Printing in Color

Optimizing the Print Sequence for Expanded Gamut

Liam O'Hara, Bobby Congdon & Brad Gasque

Expanded gamut (EG) offers printers the opportunity to reduce their reliance on spot color formulations to achieve the brand color demands of CPCs. Today's packaging often employs 4-color process printing for photographic elements in a package's design and the use of spot colors for high chroma, high impact brand colors for logos and brand recognition. Three to four spot colors are not unusual.

While some spot colors can be replicated with traditional 4-color process, the chroma that can be achieved for many hues is limited, and subsequently 4-color builds often fail to achieve the desired vividness that is required. The Pantone Color Book is a common reference for spot colors; approximately 40 percent of the Pantone book can be replicated using the GRACoL2006Coated1v2 printing gamut (Furr, 2014). Pantone claims 90 percent of its book can be replicated using CMYK supplemented with orange, green and violet EG (Gundlach, 2015). In testing previously performed at Clemson University, a CMYKOGV ink set yielded 72 percent of the Pantone library with an average Delta E 2000 of 1.39 (Furr, 2014).

The use of EG enables printers to dramatically reduce makeready and tooling costs, particularly where jobs can be ganged together (Furr, 2014). These economic drivers have bolstered the adoption of EG in packaging, and with this proliferation, the need for standardization becomes increasingly important to brand owners to ensure consistent results from printers. Toward this end, FTA has specified pigments and hue angles for CMYKOGV ink sets (depending on whether the formulations are water based, solvent or UV inks) in its *Flexographic Image Reproduction Specifications & Tolerances* (*FIRST*) methodology. However, the question remains as to what sequence these inks should be incorporated into a CMYK process.

> **"Of the four print sequences performed on press, none of them actually match the result of the predictive model. However, the predictive model does accurately rank the volume of the four printed sequences in the same fashion, and a comparison of the predicted volume and the printed volume shows they are relatively similar."**

STUDIES SAY…

Prior research into EG print sequences for flexography is fairly limited. A study at Western Michigan University (Sheth, G., et al., 2013) compared YMCKOGV to YOMGCVK, with single pigmented and two pigmented EG inks. The study found enhanced gamut with single pigmented inks, and the YOMGCVK sequence provided a greater gamut (a comparison which held true with both single and two pigment ink sets). The authors state the YOMGCVK sequence was determined based on the transparency of the overprints. The gamut increases were 5.2 percent for the single pigmented inks and 4.9 percent for the two pigment ink sets.

Another print sequence study employing flexographic printing was conducted at Rochester Institute of Technology on 4-color process inks (Patel, 2009). The RIT study attempted five print sequences (YMCK, MYCK, CMYK, KYMC and KCMY) and found that while certain sectors (red, green, blue) were enhanced by various sequences, no overall superior gamut was determined, although the greatest black point density was achieved by KYMC.

Looking beyond flexo, there are a number of studies on print sequence for offset lithography, but the wet on wet trap of litho plays a significant role in this, and is not applicable for flexography, which is a dry trap printing method. An optimization of the gravure printing process (Chung and Hsu, 2006) was performed that employed ink sequencing (along with pigment concentration and gamma adjustments). Researchers found they had improved the gamut by printing MYCK rather than the traditional KCMY generally used in gravure printing.

The study discussed in this article was undertaken to provide a set of reference data for an optimized print sequence for EG in flexographic printing, focusing on where best to place OGV in relation to their analogous process pairs (for example, green in relation to cyan and yellow: GCY, CYG, CGY or YCG). After the completion of the test trials, we set about finding a predictive model to allow one to optimize the sequence without the time and expense of multiple press trials.

METHODOLOGY

Print trials were conducted on an Omet Varyflex 530 flexo press at Clemson University. A set of characterization plates was made using 0.067-in. DuPont Cyrel DPR photopolymer plates, utilizing Esko Full HD screening on 4,000 dpi RIP with an Esko CDI Spark UV2. This technology creates plates with flat top dot profiles by employing a high intensity bank of UV lights that overwhelms the oxygen inhibition to create the necessary features.

