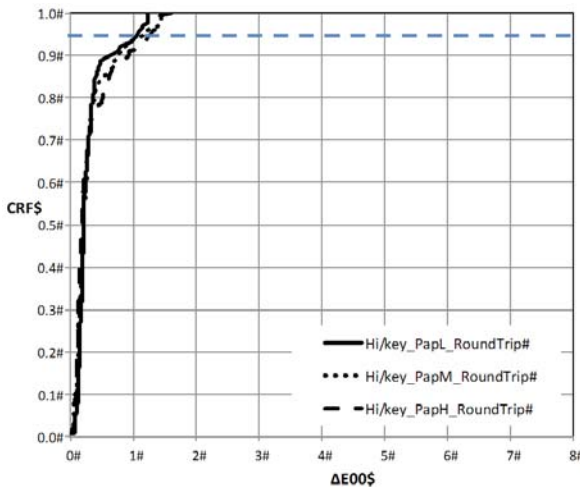


Figure 4. Simulation error at the device level

2) Print simulation visually and quantitatively

Figure 5 is the visual simulation of N4A in CRPC6 (upper center) and the three substrate-adjusted printing conditions (low OBA, medium OBA, and high OBA). In this case, the visual differences, e.g., color appearance of the border and the image, due to substrate difference, are intentional.



Figure 5. Visual simulation of the three printing conditions

Figure 6 illustrates the quantitative color differences between each of the three substrate-corrected printing conditions and the CRPC6. We can see that ΔE_{00} at the 95th percentile of the sample distribution is a reasonable predictor of the pictorial color match between the sample and the reference. Specifically, the medium OBA (Sterling) printing condition, having the smallest color difference, visually matches the reference printing condition the best. Next, the high OBA (McCoy Gloss) printing condition has more color difference with blue appearance in the highlight. Finally, the low OBA (McCoy) printing condition has the largest color difference (more than 7 ΔE_{00} at the 95th percentile of the sample distribution) with yellow appearance in the highlight.

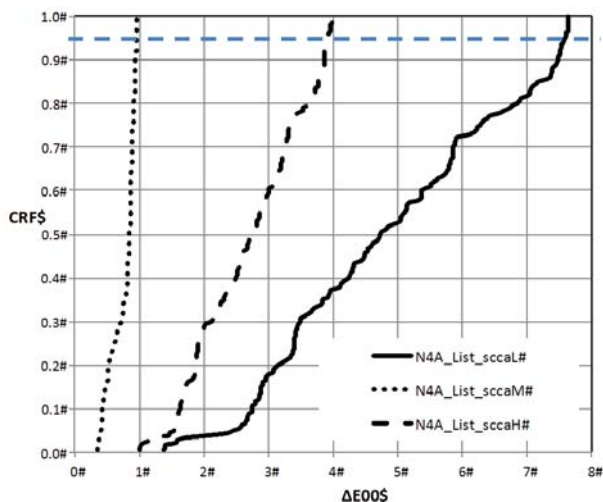


Figure 6. Quantitative color differences between each of the three printing conditions and CRPC6

3) Proof-to-print simulation visually and quantitatively

Due to the choice of printing paper, each printing condition (low OBA, medium OBA, and high OBA) represents an actual printing condition. This means that we have three use cases to study proof-to-print color match when the printing condition varies from low OBA print (sccaL), moderate OBA print (sccaM), to high OBA print (sccaH).

Case 1: Low OBA print as the reference

By simulating the printing and proofing workflow according to the methodology, the low OBA print substrate and the three proofing substrates show large ΔOBA and ΔE_{00} variations (Table 3).

