Digital Proofing with ICC CMS

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Abstract: The ICC color management system (CMS) has become a major tool for color image rendering and color matching in the printing and publishing industry. It attempts to automate color management functions, e.g., from scan to print, and from press sheet to proof, with the use of device profiles, Color Management Module (CMM), and application programming interface (API).

Earlier studies on CMS performance have shown that ICC-based digital proofing does not perform better than a well calibrated film-based proofing system, in terms of delta E assessment. There are many sources of error in a digital imaging work flow. The source of errors include instability of imaging materials, device inconsistency, and the color gamut mismatch between devices. In addition, errors can come from profile generation and the performance of CMM.

This paper describes a strategy for evaluating digital proofing performance under optimal testing conditions. Instead of conducting press runs, we use the ANSI CGATS TR 001-1995 – Type 1 reference printing condition as the source, and, hence, the published input ICC profile. Before we accept the Epson SC3000 as the digital proofer, we (1) tested the stability of the ink jet paper used, and (2) compared the color gamut

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differences between the Epson and the TR 001. The destination (proofer) profile was, then, built using the Kodak Colorflow ProfileEditor. To simulate the digital proofing effect, the IT8.7/3 basic data block, a standard TIFF (CMYK) file, was converted from source (press) to destination (proof) in Photoshop 5.0 API using ColorSync 2.6.1 and the Kodak CMM. The IT8.7/3 basic target of the ink jet proof, containing 182 patches, was measured colorimetrically (D50, 2 degree) and compared to ANSI CGATS TR 001-1995 – Type 1 Printing (SWOP) data. The average delta E between the digital proof and the CGATS TR 001 reference data set was 3.7 delta E (as opposed to 6-9 delta E reported previously.) This experiment demonstrates a significant improvement over previous research findings. The improved digital proofing performance of the ICC workflow was due to the elimination of the press variability, the use of a stable digital proofing device with a sufficiently large color gamut, and the use of improved ICC profiling and color management tools.

Introduction

The technology used in printing and publishing attempts to closely duplicate the original colors to the final reproduction. There are two approaches: closed-loop color and open-system color. In closed-loop color, the color reproduction characteristics of the output device are used to make scanner settings (see Figure 1). In order to achieve a general agreement between shop and client, standards and specifications were set by industry committees. Specifically, standardized inks and substrate, and other specifications were set to achieve consistent color among color reproduction. A scanned image is used for a specific printing process. The image needs to be scanned again under another set of scanner settings for the other output device. For instance, images scanned for offset printing cannot be used for gravure printing.

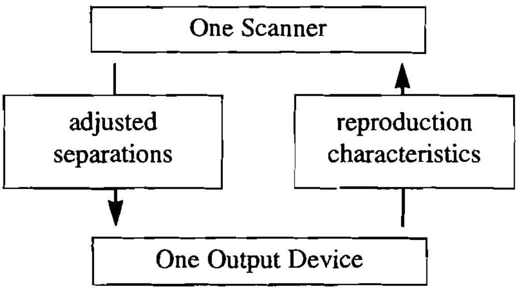

Figure 1. Closed-loop color

In open-system color, a device-independent color space, or profile connection space (PCS), is used as an intermediate step. Any individual peripheral device, using this device-independent color space, is independent of other devices. A scanned image with its input profile can be printed by different output devices as long as there is an output profile for the device (see Figure 2). Specifically, a system of color reproduction in which input and output devices are characterized using device-independent color space, allows color matching among multiple devices.

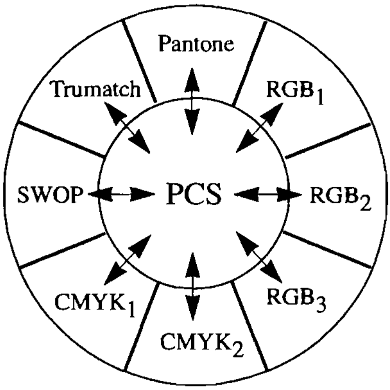

Figure 2. Open-system color

Breakthroughs in digital imaging technology have dramatically changed the infrastructure of the graphic arts industry in recent years. Increasing use of desktop scanners, on-demand printing and computer-to-plate, use of digital proofing, and the adopting wider printing specifications enforced printing industry form closed-loop color to become open-system color, or from device-dependent to become device-independent. The color management system (CMS) was therefore developed to meet the needs. The concept of open-system color was then able to be fulfilled.