The plates were imaged at 175 lpi with circular dots and a relief of 0.020-in. A randomized IT8.7/4 characterization target was used to create profiles. The IT8.7/4 was reproduced twice on each plate, with the target in different orientations in order to capture the press variation across the substrate. In addition to the characterization chart, a color bar with solid patches of the seven primaries, as well as the various 2- and 3-color overprints, was included. The overprints also overprinted black, in order to provide a basis for opacity measurements. *Figure 1* shows the overprint target, which was used to acquire opacity data.

The print trials were conducted using CMYKOGV single pigmented UV inks from Siegwerk (L39 series) that conformed to *FIRST* standards for EG printing, which are specified by hue angle. *Table 1* shows the *FIRST* specifications.

UV Inks	Hue Angle	Recommended Pigment
Orange	54 degrees	C.I. Pigment Orange 64
Green	181 degrees	C.I. Pigment Green 7
Violet	307 degrees	C.I. Pigment Violet 23

Table 1: *FIRST 5.0* EG ink specifications for UV formulations

WestRock 10-pt. Printcote paperboard was used for all trials. The press was run at 300 fpm for each of the print sequences tested. The modular nature of the press was ideal for a study of this nature—the individual print decks can be removed and repositioned to create the various ink sequences, so it was not necessary to clean the stations between sequence trials. Furthermore, the same anilox and blade were always used with each color, so there was minimal variation between the various sequences; the anilox roll, doctor blade and anilox to plate settings remained constant, and only the plate to substrate impression had to be reset. The anilox rolls were ceramic rolls with a 60 degree angle, and Flexo Concepts composite blades were employed on each station. The cpi/bcm specifications for the anilox rolls at each station were:

- K: 800/2.0
- CMY: 1200/1.8
- OGV: 900/2.2

Lastly, UV inks provide great stability, as there are no amines or solvents to monitor and replenish. The solid ink specs between pressruns were maintained within 1.0 Delta E_{ab}. Once impressions were set and solid ink colors confirmed to match between runs, the press was run at 300 fpm for a minimum of two minutes.

The study employed the Esko Equinox strategy of running four sets of characterization targets—CMYK, CGYK, OMYK and CMVK—rather than a single characterization. In this way, each of the EG primaries is only sampled with its analogous process colors—for instance, orange

Figure 1: The overprint target
All figures, charts and data courtesy of Clemson University

is only useful in the red sector, so it is only sampled with yellow and magenta for hue and chroma, with black providing tone. Equinox employs a 100 percent GCR strategy.

Because of the constraints of web width and repeat length (20-in. wide and 18-in. repeat), it was not possible to compile all four characterization targets on a single set of plates. So, the OGV plates were made identical to their complementary process colors, and once a print sequence was set up, the various print stations were turned on and off to create the four sets of characterization targets necessary to create the profile. *Figure 2* illustrates how the full 7-color target was "broken down" to create the four sets of targets.

Three print sequences were tested with the aim of placing the OGV primaries before, between and after their analogous process colors: KCMYOGV, KOGVCMY and KCGVMOY. It is standard practice at Clemson to print KCMY, and we elected to restrict the print sequence study to the placement of OGV within that sequence, a decision motivated to limit the number of pressruns for the experiment. A fourth sequence, KYOMGVC, was added to investigate the "between" strategy with the process colors reversed, to provide data on MOY and YOM (for example).

Ten samples were pulled from each of the pressruns, and from these, three sets were measured using an X-Rite i1iO table via MeasureTool 5.0.8. The three measurements were then averaged, and the averaged data was used to create EG profiles via the Equinox Profile Creator software. Color Engine Pilot was used to compare the resulting gamut volumes.

"While some spot colors can be replicated with traditional 4-color process, the chroma that can be achieved for many hues is limited, and subsequently 4-color builds often fail to achieve the desired vividness that is required."

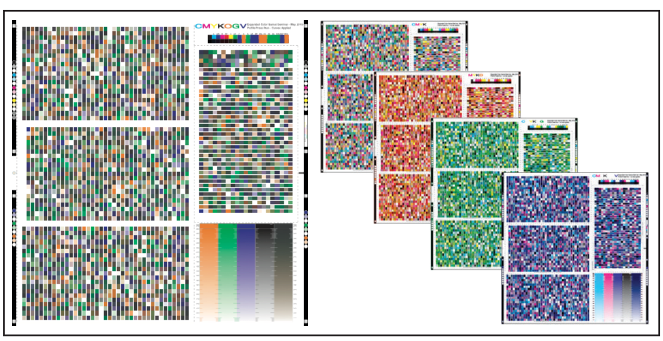

Figure 2: Four sets of characterizations for CMYK integrated with OGV

RESULTS & DISCUSSION

Figure 3 shows the resulting volumes expressed as a percentage as compared to the smallest gamut. The cubic L*a*b* units are indicated on the y-axis.

When initiating this project, our first assumption was the optimal sequence would be determined by the opacity of the primary colors. The assumption was that more opaque inks should be printed first, with higher transparency inks overprinting them. The opacity of the primaries, from high to low, are as follows:

- V: 15.71
- O: 10.48
- M: 6.34
- Y: 4.83
- C: 4.06
- G: 3.76

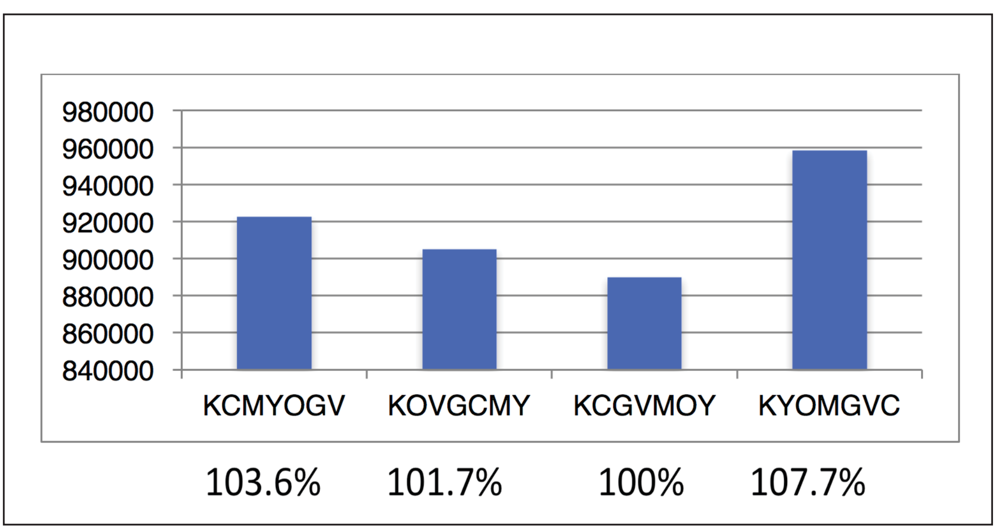

Figure 3: Gamut volumes for the print sequences

The closest sequence printed in the study to this scenario was the KOVGCMY, which has violet and orange printing before their process color pairs. Green was the least opaque ink, but the difference in opacity between it and its analogous process colors—cyan and yellow—is far less than that of violet and orange, which are two to three times as opaque as the other inks. Opacity was determined from the printed samples by measuring XYZ tristimulus values

