Spot Color Matching in ICC Color Managed Workflows

by Seunga Kang Ha

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Introduction
When creating a file for color matching, there are several different color spaces to use in Adobe Photoshop: RGB, CMYK, LAB. These modes are related to the designated device such as printer or computer monitor. Traditionally, prepress has been based on CMYK workflow. However, CMYK workflow has some limitation as a device-dependent workflow. The output from a digital camera very often is some sort of RGB. Printer uses CMYK inks. Somewhere between camera and printers, there needs to be a RGB-to-CMYK conversion. Color managed systems do this conversion using input and output profiles which can be generic or custom made. Workflows where the CMYK conversion is made near the input stage are called CMYK workflows. Workflows where the CMYK conversion is made near the printing device (RIP) are called RGB workflows. From the aspect of workflow, RGB-based workflow can support both affordability and flexibility, if the RGB-based workflow has a set of generic color space such as Adobe 1998 in Adobe Photoshop. Thus it is necessary to learn the capability of RGB workflow from the aspect of output.

Objectives
In this study, RGB workflow is defined as a file created in RGB space in Photoshop and sent to an Epson inkjet printer. CMYK workflow is defined as a file that is created as CMYK space and sent to the same printer. The Epson RIP can accept either RGB or CMYK input. The purpose of this experiment is to determine the spot color matching performance between RGB-based workflow and CMYK-based workflow.

Procedures
To compare workflows, the following steps were taken.

1. **Sample preparation for reference**
   Five physical samples of spot color are selected from paint chips. The colors selected are: neutral gray, blue, green, yellow, and orange. CIELAB values of each sample are measured five times. The median value is selected as the reference (see Table 1).

Reference	L*	a*	b*
Neutral Gray	81.39	-0.43	3.88
Green	55.25	-58.96	21.72
Blue	43.41	-7.33	-47.42
Yellow	79.28	22.04	85.21
Orange	58.23	56.05	69.14

Table 1. CIELAB value of reference.

2. **Printer profiling**
   Profiling targets are printed on Epson Stylus 5000 Inkjet Printer, and the profiles were generated by GretagMacbeth ProfileMaker 4.1. There are two different output profiles created: one is CMYK output profile, and the other is RGB output profile.

3. **ICC-based color workflow**
   Three RGB workflows and one CMYK workflow were investigated as shown Fig.1. For RGB_1 workflow, the file is set to RGB mode, and the RGB setting was Adobe (1998), then RGB space was converted to RGB output profile with absolute colorimetric intent. For RGB_ 2 workflow, the procedure is the same as RGB_ 1 workflow but it has relative colorimetric intent. For RGB_ 3 workflow, the file is set to RGB mode, and the RGB output profile created by using GretagMacbeth ProfileMaker 4.1. For CMYK workflow, the file is set to CMYK mode, and CMYK output profile was also generated by GretagMacbeth. To implement each of the four above mentioned workflows, RGB and CMYK files are created separately, because each workflow has a different starting point. Then, the CIELAB value of the references was entered using the Color Picker in Photoshop (B-to-A conversion).

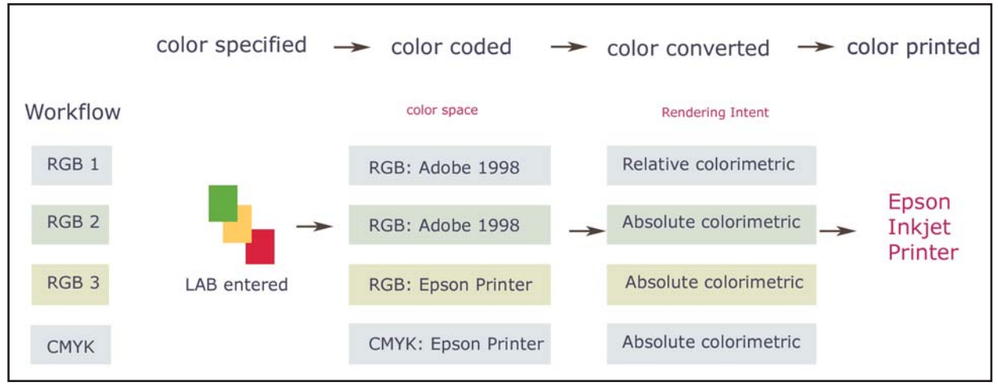

Figure 1. RGB-based workflow vs. CMYK-based workflow.