CMS attempts to automate color management functions, e.g., from scan to print, and from press sheet to proof, with the use of device profiles, a CMM, and an application programming interface. Earlier studies, conducted at RIT, showed that ICC-based digital proofing did not perform better than a well calibrated film-based proofing system. Specifically, the average delta E between ICC color managed proofs and a reference press sheet was found to be 6~9 while the average delta E between a film based proof and its correspondence press sheet was 5.

Realizing that sources of delta E errors exist in many places, e.g., printing consistency, proofer's color gamut, proofing consistency, measurement conditions, this paper discussed an improved methodology for testing the performance of color matching in a digital proofing workflow. The source profile was a SWOP press profile, supplied by Kodak, which characterizes the ANSI CGATS TR 001-1995 – Type 1 Printing condition. The destination profile was built from an Epson SC3000 ink jet printer using the Kodak Colorflow ProfileEditor at the printer's default color gamut. The IT8.7/3 basic target (CMYK) was transformed with the use of the Mac OS, ColorSync 2.6.1, Kodak CMM, and Adobe Photoshop 5.0.2, and output to the EPSON SC3000 ink jet printer.

The objective of this study was to investigate whether a color management system enabled EPSON SC3000, which had sufficiently large gamut, to simulate the SWOP color. Only colorimetric consistency based on CIELAB terms was evaluated. Visual differences could not be accessed because the reference printing conditions were expressed as a data set, and this data set was derived from an average of six actual printed sheets. There was no single example directly related to the data set. As a result, color differences were displayed as delta E values in the study. By doing so, we also investigated if there was a significant difference amongst the following two testing methods:

M1 EPSON SC3000 in default condition
M2 EPSON SC3000 in default condition with CMS compensation

Hypothesis

The hypothesis has been tested is stated below:

> There is no significant difference between M1 and M2 when comparing the SWOP reference in colorimetric CIELAB delta E values.

Limitations

Noise during the processes can usually directly impact the CMS's performance. In addition, the result can vary if a different color management profiling software or a different CMM is selected. This experiment was only tested under the following conditions:

1. Printer: EPSON Stylus COLOR 3000 ink jet printer
2. Printer driver: EPSON StylusRIP

3. Paper: DuPont/Epson Commercial Proofing paper (Super A3/B)
4. Target: IT8.7/3 basic color characterization target (182 patches)
5. System-based CMS: ColorSync 2.6.1
6. Profiling software: Kodak Colorflow ProfileEditor 2.0
7. Color matching module: Kodak CMM
8. API: Photoshop 5.0.2
9. Pagination software: QuarkXPress 3.32
10. Measuring instrument: Gretag SpectroScan system

Delimitation

The scope of this study was limited to a given proofer condition. An absolute rendering method was used for the color conversions from one CMYK to another CMYK space. Experimental errors and their impacts were not investigated separately.

Methodology

Stability and repeatability are always key elements within an experiment. A device consistency test was conducted with multiple samples printed in a month was investigated. A material stability test with one selected sample for the issue of ink and paper fade was tested. Both tests were done prior to performing the main experiment. The same ink cartridges and settings were used through the entire study.

1. Device consistency test
An 8.5" x 11" (letter size) page in QuarkXPress 3.32 was created. An IT8.7/3 basic target, an indication of the printing date, time, and a description with the proofer settings were placed within the page. This test page was saved, and then printed by EPSON SC3000 with its StylusRIP driver. All the settings were recorded. Thirty samples were printed in a month; one or two were performed from each day. The IT8.7/3 basic target form all thirty samples were measured and recorded in an Excel workbook.