Substrate	M1			M2			OBA	ΔE_{00} (sccaL_McCoy)	ΔOBA (sccaL_McCoy)
	LAB_L	LAB_A	LAB_B	LAB_L	LAB_A	LAB_B			
sccaL_McCoy	94.64	-1.32	3.38	94.61	-1.34	3.52	0.14	---	---
pfl_Epson205	93.38	-0.13	-1.28	93.35	-0.31	-0.55	0.73	4.78	0.59
pfM_EPPP	94.54	1.13	-4.75	94.31	-0.41	1.00	5.75	8.29	5.61
pfH_Outre	95.45	1.69	-9.86	95.03	-0.92	-0.12	9.74	12.21	9.60

Table 3. Proof and print (low OBA) substrate comparison

Figure 7 shows the appearance of N4A in the low OBA print (upper center) and the three color-managed proofing conditions (pfl, pfM, pfH). In this case, the visual similarity or difference is the results of color management and proofing substrates with varying OBA.

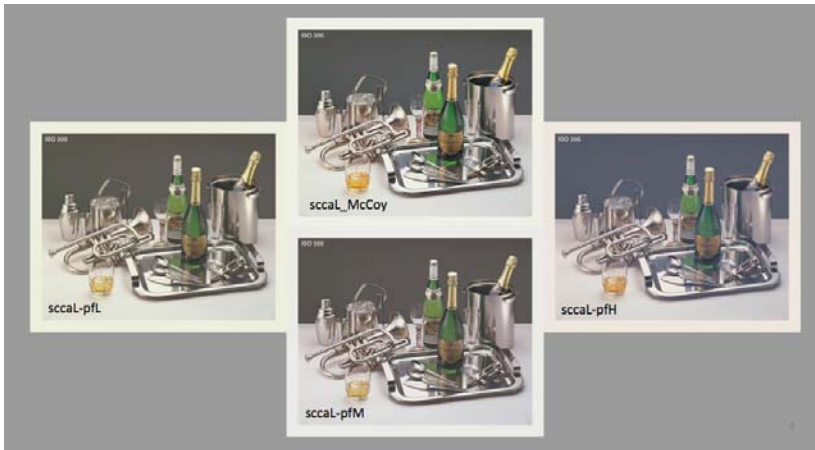


Figure 7. Visual simulation of proof-to- low OBA print match

Figure 8 illustrates the quantitative color differences between each of the three color-managed proofing conditions and the low OBA (McCoy) printing condition. We can see that ΔE_{00} at the 95th percentile of all three distributions is about $2\Delta E_{00}$ or less.

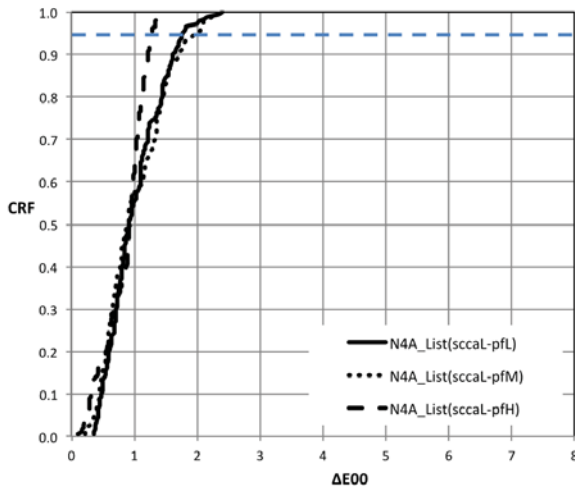


Figure 8. Quantitative color differences between each of the three proofs and the low OBA print
Case 2: Medium OBA print as the reference

The medium OBA print substrate and the three proofing substrates show less ΔOBA and ΔE_{00} variations than Case 1 (Table 4).

Substrate	M1			M2			OBA	ΔE_{00} (sccaM_Sterling)	ΔOBA (sccaM_Sterling)
	LAB_L	LAB_A	LAB_B	LAB_L	LAB_A	LAB_B			
sccaM_Sterling	93.73	1.15	-4.64	93.54	-0.21	0.15	4.78	---	---
pfL_Epson205	93.38	-0.13	-1.28	93.35	-0.31	-0.55	0.73	3.43	4.05
pfM_EPPP	94.54	1.13	-4.75	94.31	-0.41	1.00	5.75	0.50	0.97
pfH_Outre	95.45	1.69	-9.86	95.03	-0.92	-0.12	9.74	4.11	4.96

Table 4. Proof and print (medium OBA) substrate comparison

Figure 9 shows the appearance of N4A in the medium OBA print (upper center) and the three color-managed proofing conditions (pfL, pfM, pfH). While smaller ΔOBA and ΔE_{00} mean less color management challenges, highlight clipping is visible



Figure 9. Visual simulation of proof-to-medium OBA print match

between the low OBA proof and the medium OBA print.

