Gravure Process Color Gamut Optimization

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Abstract: There is an opportunity to optimize color gamut for process color printing before we address process control for repeatable color and color management for predictable color. Gamut optimization assumes that there is no applicable printing specification for an ink-substrate-press condition and it must be derived on its own merit. In this paper, we approach gravure gamut optimization from adjustments and compromises made in ink strengths, ink-down sequence and tonal gradation for packaging printing. The outcome leads to product differentiation between the optimized gravure press and other competing printing presses. Gamut optimization strategies are also discussed for other printing processes.

Introduction

Repeatable color addresses color consistency within a press run and between press runs. Repeatable color enables color management when converting color images from one color space to the other. When combining repeatable color technology and color management technology, we have confidence in color repeatability of legacy jobs and in color predictability, such as proof-to-press match.

When developing the methodology for repeatable color, we realized that there is an opportunity to optimize the color gamut of the printing device as opposed to accepting the device's default performance status. It means that extra efforts are involved. But the benefit of device optimization can be long lasting.

Describing Color and Colorant

In process color printing, every combination of CMYK input values will produce a color. For example, if CMYK are all zeros, the resulting color is the paper itself; if M and Y are solid (100%) ink coverage and C and K are zeros, the resulting color is a red color. The shade of red depends on the amount and the sequence of the inks printed.

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When we look at a color, it has three attributes: hue, lightness and chroma. Hue is the name of the color, e.g., red is the hue of that red color. Lightness describes the light or dark of the color, e.g., a light red that we call pink. Chroma is the colorfulness of the color, e.g., a fire engine red is more colorful and darker than a pink color.

In order to describe colors produced by combinations of CMYK, we rely on the use of colorimetry. Under standardized measurement conditions per CGATS.5, we can use a colorimeter to measure a color patch and the color is quantified by three numbers, labeled as L*, a* and b*. L*, ranging from 0 to 100, is the light or dark of that color; a*, ranging from -100 to 100, is the redness or greenness of that color and b*, ranging from -100 to 100, is the yellowness or blueness of that color.

In addition to describing a color by L*, a* and b*, we can also quantify a color with the use of L*, C* and h. As shown in Figure 1, C* is the symbol for chroma or saturation that measures the degree of colorfulness. 'h' is the symbol for hue angle. Hue angle at 0 degree is red; hue angle at 90^0 is yellow; 180^0 is green and 270^0 is blue. Using the Lab color space to describe color, the origin (0, 0) represents the neutral or gray axis. The departure from the origin or the distance (shown in red) is the magnitude of C* or the colorfulness of the color.

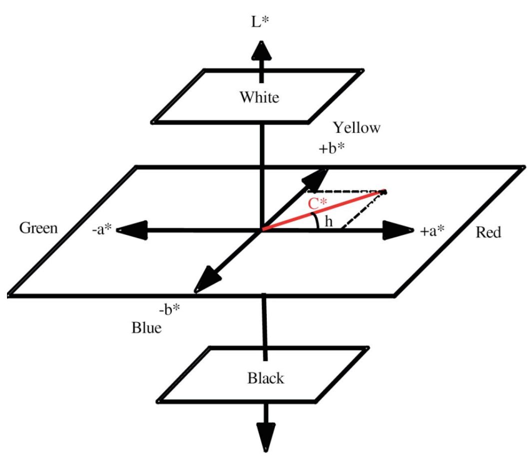

Figure 1. Lab color space

While the eye is very sensitive to detecting small color differences, one may wonder why we need colorimetry and densitometry for process color printing. The answer is simple: visual perception is subjective, difficult to describe with precision, and can be influenced by lighting and surround. On the other hand, colorimetry is useful for ink specifications and quality assurance of spot color. Densitometry is useful for process control of CMYK printing. In this paper, both densitometry and colorimetry are used to optimize amplitude response and color gamut of process color printing.

