Optimizing Chroma and Lightness of OGV Inks for Expanded Color Gamut

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Abstract

The use of Orange, Green and Violet inks to augment and expand the reproducible color gamut of CMYK process color sets has been adopted widely in the packaging industry, but the movement towards standardized processes for expanded color gamut (ECG) has only recently gained momentum. To this end, the Flexographic Image Reproduction Specifications and Tolerances document, FIRST 6.0, has specified a base set of pigments and the preferred hue angles for Orange, Green and Violet inks. However, while the hue angles for these inks have been specified, the recommended chroma and lightness of these inks have yet to be established. In this paper, the authors conduct a series of characterizations for a FIRST-compliant ECG UV ink set staged with varying pigment letdowns and anilox configurations in an attempt to optimize the chroma (and correspondingly, the lightness) for these inks, with the goal of creating the largest possible gamut of reproducible colors.

This work was conducted on a seven-color OMET Varyflex flexographic printing press using single-pigment UV inks on coated paper. Three sets of press runs were conducted to attempt to determine a recommended chroma for the OGV inks employed with CMYK. The first of these studies tested each of the OGV inks printed via a banded roll to achieve six different ink film thicknesses in conjunction with CMYK (OMYK, GCYK, VCMK). In addition, each of the inks was let down twice so that the inks were run at 100% and approximately 90% and 80% concentration along with unaltered CMYK inks. Chromas ranging from 64.3 – 100.9 for Orange, 54.9 – 78.7 for Green, and 61.8 – 77.4 for Violet were tested using a custom characterization chart designed to fit within six 3-inch bands ranging from 1.03 – 3.58 BCM.

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In order to isolate the pigment concentration from the effects of varying IFTs, a second series of tests were conducted that only employed letdowns of the OGV inks, with chromas ranging from 62.2 – 102.0 for Orange, 62.1 – 79.0 for Green, and 56.8 – 76.8 for Violet, with the CMYK inks held to consistent values. The resulting profiles for the orange, green and violet sectors were evaluated for gamut volume expressed in cubic ΔE and the number of Pantone colors each could produce.

Introduction

As expanded color gamut (ECG) has become more widely adopted in the packaging industry, there has been an effort to establish industry specifications for expanded color gamut printing. At the time of writing, the IDEAlliance is working to develop a standardized characterization target for the creation of expanded gamut profiles (Hoffstadt, 2019). Currently, an expanded color set of orange, green and violet inks has grown to become the dominant ECG ink set, with work being undertaken by the Flexographic Technical Association (FTA) to begin standardization of these inks by specifying specific pigments for water-based, solvent, and UV inks along with hue angles for printers to adhere to (FIRST 6.0, 2017). However, due to the wide range of substrates involved in packaging applications, no specifications are made for L*a*b*, or more appropriately with the hue angle, L* and C* in the FIRST 6.0 specification.

The current research is an attempt to optimize L* and C* while using UV ink formulations for OGV inks that conform to the FIRST specifications for ECG printing. To this end, a series of characterizations were performed using OGV inks applied at various ink film thickness and pigment concentrations to capture the gamuts of a wide range of chroma and lightness.

Methodology

Banded Roll Study

Print trials were conducted on an Omet Varyflex 530 flexographic printing press at Clemson University. A set of characterization plates was made using 0.067-inch Dupont Cyrel DPR photopolymer plates using circular screening on 4000 dpi RIP using an Esko CDI Spark UV2 and mounted using 3M 1320 stickyback. Due to the high volumes of ink in the banded anilox roll (up to 3.58 bcm), the plates were imaged at 120 lpi with circular dots to reduce TVI. The plate relief was 0.020 inches. A custom colorimetric target was created using MeasureTool 5.0.10 to fit within the three-inch bands of the banded roll used for the ECG inks. This approximately 3 x 18-inch target was stepped across each of the six bands, such that the OGV inks would be sampled at six different ink volumes. The banded roll specs are shown in Table 1; the target layout is shown in Figure 1. In addition, each OGV ink was run full strength and with two let-downs of 10% and 20% extender, such that there were three pigment concentrations at 100% ink strength, 90% ink strength, and 80% ink strength, for a total of 18 conditions each for Orange, Green and Violet.

900/2.0	200/1.03	1100/1.53	1000/1.75	900/2.22	800/2.85	700/3.58	900/2.0

Table 1. *Banded anilox roll specs (cpi/bcm). The end bands are control bands that were not part of the experimental treatment.*

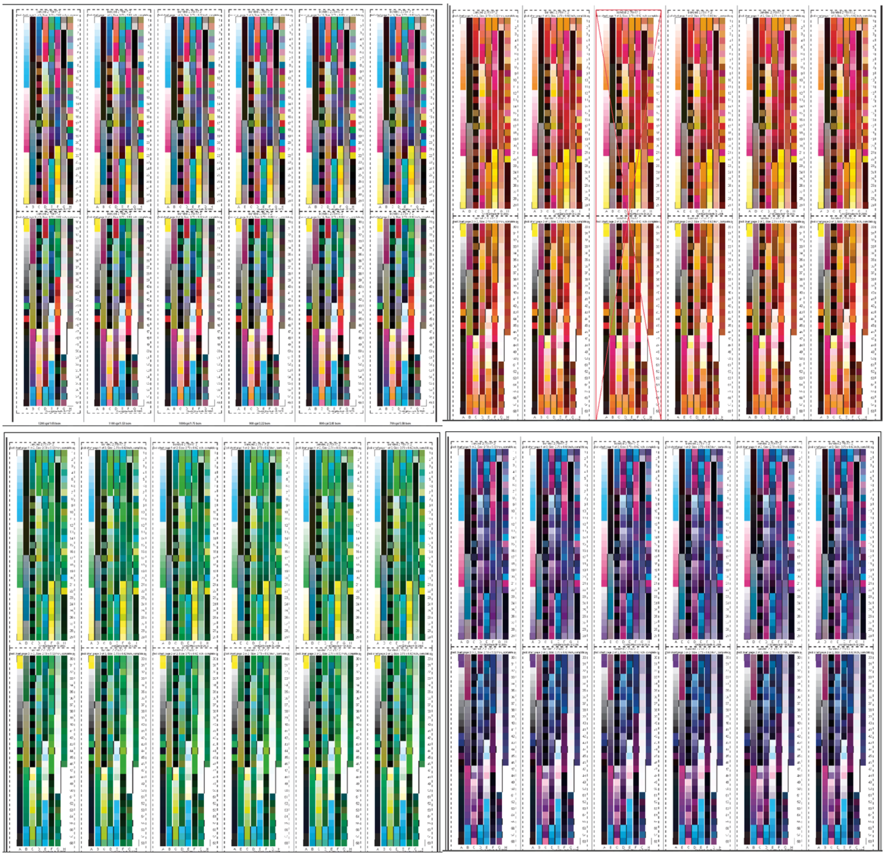


Figure 1. *Banded roll characterization targets*

The print trials were conducted using CMYKOGV mono-pigmented UV inks from Siegwerk (L39 series) that conformed to FIRST pigment specifications for ECG printing (FIRST 6.0) which are specified by hue angle. Table 2 shows the FIRST specifications.

UV inks	**Hue Angle**	**Recommended Pigment**
Orange	54°	C.I. Pigment Orange 64
Green	181°	C.I. Pigment Green 7
Violet	307°	C.I. Pigment Violet 23

Table 2. *FIRST 6.0 ECG ink specs for UV formulations*

Coated SAPPI 80# text paper was used for all trials. The press was run at 200 fpm for each of the OGV conditions tested. The anilox rolls were Harper Corporation ceramic rolls with a 60° angle, and Flexo Concepts composite, micro tip 8 blades were employed on each station. The cpi/bcm specifications for the anilox rolls for CMYK process inks were K: 900/2.2; CMY 1200/1.8. The banded roll specified in Figure 1 was used for all nine OGV inks (three inks at three strengths). Once impressions were set and the CMYK inks met G7 aimpoints, the press was run at 200 fpm for a minimum of two minutes before pulling samples.

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

A minimum of ten samples were pulled from each of the press runs, and from these, three randomly selected sheets were measured using an X-Rite i1iO table via MeasureTool 5.0.10. The three measurements were then averaged, and the averaged data was used to calculate the sector volumes for KYMO, KCMV, KYCG via Equinox Profile Creator software. Color Think 3.04 was used to compare the resulting gamut volumes.