Figure 10 illustrates the quantitative color differences between each of the three color-managed proofing conditions and the medium OBA printing condition. We can see that ΔE_{00} at the 95th percentile of all three distributions is less than $2 \Delta E_{00}$.

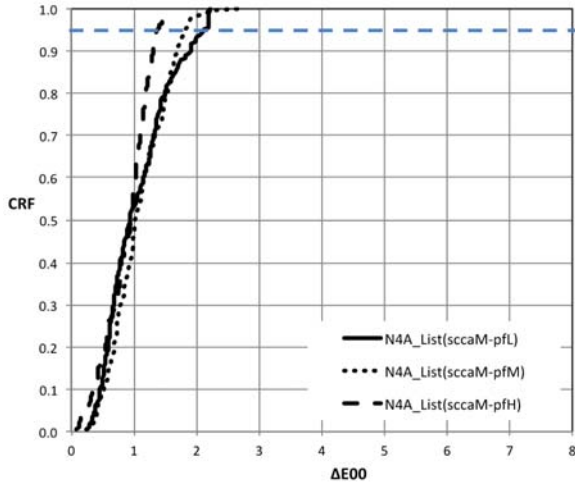


Figure 10. Quantitative color differences between each of the three proofs and the medium OBA print

Case 3: High OBA print as the reference

The high OBA print substrate and the three proofing substrates show larger ΔOBA s and ΔE_{00} variations than Case 2 (Table 5).

Substrate	M1			M2			OBA	ΔE_{00} (sccaH_McCoyG)	ΔOBA (sccaH_McCoyG)
	LAB_L	LAB_A	LAB_B	LAB_L	LAB_A	LAB_B			
sccaH_McCoyGlo	94.48	2.13	-8.73	94.05	-0.16	-0.03	8.70	---	---
pfL_Epson205	93.38	-0.13	-1.28	93.35	-0.31	-0.55	0.73	6.69	7.98
pfM_EPPP	94.54	1.13	-4.75	94.31	-0.41	1.00	5.75	3.21	2.95
pfH_Outre	95.45	1.69	-9.86	95.03	-0.92	-0.12	9.74	1.25	1.04

Table 5. Proof and print (high OBA) substrate comparison

Figure 11 shows the color appearance of the N4A image in the high OBA printing condition (upper center) and the three color-managed proofs (pfL, pfM, pfH). The low OBA and low L^* proof is not able to match the white border of the high OBA print.

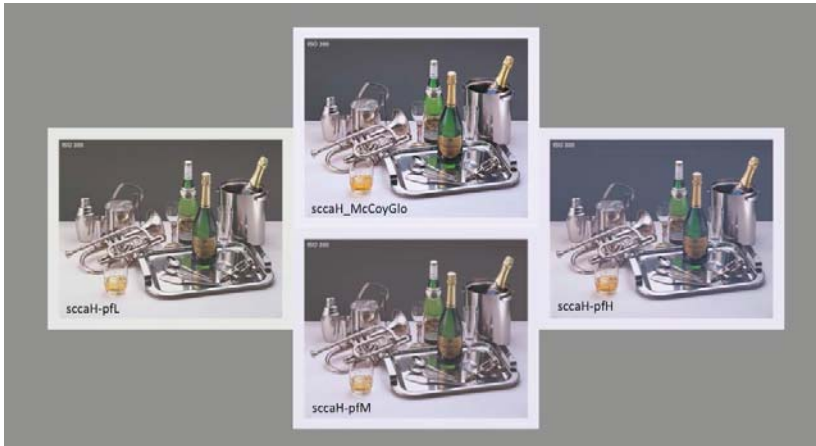


Figure 11. Visual simulation of proof-to-high OBA print match

Figure 12 illustrates the quantitative color differences between each of the three color-managed proofing conditions and the high OBA (McCoy Gloss) printing condition. Gamut clipping, due to low L* and low OBA of the proof, causes color mismatch between proof and print.