2. Material stability test
The same test page (as step 1) was used to perform the material stability test. The IT8.7/3 basic target of the printed sample was measured and recorded in an Excel workbook seven time: right after printed, 30 minutes, one, two, four, eight, and twenty-four hours after printed. Delta E of the four process colors (cyan, magenta, yellow,

and black), paper, and an average (based on all 182 patches of IT8.7/3) were calculated based on the first measurement.

3. Hypothesis testing
The first part of this experiment was to create a 8.5" x 11" (letter size) page in QuarkXPress 3.32. IT8.7/3 basic target ($CMYK_1$) and a description of the settings were included in this page. This test form was sent to EPSON SC3000.

A SWOP ICC profile was provided by Eastman Kodak to be used as a source profile. Kodak Colorflow output characterization target (TIFF format) was printed with the same condition as previous tests. The target was measured and used by the Kodak Colorflow ProfileEditor software to generate another ICC profile. Both ICC profiles were applied to the IT8.7/3 basic target ($CMYK_1$) under Photoshop 5.0.2 environment. The modified target ($CMYK_2$) was saved as a TIFF file, and then printed to EPSON SC3000 via QuarkXPress 3.32.

Data Collection

The IT8.7/3 basic target in the sheets printed from all methods were measured by a Gretag SpectroScan system in CIELAB values. Colorimetric data were measured under the condition of the CIE illuminant D50 and the 2 degree standard observer (ANSI CGATS .5-1993) with a black backing. The SWOP reference, which the IT8.7/3 has been defined in ANSI CGATS TR 001-1995 in colorimetric terms, was taken as reference. IT8.7/3 basic target containing 182 color patches at all printed proofs were measured and recorded in Microsoft Excel 98. The final color differences were made from the comparison of the reference and the the measured data in delta E terms.

Results

Assessment of EPSON SC3000 Device Consistency

To perform the consistency test, thirty color samples containing IT8.7/3 basic color characteristic targets (182 patches) were printed by the EPSON SC3000 in a month. One or two samples were generated each day. The IT8.7/3 targets of all proofs were immediately measured with a Gretag SpectroScan system right after the proofs were made. The result was thirty sets of colorimetric data in CIELAB values (D50, 2 degree) recorded in a Microsoft Excel workbook. A reference data set was achieved by averaging the value of L*, a*, and b* of each color patch of the thirty samples.

From comparing all the thirty samples to the reference respectively, the results were thirty sets of 182 delta Es, or a total of 5460 delta Es. By averaging the 182 delta Es of each sample, there was a result of 30 average delta Es which represented the performance of each sample (see Figure 3.) By doing so, there were 30 standard deviations also derived for each sample.

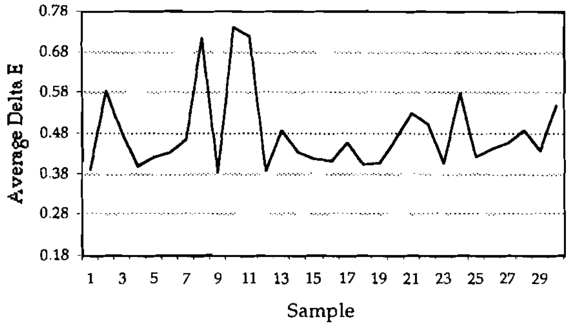

Figure 3. Average delta Es over the 30 printed samples

Of the 30 samples, there were three (#8, #10, and #11) with sufficiently larger average delta Es or larger standard deviations than the others. Within the three samples, there were 38 patches (6.96% out of 546 patches) which had a 2 delta E or higher (Max delta E of 4.43). In the remaining twenty-seven samples, there were only five patches (or 0.10%) with a 2 delta E or higher (Max delta E of 2.65) (refer to Table 1.) From the general statistics, it actually did not show a significant difference in average delta Es with and without accepting the three samples, but did significantly in the standard deviations. An average delta E of 0.45 with a standard deviation of 0.28 without taking the three error samples (#8, #10, & #11) into account, and an average delta E of 0.48 with a standard deviation of 0.36 with all thirty samples were established. The average delta E of 0.45 is fairly small comparing any two press runs (which is about 2 to 4). Therefore, the EPSON SC3000 is a very consistent device was concluded. The delta E 0.45 was, therefore, taken as a testing criteria of the hypotheses testing.