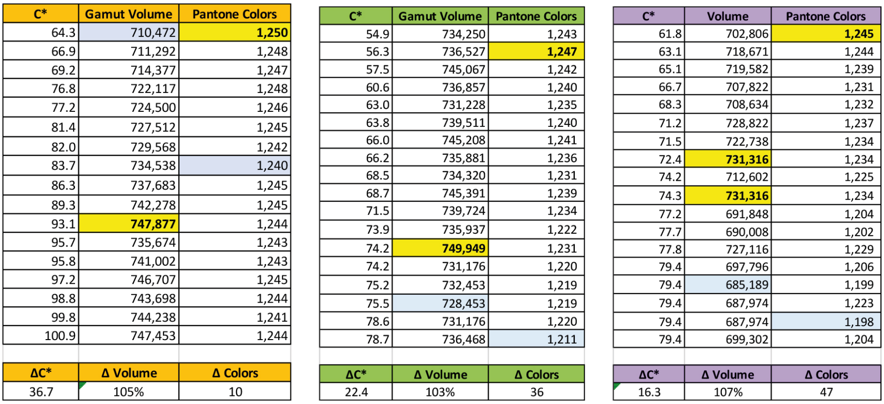
Ink Strength Only Study

A second study was conducted without the use of a banded roll in order to remove the influence of ink film thickness and the differences in TVI associated with it. Siegwerk L-39 series OGV UV inks were run at various concentrations—full strength, and then let down to approximately 90, 80, 70, 60, 50, and 40% concentrations for a total of seven conditions for each ink. An Esko EDK-07Stage33k characterization target was used to capture gamut information for sector profiles (KCMY, KCMV, KOMY, KCGY). As was done previously, once impressions were set and the CMYK inks met G7 aimpoints, the press was run at 200 fpm for a minimum of two minutes before pulling samples. The plates were 0.067-inch Dupont Cyrel DPR photopolymer plates with 120 lpi circular screening (except violet which used stochastic screening) imaged with a 4000 dpi RIP using an Esko CDI Spark UV2 and mounted using 3M 1320 stickyback. The anilox rolls were Harper Corporation ceramic rolls with a 60° angle, and Flexo Concepts composite, micro tip 8 blades were employed on each station. The cpi/bcm specifications for the anilox rolls for CMYK process inks were K: 900/2.2; CMY 1200/1.8. The orange and green inks used 800/2.8 rolls, and the violet used a 900/2.2 configuration.

Results and Discussion

Banded Roll Study

The most common metrics used to assess the color rendering abilities of a profile are calculating the gamut volume, typically in units of cubic ΔE, and estimating the number of Pantone colors that can be rendered. This study employed both strategies for assessing the CMYKOGV profiles generated. The researchers compared gamut volume expressed in cubic ΔE, as determined using ColorThink 3.04, and the number of Pantone Colors that were predicted to match within 2.0 ΔE_{2000}, using Esko's Color Engine Pilot software. The results are shown in Table 3. The highest values for volume and Pantone colors are highlighted in yellow; the lowest values are highlighted in blue. At the bottom of each chart, the overall change in chroma between the various conditions is presented (ΔC*), along with the change in gamut volume relative to one another (ΔVolume) and the change in the number of Pantone Colors predicted to be replicated within a ΔE_{2000} of 2 (ΔColors). Over the range of chromas, the hue angle for the orange moved 3.6˚ (from 52.2˚–55.6˚; target value was 54˚), the green hue angle changed by 3.1˚ (from 178.6˚–181.6˚; target value was 181˚), and the violet hue angle shifted 3.0˚ (307.1˚–310.1˚; target value was 307˚).



C*	Gamut Volume	Pantone Colors
64.3	710,472	**1,250**
66.9	711,292	1,248
69.2	714,377	1,247
76.8	722,117	1,248
77.2	724,500	1,246
81.4	727,512	1,245
82.0	729,568	1,242
83.7	734,538	1,240
86.3	737,683	1,245
89.3	742,278	1,245
93.1	**747,877**	1,244
95.7	735,674	1,243
95.8	741,002	1,243
97.2	746,707	1,245
98.8	743,698	1,244
99.8	744,238	1,241
100.9	747,453	1,244
ΔC*	**Δ Volume**	**Δ Colors**
36.7	105%	10

C*	Gamut Volume	Pantone Colors
54.9	734,250	1,243
56.3	736,527	**1,247**
57.5	745,067	1,242
60.6	736,857	1,240
63.0	731,228	1,235
63.8	739,511	1,240
66.0	745,208	1,241
66.2	735,881	1,236
68.5	734,320	1,231
68.7	745,391	1,239
71.5	739,724	1,234
73.9	735,937	1,222
74.2	**749,949**	1,231
74.2	731,176	1,220
75.2	732,453	1,219
75.5	728,453	1,219
78.6	731,176	1,220
78.7	736,468	1,211
ΔC*	**Δ Volume**	**Δ Colors**
22.4	103%	36