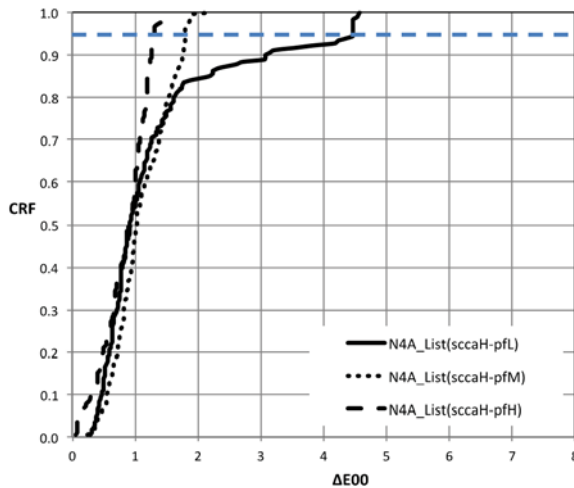


Figure 12. Quantitative color differences between each of the three proofs and the high OBA print

Discussion and Conclusion

This research uses simulation to test limited use cases where OBA amount of the printing and proofing substrates vary widely (0.6~10), and CIE-L* vary to some degree (93~95). The following issues are of interest for further discussion.

1) ΔE_{00} , OBA, and pictorial color matching

ΔE_{00} metric, in the form of a distribution, is indicative of the pictorial color difference between two color images. There is no visual difference when ΔE_{00} at the 95th percentile of the distribution is 1 ΔE_{00} . As ΔE_{00} value at the 95th percentile of the distribution increases, the probability of the visual difference increases. Many assignable causes, e.g., the scene of the image, color mapping, gamut clipping, and measurement uncertainties, contribute to the color difference.

Both ΔL^* and Δb^* between two substrates cause gamut clipping that contribute to the ΔE_{00} magnitude and influence the visual match between a proof and a print. The experimental findings indicate that high OBA proofs can match low OBA prints quantitatively, but low OBA proof or low L^* proof cannot match high OBA and high L^* print due to gamut clipping.

Figure 13 shows that the gamut of the high OBA printer color space (solid) is outside of the low OBA proofer color space (wireframe). In this instance, the proofer is unable to render the bluish white point of the printing paper and light cyan section of the printer color space.

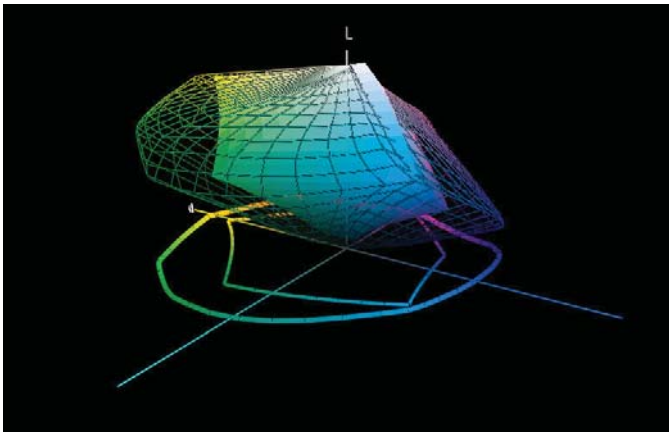


Figure 13. Gamut clipping between the low OBA proofer space and the high OBA print space

2) ΔOBA and the viewing illumination

The M1 simulation assumes that the fluorescent effect, “detected” by the measurement and “seen” in the viewing light source, are equal. In reality, the match between high OBA proof and low OBA print depends more on the viewing light source than the match between low OBA proof and low OBA print. Therefore, ΔOBA (between a proof and a print) is indicative of the criticalness of the M1 lighting, i.e., the match becomes more metameric when ΔOBA increases.