If we print and measure a synthetic test target, e.g., IT8.7/3 basic data set (Figure 2), which represents a subset of CMYK combinations, we can generate graphs of the color gamut in the a*b* dimension and the L*C* dimension.

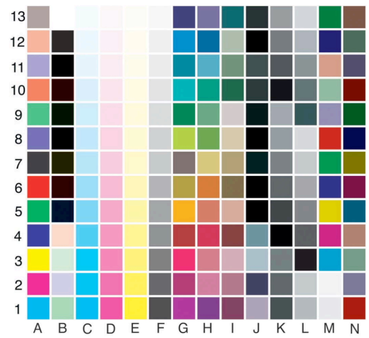

Figure 2. IT8.7/3 (CMYK) basic data set

Gamut refers to a range of colors that a printing device can render using process inks. The full-tone of process inks (cyan, magenta and yellow) and their two-color overprints (red, green, blue) mark the six end points of a device gamut as shown in Figure 3.

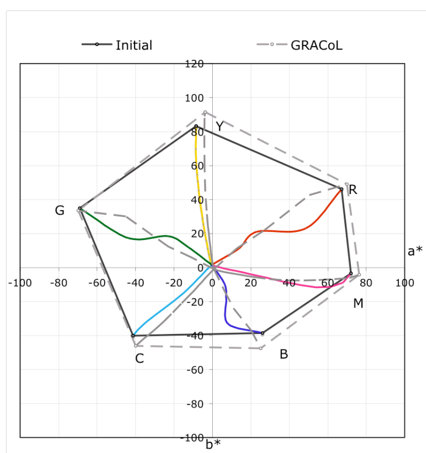

Figure 3. Comparison of a*b* gamut slice of the initial rotogravure & GRACoL

Figure 3 is an example of an a*b* plot using colorimetric data collected from the IT8.7/3 target at the initial phase of the project. It offers chromaticity (hue and chroma) capabilities of a rotogravure process. Figure 3 does not provide lightness or L* information because of the two dimensional nature of the graph.

By comparing the initial rotogravure printing condition with the GRACoL (Grade 1) data set, measured from a certified GRACoL press sheet, Figure 3 illustrates that the GRACoL gamut is larger than the initial gravure gamut. In addition, the hue progression of the GRACoL two-color overprints (R, G, B) is more linear than that of the rotogravure process.

In order to visualize the relationship between lightness and chroma for a particular hue, we can obtain L*C* plots of cyan, magenta and yellow primaries (Figure 4). Notice that the hue slice begins at the top left and that's where the paper white is located. As the ink amount increases, the color of the ink becomes more vivid and colorful; so is the magnitude of the C* moving to the right. Once it reaches to its full-tone, the hue slice becomes less saturated as it darkens. Finally, it reaches to the darkest black (lower left corner). Comparing to GRACoL (Grade 1), we observe that (1) the initial phase of the rotogravure has less chroma in all three primary inks; and (2) the composite CMYK back is less dark. The question becomes, "How can we leverage the gravure process to optimize its color gamut?"

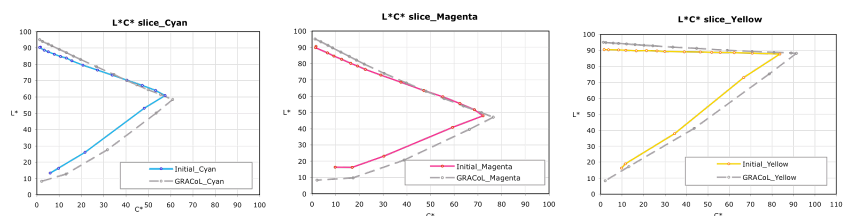

Figure 4. L*C* gamut plots of cyan, magenta and yellow hue

Calibration vs. Optimization

Calibration and optimization are different from each other. Calibration assumes that there is a well-known printing specification. By conforming to the printing specification, the press will print the same as the standard. In publication printing, publishers want the same ads, as defined by a proof, to match from press to press. Device calibration is the rule. Quality printing, as dictated by publishers, is a measure of product conformance. For example, if a publication printer wants to calibrate his presses to conform to SWOP (Specifications Web Offset Publication), he needs to: (1) select ground wood coated grade 3 paper, (2) specify SWOP certified inks, (3) adjust the gradation or dot gain during platemaking and (4) print to solid ink density aim points. In other word, printing conformance helps to realize color gamut conformance (Chung and Shimamura, 2001).