Table 1. General statistics for EPSON SC3000 consistency test

	All 30 Samples	w/o #8, 10, 11*
Total Patches	5460	4914
Average Delta E	0.48	0.45
Standard Deviation	0.36	0.28
Maximum Delta E	4.43	2.65
Minimum Delta E	0.02	0.01
Patches with Delta E > 1	346	215
Percentage	6.34%	4.38%
Patches with Delta E > 2	42	5
Percentage	0.77%	0.10%

* The reference of this data analysis to be compared with and then generated delta Es from was by averaging the 27 samples but not the three error samples.

In order to achieve better process control, it was imperative to verify what the possible causes of the errors could be. It was found that these three color proofs were the first or the second output of the day, and the EPSON SC3000 had a long rest for 24 hours or longer prior to making these proofs. Based on this finding, there was no other output accepted for the thesis study if it was the first or the second print-out of the day.

Assessment of EPSON SC3000 Material Stability

Since colors of an ink jet output rapidly fade as soon as the inks were drawn down to paper, it is imperative to find a period of time which offers a minimal change in color appearance in order to build an accurate profile for EPSON SC3000 (refer to a recommendation by Mr. Wilson Cheung at Dupont). Therefore, there was an output stability test performed. A selected color proof with the IT8.7/3 target was measured seven times in 24 hours. Delta E of the four process color ramps, paper, and an average (based on all 182 patches of IT8.7/3) were calculated based on the first measurement.

From there, a chart with six curves was created and analyzed (see Figure 4.) There was a sufficient delta E difference found in the first two hours, and a minimal between two to eight hours. This suggested that there should not have any profile built in the first two hours; and any information derived from that period of time was not good for data analysis. However, two to eight hours has appeared to be the best time for taking measurements.

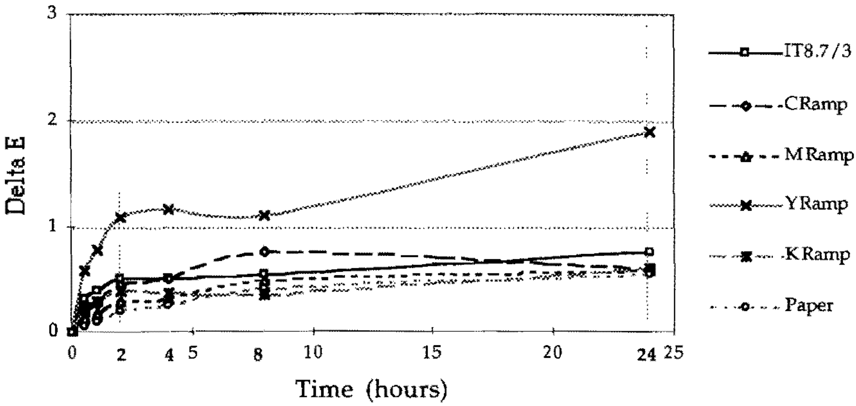

Figure 4. Color stability over time (within 24 hours)

Typically a proof's life is about two to three weeks. Therefore, another long term color variation test was conducted to evaluate the Epson SC3000 color proof's life. The sample was exposed in a viewing booth continuously for two weeks. Only the paper and CMYRGB solid color patches were evaluated. It was found that cyan had the largest delta E (refer to Table 2.). However, it was still within the acceptable range (delta E of 4).