	CV/VC	MV/VM	OM/MO	OY/YO	GC/CG	GY/YG	CM/MC	CY/YC	MY/YM	Average
Delta L*	2.5	1	3.7	0.1	1.1	0.5	0.9	2.4	1.6	1.5
Lighter	CV	MV	MO	YO	GC	YG	CM	YC	MY	
Delta C*	3.3	0.9	4.7	2	1.5	1.6	0.5	3.9	5	2.6
Increase	4.4 percent VC	1.7 percent VM	5.2 percent OM	1.9 percent YO	2.0 percent GC	1.7 percent YG	0.90 percent CM	5.4 percent YC	5.6 percent YM	
Delta h˚	3.6	4.3	2.2	0.2	3	3.5	7.1	6.4	8.2	4.6
Delta E (a*b*)	6.82	5.09	7.73	3.54	4.89	0.81	6.87	9.51	5.37	5.6

Table 2: L*C*h˚ of the EG overprints

with Illuminate C and a 2 degree observer function, and using the CIE opacity formula:

$$\text{Opacity} = 100(Y_0/Y_\infty)$$

Where: Y_0 = Black backing and Y_∞ = White backing

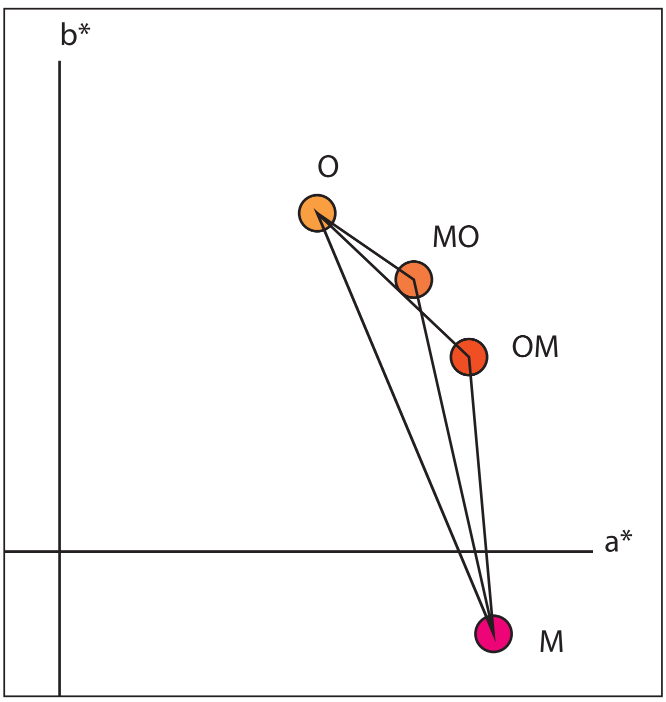

Figure 4: Hypothetical triangle area of primaries and overprints

However, as *Figure 3* illustrates, placing orange and violet first yielded one of the smaller gamuts, which suggests sequencing based on the opacity of the primaries does not yield the optimal gamut. This led us to look for other means to model and predict an optimized EG print sequence.

We next examined the changes in L*C*h˚ of the various 2-color overprints of the CMYOGV color pairs depending on sequence. *Table 2* shows the overprint pairs and the resulting Delta L*, Delta C* and Delta h˚ results, as well as the overall Delta E_{ab} of the print sequences. In addition, the average difference for the various color pairs is shown on the right; it can be seen hue angle is the color attribute most affected by the print sequence.

> **However, chroma doesn't tell the whole story, as the hue angle also plays a critical role.**

	CM	MY	CY	CV	MV	MO	YO	YG	CG
	2719.8	2004.8	4240.7	644.9	753.6	734.4	681.4	2015.7	452.6
	MC	**YM**	**YC**	**VC**	**VM**	**OM**	**OY**	**GY**	**GC**
	2721.2	2347.4	4423	664.8	733.7	889	656.9	1777.3	434.5
Delta Area	1.4	342.6	182.3	19.9	19.9	154.6	24.5	238.4	18.1