4. **Reproduction of color samples**
   After all files are made, they are sent to print to the Epson Stylus 5000 Inkjet Printer. In the printer, 'simulation off' was set, and Epson RIP is used. To verify consistent color reproduction, three sheets were printed from each of the four workflows.

5. **Measurement of CIELAB values**
   To evaluate the accuracy of color matching, the CIELAB values of the color samples of the outputs were measured. An X-Rite 500 series spectrophotometer is calibrated. In each workflow, three sheets were printed, and each color sample is measured five times. Thus, the number of measurements per sample is 15.

6. **Visual assessment**
   After measuring CIELAB value of all samples, 10 observers took the paired comparison test for color matching between sample and reference under standard viewing condition. In this study, there are four different prints. Thus, six pairs are made for the test.

Results
Results will be given by looking at in-gamut and out-of-gamut color in Adobe Photoshop.

1. **In-gamut and out of-gamut color in Photoshop**
   To produce color samples equivalent to reference, CIELAB value of reference is entered. Out of five colors, yellow and orange is out of the printer's color gamut, while neutral gray, green, and blue are in-gamut colors as seen in Table 2. Thus, the gamut warning icon is clicked in yellow, and orange and the CIELAB value is recalculated. When CIELAB values were entered, B- to- A ICC tag was used for color conversion, and when CIELAB value is recalculated, A-to-B ICC tag was applied. For the analysis of color samples, yellow and orange colors are excluded, because they are not reproducible.

Color	B to A			A to B			ΔE
	L*	a*	b*	L*	a*	b*	
Neutral Gray	82	0	4	82	0	4	0.0
Green	55	-59	22	55	-59	22	0.0
Blue	44	-7	-48	44	-7	-48	0.0
Yellow*	80	22	85	77	20	77	8.8
Orange*	59	57	70	59	50	56	15.7

* Yellow and Orange are out -of- gamut colors

Table 2. Color Conversion

2. **Color matching using measurements**
   To compare workflows, ΔE between reference and output printed through different workflows was analyzed. Table 3 and 4 shows the spot color matching in terms of ΔE.

RGB_ 1 workflow
This workflow performs well on color matching considering average ΔE (ΔE=2.3) in Table 4. In the result, RGB_1 can be ranked as the first with neutral gray (ΔE=1.1) and blue (ΔE=2.0) having low values. However, it has different background because the white point from source D65 in Adobe (1998) space and destination RGB space D50 in Epson SP5000 inkjet printer differ.

RGB_ 2 workflow
In this workflow, relative rendering intent is applied, because the bluish background should be eliminated. But the accuracy of color matching performance is very poor in ΔE (ave. ΔE = 12.8).

RGB_ 3 workflow
It performs well on color matching considering average ΔE (ΔE =2.4). Neutral gray (ΔE=0.8) and blue (ΔE=2.9) show the lowest value.

CMYK workflow
In CMYK workflow, the average ΔE is 3.4 and all three colors of ΔE is around 3 as shown Table 4.

To find out how the value of ΔE can differentiate to human, the test for the visual assessment was followed.

Workflow	ΔE's			Ave
	L*	a*	b*	
RGB_1	1.1	3.8	2.0	2.3
RGB_2	10.4	12.2	15.7	12.8
RGB_3	0.8	4.5	1.9	2.4
CMYK	3.2	3.8	3.2	3.4

