The Effect of Press Consistency on Brand Color Reproduction Using the Extended Color Gamut Process Printing

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Abstract

"Brand colors" are a key component to a brand's visual identity. Traditionally, the brand colors are defined with spot colors. While a brand color can be used in various types of packaging, the formula of the printing ink is adjusted accordingly based on the substrate, application, finishing, etc. to maintain the accuracy of the brand color. With the individuality of the color formula, the print manufacture can accumulate many leftover spot-color inks. Meanwhile, more waste was generated during make-ready and in the process of changing inks on press when dealing with multiple jobs that require various spot-color inks. With sustainability in mind, more and more printers are looking for ways to reduce waste and to optimize material management. The extended color gamut (ECG) process printing offers just the solution to achieve a sustainable production.

The ECG printing is a print reproduction process that uses orange, green, and violet inks in addition to the traditional cyan-magenta-yellow-black (CMYK) process inks. The three additional inks serve to extend the color gamut. The use of an ECG ink-set to replace spot colors reduces in press wash-up time and spot color ink inventory and improves productivity with the options to gang up different brand color jobs. But some brand owners and printers hesitate to implement the ECG process. They are not sure if the brand colors can be reproduced accurately using ECG process printing and if the brand colors will fluctuate more through the production run.

In this study, 25 predefined spot colors would be reproduced using the ECG process printing workflow. A press trial was designed to investigate the color accuracy of these predefined colors and to investigate how well these colors performed through out the production run by analyzing "within the sheet" and "from sheet to sheet" variations.

Sun Chemical

With a joint project between Sun Chemical and ESKO and with Dr. Abhay Sharma as an academic consultant for the data analysis, the ECG press trial was conducted at Sonoco Institute, