

# COLOR AGREEMENT AMONG EARLY-, INTERMEDIATE-, AND LATE-BINDING COLOR WORKFLOWS

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## KEYWORDS

early-binding, intermediate-binding, late-binding, color management workflow,  $\Delta E$

## ABSTRACT

Color management workflow connects the content/design process and the process/printing process together with the use of digital files, software, and hardware. Color management addresses color image conversion between the source and its destination. Pictorial color images are primarily in RGB color spaces. The scenario where RGB-to-CMYK color space conversion takes place defines different color management workflows. Early-binding workflow performs RGB-to-CMYK conversion in Adobe Photoshop; the intermediate-binding workflow performs conversion during PDF generation; late-binding workflow performs RGB-to-CMYK conversion in the RIP.

This paper examines the color image agreement between early conversion, intermediate conversion, and late conversion quantitatively and visually. Test forms with different color space conversion and a legacy CMYK file were printed on Epson Stylus 4000, Xerox DocuColor 6060, and Kodak NexPress 2100. The results show that: 1) color differences resulting from press variability can be considerably larger than differences due to where color space conversion takes place in the color management workflow; and 2) color agreement between different workflows depends on the similarity of the computational mechanisms of the application interface (API) and the Color Management Module (CMM).

## 1. INTRODUCTION

Color management can make color portable and predictable in various workflows with minimum human intervention. Color management applications make it possible to realize color conversion from input RGB color space to the output CMYK color space on the fly. A color management system allows color conversion to occur at different positions of the workflow. It is

important that color conversion at different scenarios produces the same outcome.

In publication printing, color management can facilitate the agreement of colors between multimedia publications. Different workflows can realize specific objectives and meet special requirements, such as soft proof, digital proof, and production work. Below are the pros and cons of early-binding and late-binding workflows.

## 2. PROS AND CONS OF BOTH EARLY-BINDING AND LATE-BINDING

Early-binding and late-binding color management workflows represent two very different digital color production methods.

### 2.1 EARLY-BINDING WORKFLOW

Publication printing industries, e.g., newspaper and magazine, are accustomed to early-binding workflow. This method dates back to the film-based color separation era whereby CMYK separations were needed prior to film assembly, proofing, platemaking, and printing. Today, early-binding occurs in Adobe Photoshop where RGB images are converted to CMYK (Figure 1). Major advantages of the early-binding method include (a) simplicity in platemaking and printing, and (b) printers are not responsible for color conversion and color proofing (this is the job of prepress houses). On the other hand, major disadvantages of early-binding method include (a) premature gamut clipping, (b) limited to one output device or loss of portability, and (c) increased file size (CMYK file is larger than RGB file).

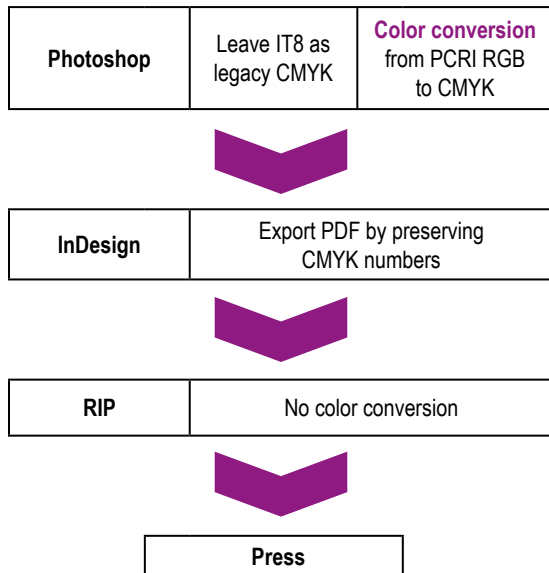


Figure 1. Early-binding workflow.