Gamut optimization is the act of adjusting the printing process such that its color gamut exhibits (1) maximum colorfulness of the primary inks, (2) maximum colorfulness of the overprint colors, (3) a very dark neutral shadow, and (4) a smooth tonal rendering from highlight to midtone to shadow for a set of ink-substrate-press combination. Gamut optimization assumes that there are no applicable printing specifications that apply to the ink-substrate-press combination in question. If there exists such a standard, it must be based on its own merit. The result is to create product differentiation between the optimized device and other competing devices. When there is no standardization in ink and substrate for packaging printing, device optimization is the rule. Quality printing, as dictated by brand owners and market performance, is a measure of product differentiation.

Optimizing a Gravure Process for Packaging Printing

This paper describes how we optimize a gravure press using solvent-based inks and non-absorbent substrates. A series of press trials were conducted in partnership with the Films Business Division of the ExxonMobil Company.

Test targets were used initially to "fingerprint" tone and color behaviors of the press. Ink concentration, ink-down sequence and cylinder engraving were treated as input variables. Both density and color are measured from sample press sheets to determine the device responses in terms of color gamut and amplitude. By implementing the following procedures and verified via subsequent press trials, we were able to optimize the gravure process color gamut by a significant amount.

1. Find out the initial color gamut and amplitude response

   Test targets represent known input values. Two types of test targets are useful: synthetic and pictorial. An example of a synthetic test target is the IT8.7/3 basic data set (Figure 2). Upon measuring of printed IT8.7/3 targets, we can generate color gamut responses of the printing condition as shown in Figure 3 and 4. We can also generate amplitude responses (density vs. % dot area) of the ink-substrate-press interactions, as shown in Figure 5.

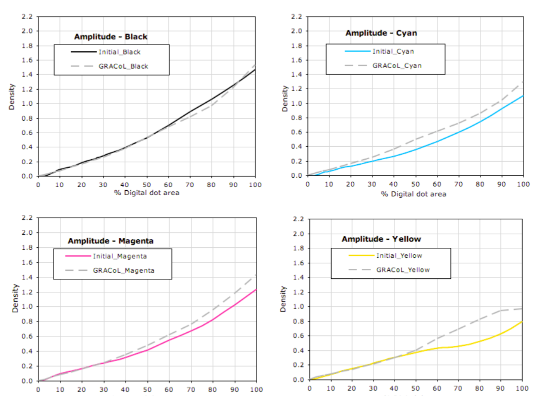

Figure 5. Amplitude responses of process color printing

An equal useful target is a pictorial test target, e.g., a SCID (standard color image data) image of Three Musicians, containing CMYK data in a TIFF file (Figure 6). Upon examining the printed color images under initial printing conditions, we can summarize our subjective view quickly about the current printing conditions. For example, does it produce pleasing flesh tone or other memory colors? Or does it produce similar results, e.g., the neutrality of the background, as the GRACoL standard? The subjective findings usually correlate with quantitative analyses.

Figure 6. Three musicians, a pictorial reference image

2. <u>Explore the effect of ink concentration on color gamut</u>

In order to achieve the optimal color gamut, we begin from the initial ink mixing and printing conditions as described. Ink concentrations are, then, increased. We would expect a change in increased chroma (C*). This, in turn, increases the color gamut. But unwanted hue shift or loss of L*, as a result of increased chroma, may be the penalty. To explore the effect of ink concentration on color gamut, we performed systematic ink concentration variations in a number of ink changeovers during a press trial. The top row of Figure 7 shows the effect of hue shift (y-axis) as a function of ink concentration (x-axis).

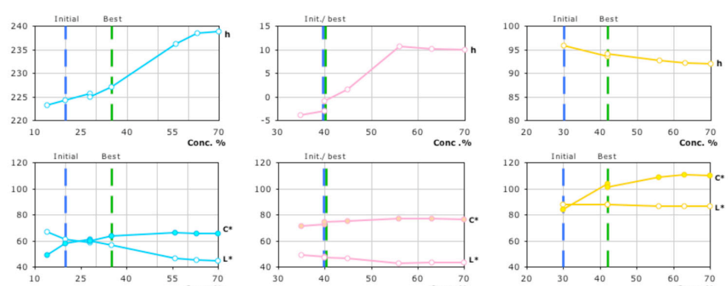

Figure 7. Effect of ink concentration on gamut extension

Looking at the three (cyan, magenta, and yellow) responses, increased ink concentration for cyan and magenta produce unwanted hue shifts quickly. Yellow is the only ink that can be extended to higher chroma without having significant hue shift.

The bottom row of Figure 7 shows the effect of chroma and lightness change (y-axis) as a function of ink concentration (x-axis). For cyan and magenta ink, the increased ink concentration did not yield significant increase in chroma (C*) while there is a slight darkening effect or loss of lightness. The yellow ink, again, is the only one that can be extended to higher chroma without having significant loss in lightness.

The optimal ink concentration, as shown by (green) dash lines or labeled as ‘Best,’ in Figure 7, is when the metric chroma is extended while its hue angle and lightness are maintained. As a result of the ink concentration experiments, we achieved a compromise between wanted features (higher chroma) and unwanted demerits (hue shift and drop in lightness).

Figure 8 compares color gamut of the gravure press under its initial inking (dotted line) and concentration adjusted (solid line) condition. Notice that the major change between the two gamut conditions is the extended chroma of the yellow ink. Not only yellow becomes more saturated, red and green regions of the gamut are also extended. Translating the effect of extended color gamut into a pictorial color image, we will see that reds are redder and greens are greener.

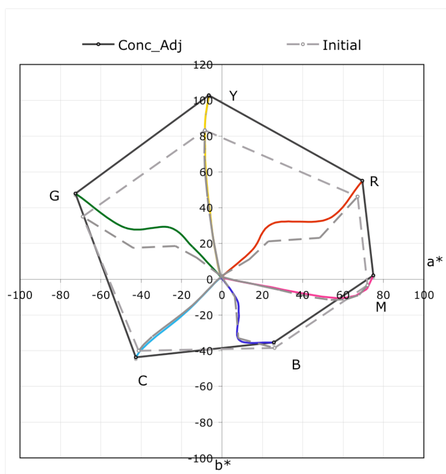

Figure 8. Effect of ink concentration on color gamut extension

Figure 9 compares the amplitude of the yellow printer before and after the concentration adjustment. Notice that the change in density is proportional to the input dot area, i.e., there is an increase in chroma as the concentration of the yellow ink increases in all region of the tonal scale.

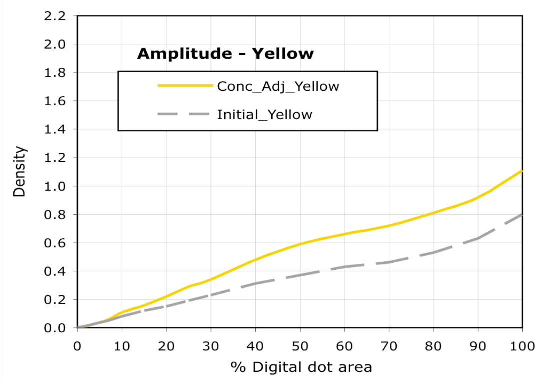

Figure 9. Effect of ink concentration on yellow printer amplitude

3. Determine the effect of ink-down sequence on color gamut

The color gamut, shown in Figure 8, has a number of flaws. First, the hue progression of the green (yellow over cyan) two-color overprints is not straight. This is also true of the red (yellow over magenta) two-color overprint. The chroma in the blue (magenta over cyan) two-color overprint is limited and its hue progression is seriously shifted towards magenta. Finally, the patch with the highest TAC (total area coverage or B11) in the IT8.7/3 target was neither neutral nor dark enough.

Wavy hue progression and the limited dynamic range present color management problems when attempting to model the printer color space accurately. The causes were not obvious to us, but we decided to explore the effect of ink-down sequence on two-color overprints and on the shadow region of the color gamut.

K-C-M-Y (black first and yellow last) was the ink-down sequence at the initial printing condition. Since magenta was printed on top of cyan to produce blue with its hue seriously shifted toward magenta, a possible solution is to print cyan (first-down) over magenta (second-down). In addition, we moved the black printer from the first ink-down position to the last ink-down.

By moving the black printer as the last ink-down, the L* of the highest TAC patch, i.e., B11 of the IT8.7/s target, was lowered from 17.0 L* to 8.6 L*. The neutrality of the composite black also improved (Table 1).

Table 1. Effect of ink sequence on composite black

Towards device optimization	Ink sequence	TAC 400 (B11)		
		Density	L*	C*
1. Initial	KCMY	1.6	16.3	9.7
2. Conc_Adj	KCMY	1.6	17.0	11.2
3. Seq_Adj	MCYK	2.0	8.6	2.6

As shown in Figure 10, we improved both chroma and hue progression in the blue region of the color gamut by printing cyan over magenta. It was amazing to recognize the significance of ink-down sequence on overprint colors and neutral shadows.

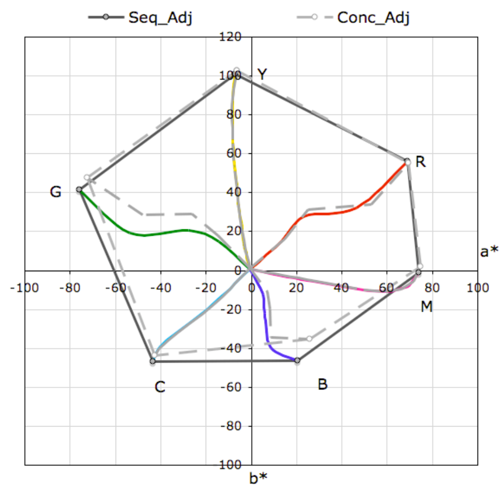

Figure 10. Effect of ink-down sequence on extended color gamut

4. Look into the effect of gradation on hue progression of two-color overprint

We witnessed improvement on color gamut extension through changes in ink-down sequence. But we continued to observe hue shift in two-color overprint regions of the gamut. We asked ourselves, "Is the color gamut optimized? If not, what else can we do?" Eventually, we asked ourselves, "What about cylinder engraving?"

Cylinder engraving controls the ink volume from highlight, to midtone to shadow for each of the process color ink. That is a degree of freedom we need to exploit from tone and color optimization point of view. We may be able to correct the hue shift of two-color overprints by controlling the gradation of the engraving. We postulate that by printing higher yellow ink amount from midtone to shadow where magenta also prints, under the "yellow over magenta" ink-down sequence, we may be able to straighten out the hue progression of the red.

Consequently, a new engraving curve with higher cell volume in the three-quarter tone was applied to the yellow cylinder. The left hand side of Figure 11 is the density amplitude (density vs. % dot) of the yellow printer. The solid line is the density amplitude of the new engraving and the dotted line is the initial engraving. The right hand side graph is the density amplitude expressed as % digital dot (in) vs. % print dot (out).