Table 3: Delta Area for overprint print sequence

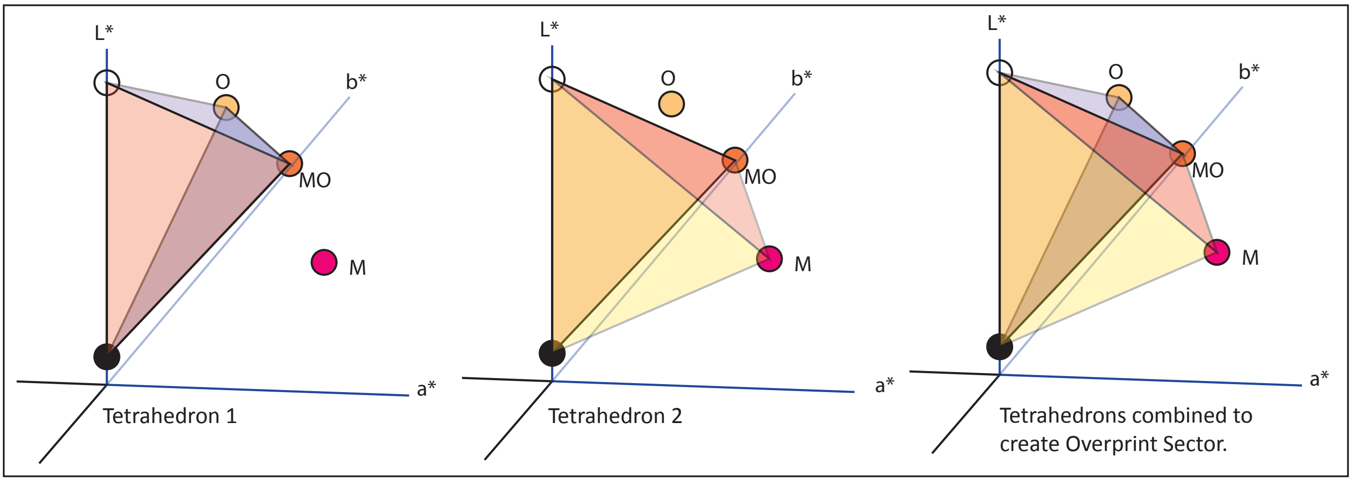

Figure 5: Tetrahedrons that form an overprint sector volume

The change in chroma due to sequence is more pronounced for some pairs than others. A sequence based on C*, in which the sequenced pair yielding the highest chroma is selected, would yield a sequence of KYGVOCM. Of the sequences actually performed on press, this is closest to the KYOMGVC sequence, which yielded the highest gamut.

However, chroma doesn't tell the whole story, as the hue angle also plays a critical role. If the chroma is the same between two overprints, the overprint that is more centered on hue angle between the primaries will create the greatest area. This is illustrated in *Figure 4*, which depicts a hypothetical set of data in which the chroma is equal but the hue angle changes. Two overprint sequences are depicted, one of which is closer to its primary than the other. When the primaries and the overprints are connected, it is clear the area of the triangle of the centrally located overprint (OM) is greater than the one that is closer to one of its primaries (MO).

Again, *Figure 4* depicts hypothetical data for illustrative purposes. The actual triangle areas can be calculated by determining the length of the sides with a simple Delta E_{ab} equation, and then once the lengths of each side are known, the area of the triangle can be calculated using Heron's formula:

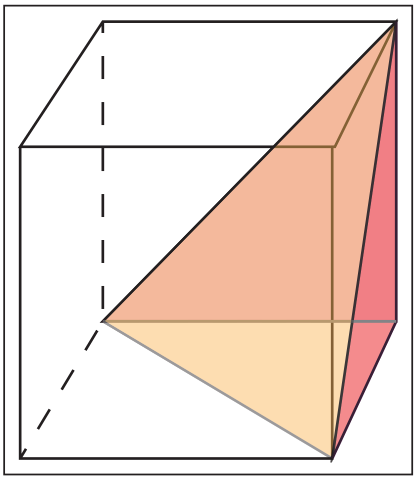

Figure 6: Extrapolating a parallelepiped from the four points of a tetrahedron

$$\text{Area} = \sqrt{[p(p-a)(p-b)(p-c)]}$$

Where p = half the perimeter of the triangle, and the perimeter of the triangle is the sum of sides a, b and c, in which:

- a = Delta E_{ab} of Primary 1 to Overprint (i.e. M to MO)
- b = Delta E_{ab} of Primary 2 to Overprint (i.e. O to MO)
- c = Delta E_{ab} of Primary 1 to Primary 2 (i.e. M to O)

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Table 3 shows the resulting areas of triangles formed between the primaries and their overprints, and the differences (denoted as Delta Area) between the print sequences. The largest area for each sequence is highlighted in gray. Some pairs yield much larger changes in area than others; these are highlighted in yellow.

The differences in sequence for the others were marginal. This suggests the sequences for orange in relation to magenta, and green in relation to yellow, are critical, but the sequence for violet in relation to cyan and magenta is not. The resulting print sequence based on triangle area is KYOMVCG; this is close to the KYOMGVC that had yielded our highest printed gamut volume.

	CM	MY	CY	CV	MV	MO	YO	YG	CG
	101,212	162,587	164,328	81,576	51,894	86,489	94,980	165,617	63,953
	MC	**YM**	**YC**	**VC**	**VM**	**OM**	**OY**	**GY**	**GC**
	100,319	171,066	169,872	81,567	51,675	89,697	95,007	159,189	64,771
Delta V	893	8,479	5,544	9	219	3,208	27	6,428	818
Percentage	0.89 percent	5.22 percent	3.37 percent	0.01 percent	0.42 percent	3.71 percent	0.03 percent	4.04 percent	1.28 percent

Table 4: Delta V for overprint sector volumes

The triangle area method is instructive, but the real issue in gamut optimization is volume. In order to predict volume based on 2-color overprints, the three points of the triangles are combined with an L*min and L*max to create a three dimensional (3-D) shape. L*max is defined by the white point of the paper, but L*min can be a moving point due to the fact that it's commonly a build of black and another color (a rich black rather than 100 percent black). This could result in the black point of the various color pairs overlapping or leaving "gaps" in the overall gamut.

So for this model, a common, neutral black point was selected: L* = 9.5, with a* and b* being zero. We recognize the true black point may not be captured in this fashion, but the goal of EG is to expand chroma, not the black point, so we assume a common black point will serve the purpose of optimizing for gamut expansion.

To calculate the volume of each gamut sector, the sector can be divided into two tetrahedrons:

- L*max, L*min, Primary 1, Overprint
- L*max, L*min, Primary 2, Overprint

Figure 5 shows the individual tetrahedrons and how they combine to create the volume of an overprint sector, in this case MO. Each of the tetrahedrons shares a common face, L*max, L*min and the overprint, MO.

To calculate the volume of each tetrahedron within the overprint sector, one can use the four L*a*b* points of the tetrahedron to extrapolate a parallelepiped, as illustrated in *Figure 6*.

The volume of a parallelepiped (V_p) can be calculated from the four L*a*b* points:

$$V_p = (L_4-L_1)[(a_2-a_1)(b_3-b_1)-(b_2-b_1)(a_3-a_1)]$$
$$+(a_4-a_1)[(b_2-b_1)(L_3-L_1)-(L_2-L_1)(b_3-b_1)]$$
$$+(b_4-b_1)[(L_2-L_1)(a_3-a_1)-(a_2-a_1)(L_3-L_1)]$$

Once the volume of the extrapolated parallelepiped has been determined, the volume of the tetrahedron can be determined:

$$V_t = V_p/6$$

To determine the volume of the overprint sector, simply add the two tetrahedrons'