Table 2. Long term color variations over two weeks

	Timing	L*	a*	b*	ΔE	Remark
Cyan	Initial	42.01	-24.72	-61.69	---	
	2 weeks	42.45	-27.37	-59.73	3.33	Greener
Magenta	Initial	49.38	82.49	10.58	---	
	2 weeks	49.09	82.62	9.33	1.29	Bluer
Yellow	Initial	87.00	10.27	105.69	---	
	2 weeks	87.16	9.10	103.19	2.76	Less yellow
Blue	Initial	17.26	28.88	-56.94	---	
	2 weeks	17.17	29.17	-57.68	0.80	Bluer
Green	Initial	40.58	-65.34	21.53	---	
	2 weeks	41.44	-67.58	20.87	2.49	Greener
Red	Initial	53.37	73.54	57.31	---	
	2 weeks	53.04	73.39	56.55	0.84	Less yellower
Paper	Initial	96.48	2.08	-5.82	---	
	2 weeks	96.14	1.87	-4.39	1.48	Yellower

Testing of Hypothesis

Method One EPSON SC3000 in default condition

Method Two EPSON SC3000 in default condition with CMS compensation

In the hypothesis, the color performance of EPSON SC3000 with and without CMS, under the default condition, were investigated. The null hypothesis was that there is no significant difference between Method One and Method Two in colorimetric CIELAB delta E values. The delta Es were derived from L*, a*, and b* values (D50, 2 degree), between the SWOP reference (ANSI CGATS TR-001-1995 – Type 1 Printing) and EPSON SC3000 color proofs.

Two sets of data which represented the two methods were analyzed. A t-Test of the hypothesis that the data from Method One and Method Two belonged to the same distribution was conducted (see Table 3.) Spot checking of the results showed that a large number of points were significantly different at the > 90% probability level. This showed that the data from the two color proofs actually represented two different populations. Looking at the data, since t Stat was positive, Method Two with CMS compensation did provide smaller delta Es than Method One without CMS. A histogram (absolute frequency and cumulative relative frequency or CRF) of the delta E distribution of the two methods is shown in Figure 5.

Table 3. t-Test: Paired Two Samples for Means

	Method One	*Method Two*
Mean	14.62340189	3.625360038
Variance	26.38557017	6.853639535
Observations	182	182
Pearson Correlation	0.273989972	
Hypothesized Mean Difference	0	
df	181	
t Stat	29.17098437	
P(T<=t) one-tail	1.24965E-70	
t Critical one-tail	1.286246061	
P(T<=t) two-tail	2.4993E-70	
t Critical two-tail	1.653315849	

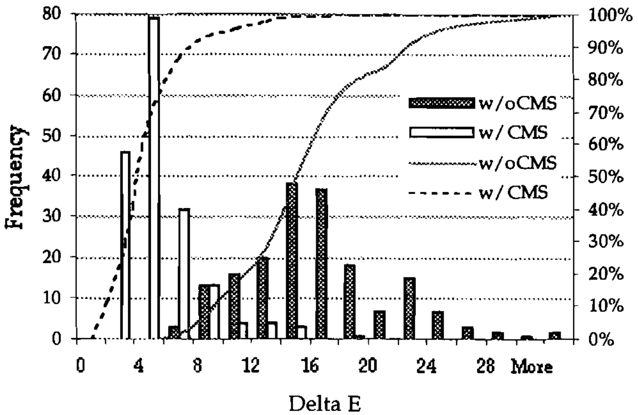

Figure 5. Histogram of Delta E values of Method One & Method Two

Of the two sets of 182 delta Es, an average delta E of 14.62 without CMS and an average delta E of 3.63 with CMS were found (see Table 4.) There were 179 patches (98.35%) which had a 6 delta E or higher and 130 patches (71.43%) with a 12 delta E or higher (Max 32.88 delta E) from Method One. It was found that Method Two had a total of 25 (13.74%) which had a 6 delta E or higher and a total of 4 patches (2.20%) with a 12 delta E or higher (Max 17.10 delta E). Since the two color proofs actually represented two different populations and the average delta E difference of 10.99 was greater than the testing criteria 0.45, that Method Two had better proof-to-SWOP agreement than Method One was concluded. Therefore, the null hypothesis was rejected.