C*	Volume	Pantone Colors
61.8	702,806	**1,245**
63.1	718,671	1,244
65.1	719,582	1,239
66.7	707,822	1,231
68.3	708,634	1,232
71.2	728,822	1,237
71.5	722,738	1,234
72.4	**731,316**	1,234
74.2	712,602	1,225
74.3	**731,316**	1,234
77.2	691,848	1,204
77.7	690,008	1,202
77.8	727,116	1,229
79.4	697,796	1,206
79.4	685,189	1,199
79.4	687,974	1,223
79.4	687,974	1,198
79.4	699,302	1,204
ΔC*	**Δ Volume**	**Δ Colors**
16.3	107%	47

Table 3. *1st Study gamut volumes and Pantone colors for orange (KCMYO), green (KCMYG) and violet (KCMYV) sectors, respectively.*

A couple of common assumptions are challenged by these results. First of all, the highest chroma does not yield the greatest volume for any of the OGV inks, although the gains in volume due to ink strength are fairly modest, ranging from 3–7%. For the green and violet inks, some of the lowest volumes are generated by higher chroma values. However, there is not a clear trend in the relationship of chroma to volume when examining the green and violet results. The orange data trends in a fairly linear relationship until the higher chromas, as shown in Figure 2. But the green and violet data in Figure 2 show considerable noise, likely due to the way the data was collected. In addition to adjustments in the ink strength by diluting it with extender, a banded anilox was used to manipulate the ink film thickness. It appears that the various ink volumes, ranging from 1.03–3.58 bcm, play a role beyond the amount of pigment deposited—certainly, the TVI for the various bands varied considerably. Figure 3 separates the data by ink concentration. It can be seen that a more distinct pattern appears as the chroma rises due to ink volume for the 80, 90 and 100% concentrations.

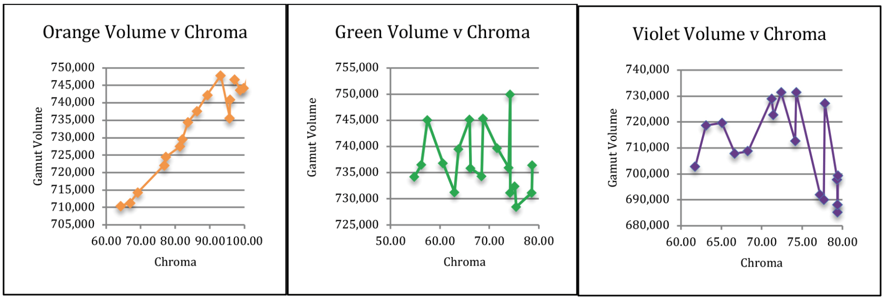


***Figure 2.** Chroma to gamut volumes for orange, green and violet*

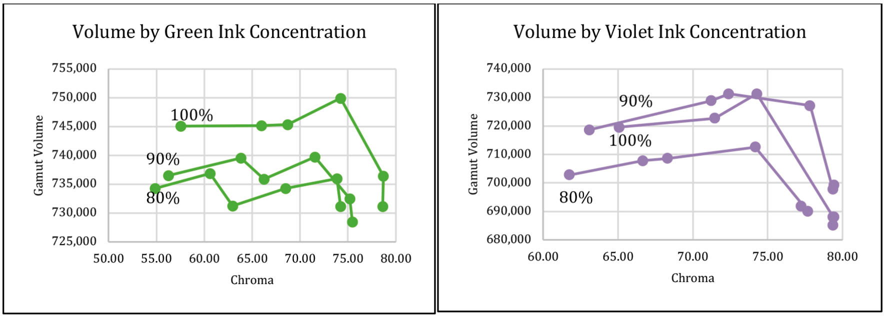


***Figure 3.** Volumes broken out by ink concentrations. The points indicated on each line represent the six bands on the anilox roll, so the ink film thickness is increasing to raise the chroma.*

Returning to Table 3, the other metric assessed was the number of Pantone colors that were predicted to print within 2 ΔE_{2000}; it can be seen that the lowest chroma (and subsequently the highest L*) values yielded the greatest number of Pantone colors for each of the OGV sectors, while for the green and violet sectors, the lowest number of Pantone colors were generated by high chroma, low lightness inks. In the orange sector, there was very little impact on the number of Pantone colors as they only vary by 10 colors, whereas green and violet vary by 36 and 47, respectively. The L* values for orange ranged approximately 10 points, from 67.0–75.9; green L* ranged approximately 16 points, from 57.6–72.4; and the violet L* ranged approximately 28 points, from 17.5–44.3.