### 2.2 LATE-BINDING WORKFLOW

The development of digital imaging technology has impacted the photographic industry as much as it has impacted the publishing printing industry, i.e., digital camera with CCD sensors have replaced cameras using silver halide films, and inkjet printers have replaced wet photographic chemistry. Today, RGB images, upon capturing and editing, are sent to inkjet printers directly utilizing the late-binding method (Rodney, 2005). In other words, the printer driver or RIP carries out the RGB-to-printer color space conversion directly (Figure 2). Major advantages of the late-binding method include (a) higher color portability; (b) gamut preserved till the output stage; (c) relatively small file size (RGB file is smaller than CMYK file); and (d) flexibility in cross-media publishing. Major disadvantages of late-binding method include (a) complexities of color spaces that are associated with multiple images within the same document, and (b) uncertainty of color predictability when source images are from multiple locations and output devices are unknown or undefined.

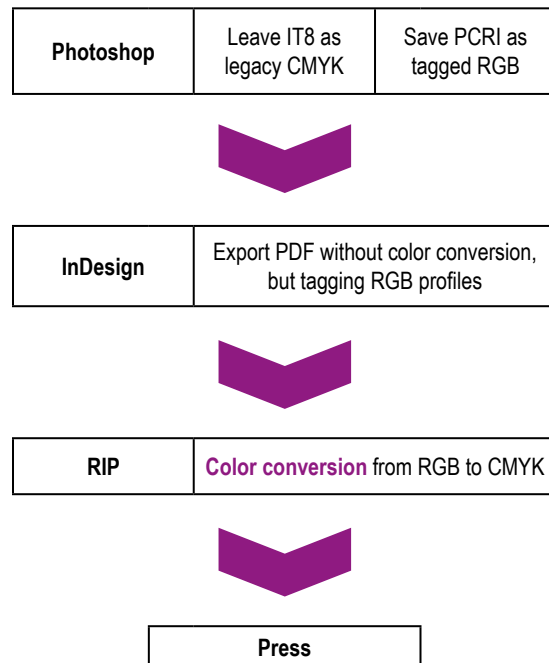


Figure 2. Late-binding workflow.

## 2.3 INTERMEDIATE-BINDING WORKFLOW

As color management technology continues to evolve, it is possible to address color conversion in the middle of the digital color imaging workflow. Therefore, the color management application interface (API) in pagination software, e.g., Adobe InDesign, and API in PDF-based utilities, e.g., Alwan PDF Standardizer, becomes an intermediate-binding workflow enabler (Alwan Color Expertise, 2008). See Figure 3.

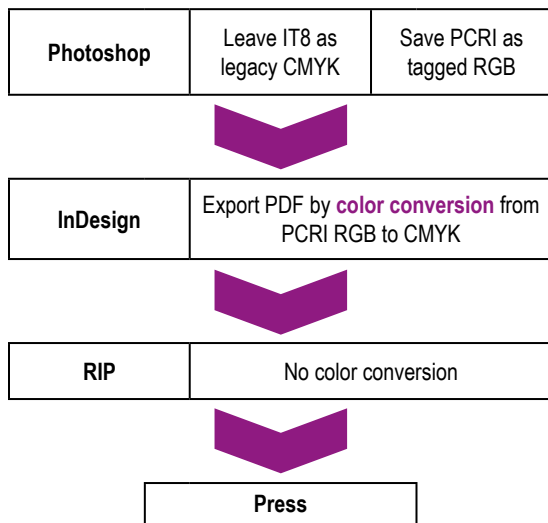


Figure 3. Intermediate-binding workflow.

## 3. OBJECTIVES

1. Find out device stability over time (also known as temporal consistency).
2. Find out the degree of color agreement among the three color conversion methods.
3. Answer the question, “What could be the causes for the difference of the color agreement among different workflows?”

## 4. METHODOLOGY

The methodology discusses two aspects: 1. device stability over time; and 2. the procedural steps for finding the degree of color agreement among the three color conversion methods.

## 4.1 DEVICE STABILITY OVER TIME

The only way we can know where the disagreement exists is by measuring and looking at an actual print on paper. This implies that color disagreement between prints could also come from variability of the printing devices. Therefore, if device variability is not very small, it will make it very difficult to detect small differences due to binding workflow.

The original IT8 Basic target is defined in terms of CMYK values. Therefore, different binding workflows have no effect since the target is already CMYK and does not need to be converted. For this reason, the IT8 target is only subject to print variability, while the PCRI chart (which is an RGB file showing sample colors that were collected from various images) is subject to both, print variability and variability of binding workflows. Therefore, if it is found that the total variability of the PCRI chart is bigger than the variability of the IT8 target, the difference could be due to binding workflow.