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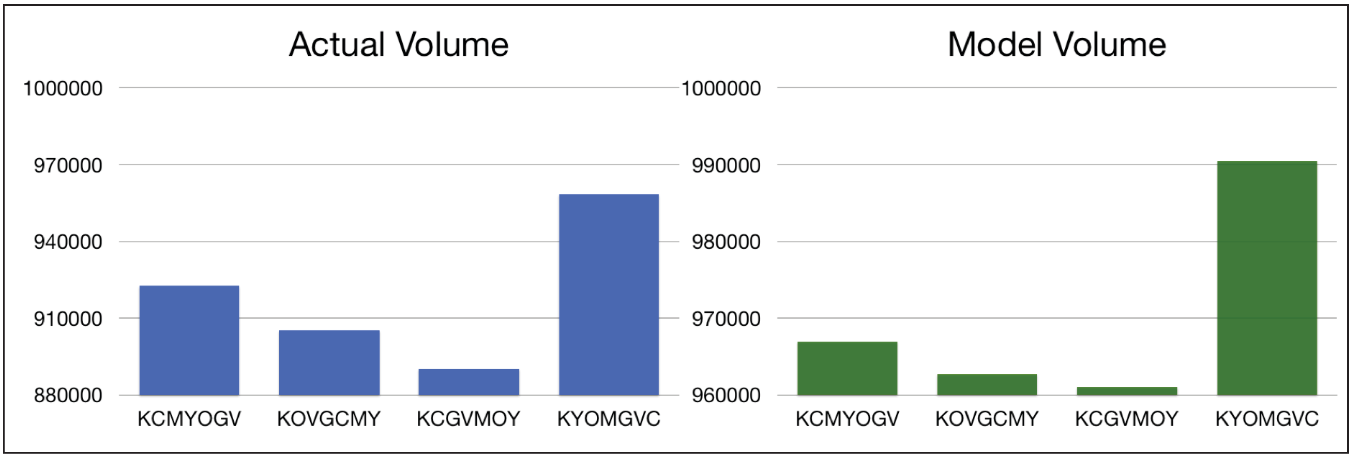

Figure 7: Graphs comparing actual volume vs. model volume

volumes together. Once the volume of each sector dependent on the print sequence of the overprint has been determined, the larger volume is the optimal sequence for that particular color pair. Of course, this is a simplified model for the gamut sector, as it reduces the shape to straight lines and flat planes, whereas the actual shape of a gamut sector is a curved geometry due to factors such as TVI, trapping and hue error, but the goal of the model is to be able to optimize a sequence based on the primaries and overprints. To calculate the curved geometry would require far more data, which could be prohibitively complex.

Working from the printed overprints from the various experimental sequences, the overprint sector volumes for each color pair and their differences (denoted as Delta V) were determined and shown in *Table 4*. The largest volume for each sequence is highlighted in gray. Some pairs yield much larger changes in area than others; these are highlighted in yellow. The differences in sequence for the others were marginal. As was true of the triangle area method, this suggests the sequence for orange in relation to magenta and green in relation to yellow has a relatively high impact, but the sequence for violet in relation to cyan and magenta does not. The resulting print sequence based on overprint sector volume is KOYGCMV.

Thus, of the four print sequences performed on press, none of them actually match the result of the predictive model. However, the predictive model does accurately rank the volume of the four printed sequences in the same fashion, and a comparison of the predicted volume and the printed volume shows they are relatively similar. Again, the predictive model is a simplified geometry of flat planes, as opposed to the curved contours of the actual gamut. *Figure 7* shows the calculated volumes and actual printed volumes for comparison.

In looking at the results of the four printed sequences, it is interesting to isolate the gamut expansion of the KCMY sequence as well. There was a 106.2 percent increase in gamut volume between running KCMY and KYMC.