Figure 4 shows gamut comparisons generated in ColorThink 3.04 for lighter, relatively low-chroma inks and darker, high-chroma ink for orange, green and violet. It can be seen that the darker, high chroma inks extend the CMYK gamut further in chroma, but that the light OGV inks tend to extend the CMYK gamut upwards along the L* channel, enabling the printing of pastel colors. There are greater gains to be made in the number of Pantone colors that can be printed in the pastel colors than there are in more saturated and subsequently darker colors. The differentiation is not as great for orange (depicted in Fig. 4a), as orange remains a very light color at full strength. In Fig. 4d, the gamut projections for the violet inks illustrate the "hook" in the violet gamut sector common with high chroma violet inks. It appears that there is little to no expansion when mixing violet with magenta for certain hue angles, and then dramatic push outward at others. This "hook" does not occur with the lighter violet colors.

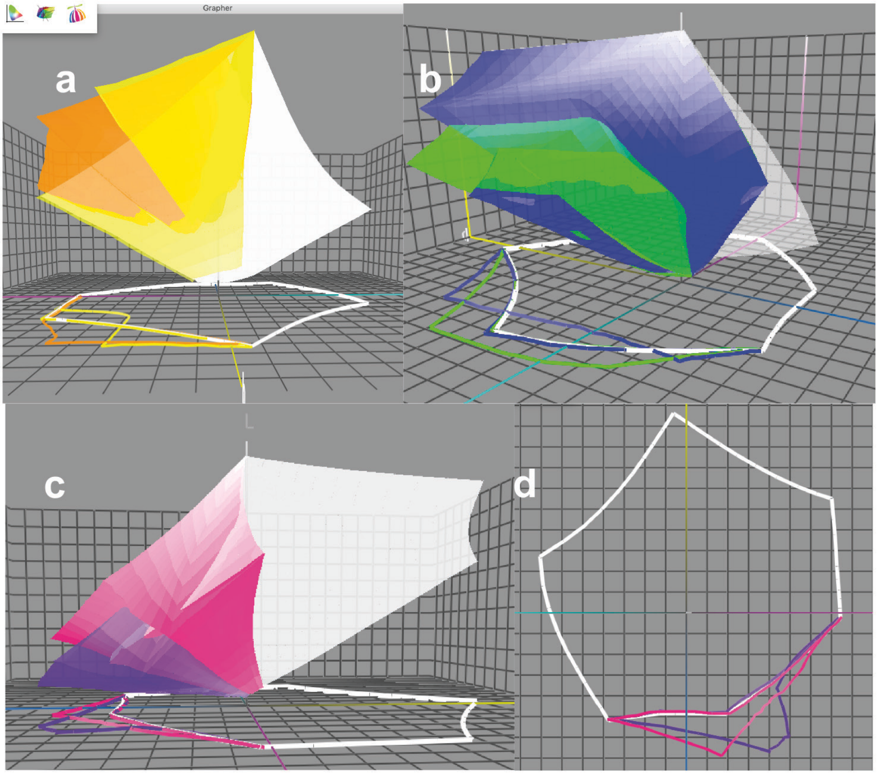
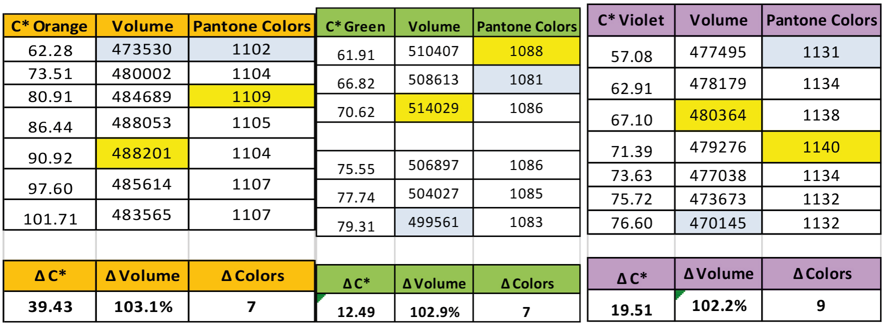