Within one month, on different days, the following sheets were printed: 5 test sheets for each workflow for Xerox DocuColor 6060; 3 test sheets for each workflow for Epson Stylus 4000; and 2 test sheets for each workflow for Kodak NexPress 2100.

## 4.2 PROCEDURAL STEPS FOR FINDING THE DEGREE OF COLOR AGREEMENT AMONG THE THREE COLOR CONVERSION METHODS

1. Output profiles were made for Epson Stylus 4000, Xerox DocuColor 6060, and Kodak NexPress 2100.

2. A test form was designed with two PCRI images, one PCRI chart, and one IT8 Basic target (Figure 4). PCRI images were used for subjective visual comparison; the PCRI chart was used for quantitative comparison; the IT8 Basic target was used to test the repeatability of the press.



Figure 4. Test form arrangement.

3. Besides press variability, there is another potential source of variability for the binding workflows: the CMMs (Color Management Modules) may be different for different RIPs or APIs such as Adobe Photoshop, InDesign, or Acrobat. The applied rendering intents could also be different. To test for this, different RIPs are required, which, in this investigation, meant that different output devices had to be used. Table 1 shows the different applications and RIPs used to realize these three workflows.

The test form was printed over several days during a month on Epson 4000, Xerox DocuColor 6060, and Kodak NexPress 3000 printers. On each printer, early-binding, intermediate-binding, and late-binding workflows were used.

4. Measure CIELAB values for IT8 target and PCRI chart on each print.

5. The color measurements from the test charts are in terms of CIELAB. There are many patches in each chart. To make comparisons between different workflows, this large number of data

points needs to be reduced to one number per data set. This was achieved by first taking the average of the three workflows for each patch of each target of each print. Then, the  $\Delta E_{ab}$  color difference between each patch and this reference average was calculated. This reduces the three dimensional measurement to a single dimension and cancels out the overall magnitude of the color of that patch. But there are still too many data points. By plotting the Cumulative Relative Frequency (CRF) of all the patch deviations, e.g., see Chart 1 (Chung and Shimamura, 2001), and then finding the 90 percentile value, it is possible to reduce the number of data points to a single number per workflow and print. Now, these 90 percentile numbers can be compared to evaluate color differences among the three workflows.

6. Perform subjective visual comparison.

## 5. DATA ANALYSIS

Various causes for the color differences were investigated. Each cause requires a different reference. When doing the analysis of the measurements, reference R1-IT8 is defined as the average measurement for a given press for each patch of the IT8 target within one day, and, similarly, R1-PCRI is defined as the average measurement for a given press for each patch of the PCRI chart within one day. Reference R2 is defined as the average measurement of a given press for each patch of the IT8 target within one month (for Kodak NexPress 2100, it is the average of 6 test sheets for two days; for Epson Stylus 4000, 9 test sheets for 3 days; for Xerox DocuColor 6060,

Table 1. Setup of Early-, Intermediate-, and Late-binding.

	Early-binding	Intermediate-binding	Late-binding
Color management applications (API)	Photoshop	InDesign	Press's RIP
Color Management Modules (CMM)	Adobe (ACE)	Adobe (ACE)	ColorBurst, Fiery 6000 RIP, or NexStation

15 test sheets for 5 days). R1-IT8 and R1-PCRI will be used for calculations of Table 2; R2 was used for calculation of Chart 1.

### 5.1 PRESS REPEATABILITY WITHIN ONE MONTH FOR XEROX DOCUCOLOR 6060

Chart 1 shows the Cumulative Relative Frequency (CRF) of the color differences between each patch of IT8 of each press sheet with corresponding patch of R2. Different days show different amounts of variability. For instance: at the 90 percentile of the curves, Day3 curves (three black curves) have the least difference (about  $7 \Delta E_{ab}$ ), and Day5 curves (three brown curves) have the largest difference (about 14 to 15  $\Delta E_{ab}$ ). Curves of any given day are very much alike. In other words, the Xerox 6060 shows higher stability within one day than within one month.

Similar curves could be made for the other output devices, but they are not shown here.