Table 4. General statistics of Method One & Method Two

	Method One	**Method Two**
Total Patches	182	182
Average Delta E	14.62	3.63
Standard Deviation	5.14	2.62
Maximum Delta E	32.88	17.10
Minimum Delta E	4.78	0.49
Patches with Delta E > 6	179	25
Percentage	98.35%	13.74%
Patches with Delta E > 12	130	4
Percentage	71.43%	2.20%

Looking at the a*b* hexagon diagrams (Figure 6.), the gamut of Method One (EPSON SC3000 in default condition without CMS) was sufficiently larger than the SWOP reference. In other words, the EPSON SC3000 was capable of reproducing SWOP colors within its limit (only 256x256x256 colors for 8-bit color). It was also found that there was significant color shift in the high density area of cyan, magenta, and yellow colors. This situation was improved using the CMS. A significant improvement shown in gamut mapping and in color corrections of the three colors was observed.

Note: Solid gray line represents SWOP reference, dotted line does of Method One, and solid black line does of Method Two

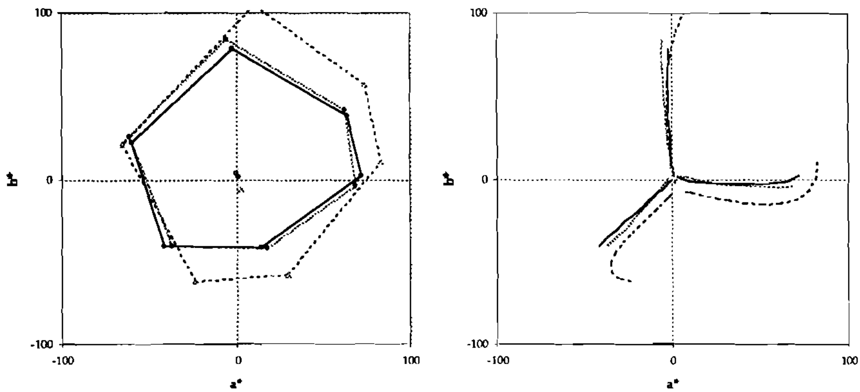

Figure 6. a*b* diagrams of SWOP reference, Method One, and Method Two

Further Finding and Discussion

Tone Reproduction and Chroma Ratio Analysis

The two methods were also analyzed for tone reproduction and chroma ratio against the SWOP reference (see Figure 7.) All 182 color patches of the IT8.7/3 basic target were used to test for the tone reproduction, however, only C*s of 40 or greater (based on the SWOP reference) were sampled for the chroma ratio analysis. The results showed that Method One tended to print lighter in highlight areas and darker in shadow area. By contrast, Method Two was very accurate through the entire section. It was also found from the chroma ratio analysis that the Epson SC3000 provided much more saturated colors than the SWOP reference (Method One). However, Method Two was fairly precise in reproducing C*s.

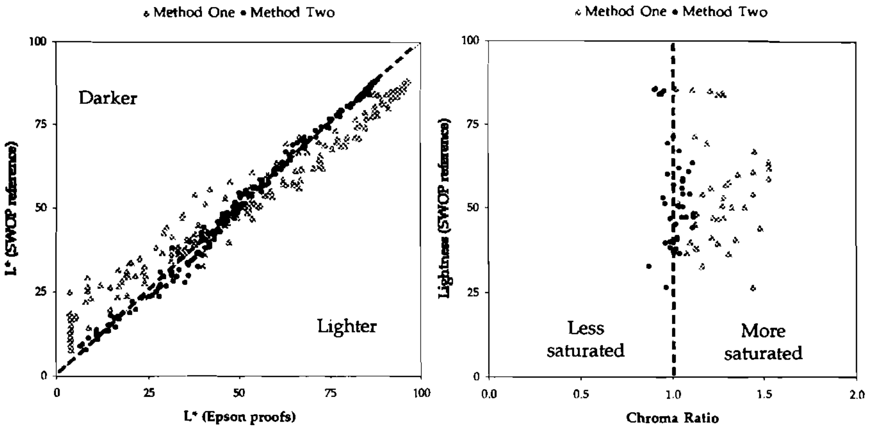

Figure 7. Tone reproduction and chroma ratio chart of Method One without CMS and Method Two with CMS