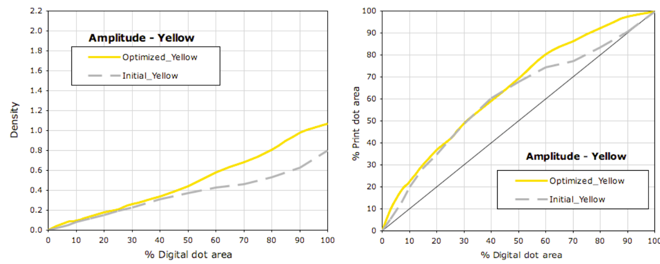

Figure 11. Increased yellow ink gradation and amount

Long be hold, we discovered that both ink sequence and tonal gradation have a profound effect on the hue progression of two-color overprints. Figure 12 shows the color gamut difference from ink sequence adjusted (dotted line) to the engraving adjusted or "optimized" state (solid line). The adjusted tonal gradation of the yellow printer from the midtone to shadow helps straighten the green and red hue progression.

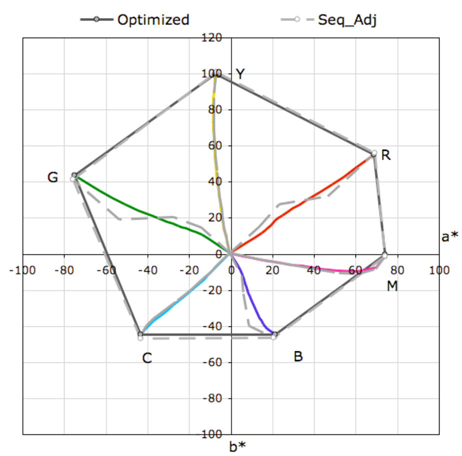

Figure 12. Effect of gradation on extended color gamut

Thus far, color gamut analysis, a three-dimensional phenomenon, has been limited in two-dimension. ColorThink (ChroMix, 2003) offers a visual solution that is based on ICC color management and 3-D animation. Figure 13 is a screen capture of the initial color gamut and the optimized color gamut. Notice the initial color gamut of the gravure press is displayed as color solids and the optimized color gamut is displayed in wire frame. We not only see the extended gamut in the yellow, blue, and shadow region, but also the extended gamut in red and green via its frontal projection. By means of gamut volume estimation with the use of Monaco GamutWorks (X-Rite, 2005), the optimized color gamut is one-third larger than that of the initial color gamut.

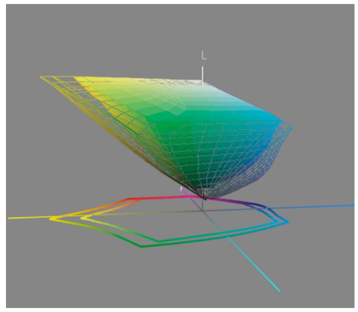

Figure 13. Gamut visualization in 3-D

Conclusions

Figure 14 (left) compares the initial gravure color gamut being smaller than the GRACoL (Grade 1) color gamut. Figure 14 (right) compares the optimized gravure gamut, now, larger than the same GRACoL reference. The difference is the result of gamut optimization involving not only ink concentration adjustment, but also choices made in ink-down sequence and gradation in cylinder engraving.

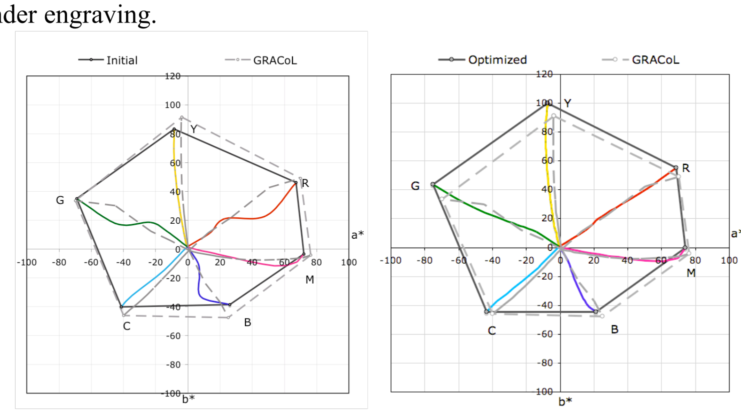

Figure 14. (left) Gamut comparison of the initial rotogravure and the GRACoL reference; (right) Gamut comparison of the optimized rotogravure and the GRACoL reference

A lesson learned in the project is that a legacy print production process does not necessarily represents the best color gamut it can achieve. Pictorial color reproduction looks more pleasing and vivid when printed under the optimized gamut condition.