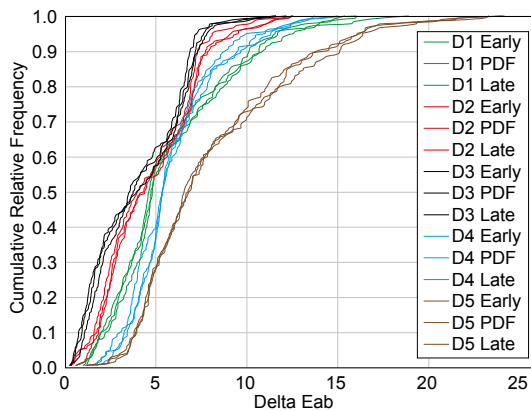


Chart 1. Color consistency of Xerox 6060 indicated from IT8 target.

### 5.2 PRESS REPEATABILITY WITHIN ONE DAY

The left side of the Table 2 shows the color difference of  $\Delta E_{ab}$  at the 90 percentile of the CRF curves between each workflow of the IT8 target relative to R1-IT8. It is obvious that the choice of a different reference gives a different comparison result. The color difference within one day

is much smaller comparing with that within one month. This indicates a higher color consistency within one day than within one month.

### 5.3 COLOR AGREEMENT BETWEEN EARLY-, INTERMEDIATE-, AND LATE-BINDING

The right side of Table 2 shows the color difference of  $\Delta E_{ab}$  at the 90 percentile level of the CRF curves between each workflow of the PCRI charts relative to R1-PCRI for all three printers.

When comparing with the left side of Table 2, a larger color difference within one day is shown even though the IT8 targets and the PCRI charts are printed on the same press sheet for each workflow. Therefore they are both subject to the same printing variability. But the PCRI chart data is additionally also subject to the differences due to the changes of the workflows.

Table 2. Comparing color differences at the 90 percentile between IT8 targets and PCRI charts.

Day	EpsonStylus 4000_ IT8 Basic						
	IT8 target			Mean	PCRI chart		
	Early	PDF	Late		Early	PDF	Late
1	0.4	0.5	0.6	0.5	0.9	1.5	1.1
2	0.3	0.4	0.4	0.3	0.8	1.0	1.3
3	0.4	0.6	0.7	0.5	0.9	1.1	1.5
Mean	0.3	0.5	0.6	0.5	0.9	1.2	1.3

Day	Xerox 6060_ IT8 Basic						
	IT8 target			Mean	PCRI chart		
	Early	PDF	Late		Early	PDF	Late
1	0.8	1.0	1.1	0.9	1.7	1.7	3.0
2	0.9	1.1	0.8	0.9	1.5	1.7	2.9
3	1.1	1.5	1.0	1.2	2.0	2.0	2.5
4	0.8	1.0	1.0	0.9	1.8	1.7	3.0
5	0.8	0.9	1.0	0.9	1.8	1.8	2.9
Mean	0.9	1.1	1.0	1.0	1.8	1.8	2.9

Day	NexPress 2100_ IT8 Basic						
	IT8 target			Mean	PCRI chart		
	Early	PDF	Late		Early	PDF	Late
1	0.7	0.8	0.8	0.8	2.3	2.1	4.7
2	0.8	0.7	0.7	0.7	3.0	2.4	5.2
Mean	0.7	0.8	0.8	0.7	2.7	2.3	5.0

Therefore, the higher number for the PCRI charts indicates that there is an effect due to the change of workflows.

In general, the numbers for PCRI data in Table 2 for late-binding are bigger than for early- and intermediate-binding. One possible explanation for this pattern could be the fact that different CMMs were used for the different workflows as shown in Table 1. Actually, the early- and intermediate-binding workflows both use Adobe CMM and also have similar  $\Delta E_{ab}$  differences as shown in Table 2. On the other hand, the late-binding workflows use different CMMs

and also have higher  $\Delta E_{ab}$  differences. Different CMMs differ in their precision and their calculations of white point adaptation and interpolation methods (Fraser, Murphy, & Bunting, 2004). Potentially, the late-binding workflows also use different rendering intents.