L*–C* Diagram

Although the a*b* hexagon diagram (shown in Figure 6.) illustrates that the Epson SC3000 has larger default gamut than the SWOP reference in a two dimensional color space, it does not mean that Epson was capable of reproducing all colors in a three dimensional color space. Therefore, L*–C* slices of RGB and CMY were investigated for another aspect (refer to Figure 8. on the following page). Be aware that the L*–C* diagrams were not generated from measuring actual printed samples, but were simulated with ICC profiles via Photoshop 5.0.2. This method has offered a best estimate of the printable color space of each condition based upon the ICC profiles.

In general, Epson SC3000 in default condition covers the SWOP reference very well in L*–C* dimension from midtone to highlight. However, there are some problems in mapping the shadow area for magenta, yellow, red, and green. This phenomenon is due to the fact that Epson SC3000 does not print black but only cyan, magenta, and yellow three colors for color images. In other words, the Epson SC3000 converts CMYK information to CMY data with its own black-box. Problems occur as the conversion of CMYK to CMY is rendered from highly saturated color with large amount of black over-print.

Note: Dotted lines represent L*–C* chart of SWOP reference, solid lines represent Epson SC3000 in default condition

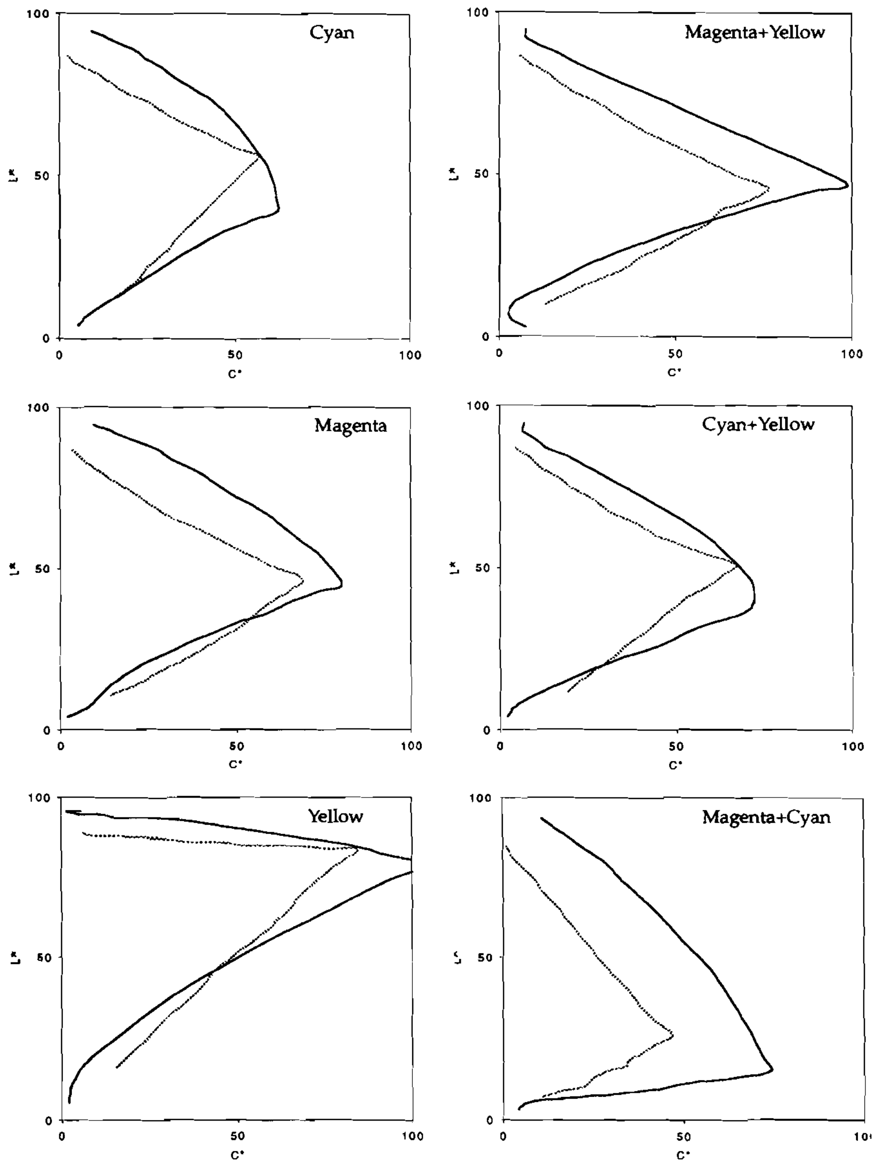

Figure 8. L*–C* slices for the SWOP reference, Epson SC3000 in default condition, and Epson SC3000 in default-to-SWOP condition

Summary

The purpose of this study was to answer whether ICC-based CMS with currently available CMS software would help a sufficiently large gamut digital proofer to simulate the SWOP reference (ANSI CGATS TR 001-1995 Type 1 Printing). To test this question, two methods were proposed:

Method One EPSON SC3000 in default condition

Method Two EPSON SC3000 in default condition with CMS compensation

The results of the testing methods are shown in Table 5.

Table 5 Result of the two testing methods

Method	Description	Average Delta E
Method One	Default w/o CMS	14.62
Method Two	Default w/ CMS	3.63

The hypothesis which has been tested was:

> There is no significant difference between Method One and Method Two when comparing the SWOP reference in colorimetric CIELAB delta E values (D50, 2 degree). Rejected