Figure 4. *Gamut comparisons of lighter, lower chroma inks and darker, higher chroma inks for a) orange, b) green, c) violet; d) shows the gamut projections for violet to illustrate the "hook" ink high chroma violet.*

Ink Strength Only Study

As noted in the Methodology section, a second set of press runs was conducted using uniform anilox rolls in order to remove the variable of ink film thickness from the study. As before, the impact of chroma was assessed by determining the gamut volume in cubic ΔE and the number of Pantone colors that could be met by each gamut sector. However, due to the selection of an Esko EDK-07Stage33k characterization target, the gamut volumes could not be assessed in ColorThink due to the proprietary nature of the Esko target, which does not use ICC standardization. In order to process the data, the researchers turned to Dr. Kiran Deshpande at Siegwerk, who used the characterization data to calculate the gamut volumes expressed in cubic CIELAB units and the number of Pantone colors using a proprietary process. The number of Pantone colors was not calculated within a tolerance of 2 ΔE_{2000}, but rather zero tolerance of either within the gamut or out. This data is presented in Table 4. Due to the different metrics involved in the two studies, direct comparisons between the two are not possible, although the general trends are notably similar.



C* Orange	Volume	Pantone Colors
62.28	473530	1102
73.51	480002	1104
80.91	484689	1109
86.44	488053	1105
90.92	488201	1104
97.60	485614	1107
101.71	483565	1107
Δ C*	**Δ Volume**	**Δ Colors**
39.43	**103.1%**	**7**

C* Green	Volume	Pantone Colors
61.91	510407	1088
66.82	508613	1081
70.62	514029	1086
75.55	506897	1086
77.74	504027	1085
79.31	499561	1083
Δ C*	**Δ Volume**	**Δ Colors**
12.49	**102.9%**	**7**

C* Violet	Volume	Pantone Colors
57.08	477495	1131
62.91	478179	1134
67.10	480364	1138
71.39	479276	1140
73.63	477038	1134
75.72	473673	1132
76.60	470145	1132
Δ C*	**Δ Volume**	**Δ Colors**
19.51	**102.2%**	**9**

Table 4. *2nd Study gamut volumes and Pantone colors for orange (KCMYO), green (KCMYG) and violet (KCMYV) sectors, respectively.*

Conclusions

The authors recognize some flaws in this study, particularly in that different metrics for assessing the gamut volumes and Pantone colors make comparison between the two data sets difficult. However, the authors hope that these efforts offer some insights towards the application of OGV inksets for expanded gamut printing. First, higher chroma inks may not yield greater gamut volumes. Second, it is noteworthy that these experiments indicate that the largest gamut volume may not yield the greatest number of Pantone colors—the lower chromas (and perhaps more to the point, the higher lightness values) often have more Pantone colors despite having smaller volumes, as Pantone colors are a non-uniform sampling of the color space. Lighter OGV inks yield gamuts better able to render pastel colors, whereas darker (and more saturated) OGV inks enable higher chroma colors. This is particularly true of green and violet inks—orange ink is much lighter in general and appears to have less of a trade-off between lightness and chroma.

Recommendations for Further Study

The effort to optimize an ECG system necessitates some discussion of what the "optimal" gamut should be. One approach is to attempt to create the largest gamut volume—the broadest range of colors as defined by cubic ΔE. However, another common approach is to determine the number of Pantone colors that can be rendered from a given gamut. Arguably, the driving force behind the adoption of ECG is building brand colors through expanded process color builds instead of relying on spot color inks, so perhaps this is a more useful metric than the gamut volume.

However, the effort to establish a standardized OGV inkset should take into account more than the total number of Pantone colors—inevitably, some Pantone colors are going to be in greater demand for packaging as a whole than others. But which Pantone colors are of the greatest importance? In optimizing the inks for a broad specification, a determination is necessary as to what gamut will best serve the greatest number of printers—is it more important to ensure high-demand colors are included in a recommended gamut than it is to simply provide the greatest number of colors? If so, consensus must be reached as to what colors are in greatest demand in order to standardize the inks to accommodate that demand. The authors are currently undertaking work to make a
recommendation in that regard.

Acknowledgements

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