The process of gravure process color gamut optimization was one of discovery. Without colorimetric, densitometric and visual analyses of printed samples, we would not able to produce the insights between input variables and response parameters.

Discussion

<u>Ink-down sequence vs. hue progression</u>

The hue progression of two-color overprints in both gravure and offset printing processes are linear, but with different ink-down sequences. Offset lithography uses KCMY (yellow being the last-down ink). Yet, we had to change the gravure from KCMY to MCYK.

We suspect that the difference may have to do with wet-on-wet printing in offset vs. inter-station drying in rotogravure printing. With either sheet-fed or web offset printing, process inks are trapped wet-on-wet. Poor trapping of the second-down ink compensates spectral impurity of the first-down ink. Thus, the most spectrally pure yellow ink is last-down ink. On the other hand, gravure press is equipped with dryers between printing stations. Thus, there is no ink trapping issue. The ink that is printed on top of a previously inked area in rotogravure will have a predominant effect in the resulting overprint colors, and this includes the effect of the black ink.

<u>Gamut optimization vs. adjusting color on press</u>

Gamut optimization and adjusting color on press (or process control) are two different approaches in managing color in the pressroom. Gamut optimization is the process of finding the best the printing can do and, then, leveraging the color management in prepress for repeatable and predictable color. Thus, gamut optimization is a systems approach to quality color reproduction and the approach is prevention-based.

Adjusting color on press, on the other hand, takes on the position of either not knowing what the printing specifications are or anything is possible. Typically, pressmen are deviating from the norm in order to salvage a customer's job. In short, the approach to adjusting color on press is defect-detection based.

In addition, there is a false pretense in adjusting color on press, i.e., thinking there is a degree of freedom when, in fact, there isn't. Below are two examples that support this claim: (1) the increase in the concentration of a process ink may not increase its chroma, but caused hue shift and darkened L*, and (2) unlike color adjustment in the pre-media stage, the inter-dependency of process color printing dictates that when one process color is altered on press, the color of that ink plus two overprint colors are also altered.

<u>Gamut optimization and color management</u>

The success of color management depends on a repeatable color platform because that's what a printer profile represents. From product differentiation point of view, repeatable color needs to be at the peak performance of the printing device. Therefore, gamut optimization is more of a strategic issue than implementation issue.

Although this paper argues that a more linearly behaved color gamut will yield greater color accuracy in color management practices, it did not provide evidences that being the case. A follow-up study would be to apply a round-trip (B-to-A-to-B) colorimetric analysis of the press ICC profile in question and evaluate the distribution of color differences in all region of the color space.

We can extend color gamut by printing more than four process inks, e.g., Hexachrome. We limited the ink set to only four in this study for two reasons: (1) separating color images from three channels into more than four channels requires additional software and is not a common practice for gravure packaging printing, and (2) there is a higher ink costs involved. Printing more than four process colors someday may become very attractive when we can match a variety of spot colors and, at the same time, producing vivid pictorial color images with a standard set of inks.

Adopting color gamut optimization for other printing processes

We can adopt gamut optimization methodology to other printing processes. Using offset as an example, inks are shipped as press-ready. So, transfer curves in platemaking and ink film thicknesses during printing become the main variables that impact color gamut. For flexographic printing using solvent-based ink, the gamut extension follows the methodology of the gravure solvent-based ink. For flexographic printing using UV ink, the gamut extension follows the methodology of offset ink. For digital printing, most vendors already fixed the color gamut. The opportunity is to adjust tonal gradation or gray balance so that it will print legacy files that match a standard printing condition, e.g., SWOP, without colorcast in near neutrals but with more colorfulness in high chroma areas.

Acknowledgments

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