There were 182 delta Es derived from each testing method. A total of two sets were generated for the hypotheses testing. The two sets of data which represented the two methods for the hypothesis testing were analyzed. The t-Test of the hypothesis that the data from the methods belonged to the same distribution was conducted. Spot checking of the results showed that a large number of points were significantly different at the > 90% probability level for the hypothesis. The results showed that the data from the two color proofs actually represented two different populations for the hypothesis. In other words, there was a significant difference between Method One and Method Two, comparing to the SWOP reference in colorimetric CIELAB delta E values (D50, 2 degree). Therefore, the hypothesis was rejected.

This study has successfully brought the average delta E inside of 4 between the color proof and the SWOP reference. It was contributed to the ANSI CGATS TR 001-1995 Type 1 Printing data set and to the consistent output of the EPSON SC3000. It was also found that the CIE a*b* plot was not able to represent the color gamut of any device since it fails to provide a three-dimensional perspective. Additional findings and conclusions of the study are stated below:

1. The EPSON SC3000 is a very stable device (an average delta E of 0.45 with a standard deviation of 0.28) when comparing any two press runs (which has about 2 to 4 delta E).

2. The EPSON SC3000 generates color proofs that fade over time. Color differences become apparent when comparing the first measurement (right after printed) to a period of 24 hours and three weeks, respectively, are 0.76 delta E and 1.42 delta E. While the color difference impacts the color matching experiment, its magnitude is well within the tolerance of most proofing systems.

3. Digital proofer with CMS performs better than without CMS. It is evident that CMS with the current available technologies does help a sufficiently large gamut digital proofer simulate the SWOP reference (ANSI CGATS TR 001-1995 Type 1 Printing).

4. The use of CMS results in accurate control of tone reproduction. If the color gamut of the output is less than the color gamut of the source, as evidenced in the L*C* plots, this will result in lost of saturation.

Further Research

We plan to conduct a full-scale color management study involving press calibration, profiling, color managed press run from scanner to press, and digital proofing. This will provide visual assessment of pictorial images between press sheets and digital proofs. In addition, we plan to further refine our color matching analysis, with the use of cumulative relative frequency (CRF) vs. delta E, between proofs and press sheets.

Acknowledgements

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