- 3) Below is the guideline for implementing the M1 workflow to match OBA-loaded prints:
- a) Viewing and color measurement are in M1 compliance.
 - b) Printing is calibrated to the substrate-corrected dataset.
 - c) Proofing system has adequate selection of proofing substrates and capable of proofing to the substrate-corrected dataset. In addition, the proofing substrate has adequate “head room” to avoid gamut clipping, i.e., a proofing substrate should have a slightly larger L^* value (no higher than $2 L^*$) and a larger OBA value (no higher than 5 OBAS) than the printing paper (Figure 14).

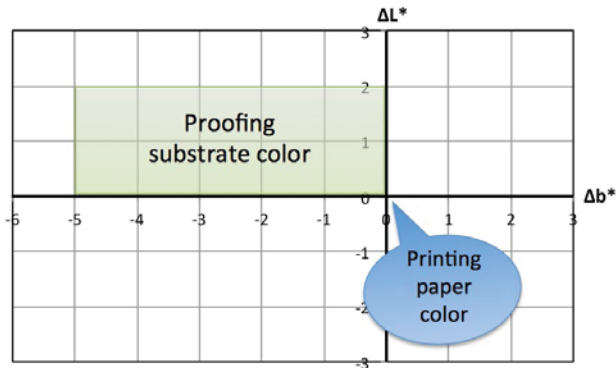


Figure 14. Proofing substrate selection criteria

Further Research

Printing and proofing require resources (ink, paper, plate, press). It takes time and effort to reproduce the output. Yet, there is no guarantee that they can be reproduced dead centered at the bull’s eye. When printing and proofing are simulated, it saves resources and simulates the results accurately. While simulation is an effective approach to study proof-to-print color match, it assumes that the opacity, gloss, and surface texture of the substrates are the same. It is recommended that the simulation techniques be used to test more use cases and verified by actual printing and proofing systems.

Quantitative simulation of printing and proofing conditions may be improved if the pixelated image contains scene-dependent colors and information regarding color gamut of the device. It is recommended that the first row of the pixelated image be replaced with the following 15 color patches: C100, M100, Y100, K100, R, G, B, Paper, C50, M50, Y50, K50, C50M40Y40, C25M19Y19, and TAC400 (Figure 15).

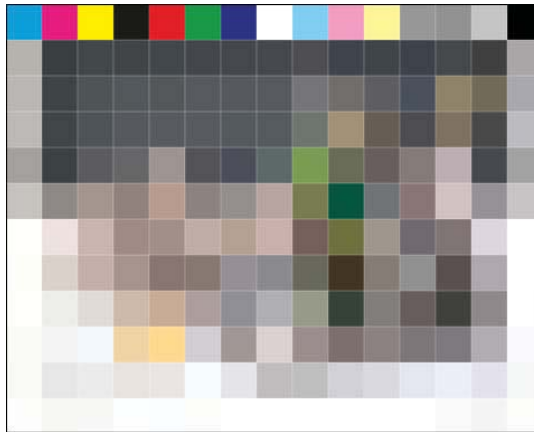


Figure 15. A pixelated image with gamut patches

The simulation, based multiple application software packages (Adobe Photoshop, CHROMiX ColorThink Pro 3, Microsoft Excel, and Microsoft PowerPoint), is manual and tedious. Automation is highly desired when testing more substrate conditions and SCID images.

Acknowledgments

The author wishes to acknowledge Mr. Bruce Bayne, Alder Technology, Inc., OR, for providing the proofer ICC profiles with varying OBA to support the research; Mr. Steve Upton, CHROMiX, for providing ColorThink Pro 3 software. He also wishes to thank Mr. Mike Rodriguez for his advice and review of the manuscript.

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