Figure 8 shows the gamut expansion between the best of the printed sequences (depicted in green) and the worst printed sequence (depicted in red) in terms of gamut area of a*b* plots at various L* levels. The brown in *Figure 8* is where they overlap. It can be seen that the greatest expansion is in the green and orange sectors, with little difference in the violet sector. This is due primarily to the sequence of MO and YG (which are shown to have the greatest impact on volume in *Table 4*), and reinforces the observation that violet's sequence with cyan and magenta has minimal impact on the gamut volume. The gamut expansions are most prevalent at L* values less than 50.

OPPORTUNITIES FOR FURTHER RESEARCH

Four EG print sequences were performed on press: KCMYOGV, KOVGCMY, KCGVMOY and KYOMGVC. The experimental press trials yielded the greatest gamut with KYOMGVC. Subsequent work with the predictive model suggested that KOYGCMV would have yielded a somewhat larger gamut. We intend to perform press trials to confirm this finding.

"We are hopeful the predictive model developed in this paper will allow printers to work from a set of drawdowns of primaries and their overprints to optimize print sequence without the expense of multiple pressruns, regardless of whether they use standardized OGV to supplement CMYK or if they adopt other spot colors into an EG strategy."

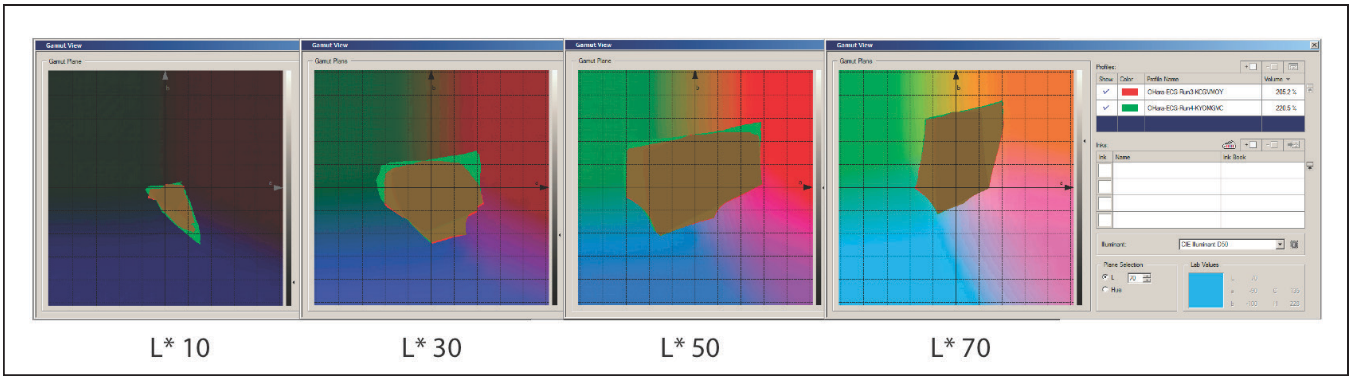

Figure 8: a*b* gamut views at various L* levels

Clemson University's Sonoco Institute of Packaging Design and Graphics will be hosting a three day seminar on expanded gamut (EG). It will feature nine presenters covering topics like defining EG inks and process limitations, color tolerances, proofing options and more, and include hands on sessions for converting from RGB or CMYK to 7-color in Adobe Photoshop, press calibration and other operations. To learn more about the seminar and to and register, visit www.sonocoinstitute.com.

The research also indicates opportunities to improve 4-color process work by moving from KCMY to KYMC (a 106 percent increase). Further exploration of print sequence for KCMY also seems warranted.

We are hopeful the predictive model developed in this paper will allow printers to work from a set of drawdowns of primaries and their overprints to optimize print sequence without the expense of multiple pressruns, regardless of whether they use standardized OGV to supplement CMYK or if they adopt other spot colors into an EG strategy. Future research will explore the application of this methodology to n-color and modified process situations. ■

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