Table 3. ΔE Difference in Workflow

Patch	Reference			Workflow	Sample (Average)		
	L*	a*	b*		L*	a*	b*
Neutral grey	81.39	-0.43	3.88	RGB_1	82.22	-0.73	4.45
				RGB_2	75.57	4.16	11.12
				RGB_3	81.93	-0.60	4.11
				CMYK	80.51	-0.73	0.79
Green	55.25	-58.96	21.72	RGB_1	54.94	-55.25	21.08
				RGB_2	52.86	-47.30	24.38
				RGB_3	54.88	-54.53	21.14
				CMYK	54.72	-55.43	20.43
Blue	43.41	-7.33	-47.42	RGB_1	44.04	-9.25	-47.24
				RGB_2	42.69	-6.35	-31.78
				RGB_3	44.14	-8.99	-47.22
				CMYK	43.96	-10.29	-48.38

Table 4. ΔE Difference in Color Patch

3. **Visual Assessment**
   To learn how spot color matching correlates with human visual assessment, 10 observers took the test of paired comparison. Each person examines two prints with different workflow at a time, and decides which one he/she thinks is a better matching to the reference. This test is referred to as the paired comparison test of print quality (Bob Chung, 2003, the lecture of Color Perception and Measurement). For this test, a judge can be inconsistent with themselves.
   Consistency need to be tested, because it helps to determine that the difference in ΔE are significant to the observer or not. Inconsistency could be an indication that the differences are shown. All judges (10 observers) are consistent for neutral gray. But only 6 judges are consistent for green, and 5 judges are consistent for blue.

Patch	Workflow	Consistent Judge			Inconsistent Judge		
		No.	Ave.	Rank	No.	Ave	Rank
Neutral	RGB_1	10	1.3	3	0	--	--
	RGB_2		0.0	4		--	--
	RGB_3		1.7	2		--	--
	CMYK		3.0	1		--	--
Green	RGB_1	6	1.8	2	4	2.0	1
	RGB_2		0.0	4		0.0	4
	RGB_3		1.7	3		2.0	1
	CMYK		2.5	1		2.0	1
Blue	RGB_1	5	0.2	4	5	1.2	2
	RGB_2		1.6	3		2.2	1
	RGB_3		1.8	2		1.2	2
	CMYK		2.4	1		1.4	4

Table 5. Visual Assessment in Color Matching Performance

In the result, CMYK workflow performs the best color matching for all three colors in Consistent Judge as shown Table 5. This result shows different result of the analysis in ΔE (see Table 4). From the analysis of ΔE and visual assessment, there is no significant difference between ΔE 2 and 3.

Conclusions

RGB- based vs. CMYK- based Workflow
Based on the analysis of ΔEs, RGB_1 and RGB_3 workflows offer small numerical value for average ΔEs. However, for the visual assessment, CMYK workflow shows the best color matching for neutral gray, blue and green for consistent judges. RGB_3 and CMYK workflows are device-dependent workflows. RGB_1 workflow is device-independent workflow by using the Adobe 1998 color space. From the results, device-dependent workflow such as RGB_3 and CMYK workflow has a good capability for spot color matching. Also, device-independent workflow, which is RGB_1 workflow, has possibility of spot color matching, considering an average ΔE of 2.3.

Rendering Intent
The rendering intent from a source with a bluish white to a destination with yellowish-white paper puts cyan ink in the white areas to simulate the white of the original (Fraser, Murphy, Bunting, 2003). With relative colorimetric intent after converting output profiles in RGB_2 workflow, overall color samples look desaturated. Thus, RGB_2 workflow should be avoided for spot-color matching. Among the four workflows, RGB_1 workflow with absolute colorimetric intent has a bluish surround. Therefore, the rendering intent in color management is an important variable for spot color matching.

Further Testing of Color Matching
The concept of RGB workflow usually provides the best matching in the display, while CMYK workflow provides best matching in printed output. This conclusion is based on only three sample colors. More samples need to be looked at to draw better founded conclusions. Today, the concept of workflow should be considered as integrated workflow, which means that it should be applied not only for display but also for printed output. In this study, device-dependent workflow such as RGB_3 and CMYK workflow show best color matching in print. But there is the possibility that RGB_1 workflow has good capability in print. For the further study, the capability in RGB workflows and CMYK workflow should be researched to find out not only the accuracy of printed output but also that of display monitor.

Literature Cited

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