## 6. OUTCOME OF SUBJECTIVE VISUAL COMPARISON

Three PCRI images were cut from the press sheet of each workflow and each was glued on a gray color panel with a label on the back of the panel. These three panels were shown to

Table 3. Subjective visual comparison on three workflows within one day printed by EpsonStylus 4000.

Epson Stylus 4000	Question 1		Question 2		
	Intermediate Binding	Late Binding	Early Binding	Intermediate Binding	Late Binding
Observer 1	X			X	
Observer 2	X		X		
Observer 3		X		X	
Observer 4	X		X		
Observer 5		X			X
Observer 6	X				X
Observer 7	X			X	
Observer 8		X	X		
Observer 9		X			X
Observer 10	X				X

Table 4. Subjective visual comparison on three workflows within one day printed by Kodak NexPress 2100.

Kodak Nexpress 2100	Question 1		Question 2		
	Intermediate Binding	Late Binding	Early Binding	Intermediate Binding	Late Binding
Observer 1	X				X
Observer 2	X			X	
Observer 3	X				X
Observer 4	X				X
Observer 5	X				X
Observer 6	X				X
Observer 7	X			X	
Observer 8	X				X
Observer 9	X				X
Observer 10	X				X

10 observers, one at a time, in a light booth under D50 illumination. Two questions were asked from the observers. For question 1, the early-binding panel was shown as a reference, and then the question was asked, “Which of the other two panels is a better match to the reference in terms of tone and color?” Question 2 was, “Which one of these three panels is least like the other two in terms of tone and color?” The answers are summarized in Table 3.

Table 3 clearly indicates that the responses are pretty random. This is no surprise since the differences are in the order of magnitude of  $1 \Delta E_{ab}$ , as shown in Table 2. Therefore, although there are systematic measurable differences, they are not visually significant.

Table 4 shows the subjective visual comparison results of Kodak NexPress 2100: all of the observers chose the PCRI image of intermediate-binding as the one closer to the PCRI image of early-binding; 8 of 10 observers chose the PCRI image of late-binding as the one least like the other two. Both questions indicate that the PCRI image printed for late-binding workflow shows larger difference from the other two, which correlates with the data in the Table 2.

The differences between Table 3 and Table 4 are the magnitude of the differences. The difference for the Epson inkjet shows the same pattern as does NexPress, but they were too small to be visually significant.

## 7. CONCLUSION

One of the challenges in this project is the need to separate color variations due to color conversion methods from color variation due to output devices. IT8.7/3 (Basic) target was used to assess device variation and the PCRI chart was used to assess color variation due to color conversion methods. The results show that long-term color

variability of printing devices in terms of weeks are quite large, i.e.,  $7-15 \Delta E_{ab}$ . But short-term color variability (within a day) are quite small, i.e.,  $0.3-1 \Delta E_{ab}$ . Therefore, it was important that the workflow-dependent prints are output one right after the other within a day.

In terms of conversion-dependent color variation, the results show that overall color variation due to conversion method, although small in magnitude, is greater than device variation. The extraneous variation is believed due to different CMMs and color rendering intents used in API. This finding is further verified by subjective visual comparison whereby the visual match between early- and intermediate-binding is better than that of early- and late-binding. In conclusion, color agreement among early-, intermediate-, and late-binding workflows is acceptable if printing devices are repeatable and if CMM and rendering intents are aligned.

## 8. FUTURE WORK

One of the improvements to the experimental design of this experiment could be the use of Analysis of Variance to determine the statistical significance of the differences due to color binding workflows.

## 9. REFERENCES

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# TOTAL AREA COVERAGE CHART

TR4V03U.EPS



P4BAR03U.EPS

TAC Chart v 1.3 RIT, 2003

	45 C 36 M 36 Y	58 C 47 M 47 Y	70 C 58 M 58 Y	82 C 70 M 70 Y	95 C 84 M 84 Y	100 C 88 M 88 Y
A1 paper	B 117	C 152	D 186	E 222	F 263	G 276
2 50 K	167	202	236	272	313	326
3 60 K	177	212	246	282	323	336
4 70 K	187	222	256	292	333	346
5 80 K	197	232	266	302	343	356
6 90 K	207	242	276	312	353	366
7 100 K	217	252	286	322	363	376

TR4V03U.EPS



P4BAR03U.EPS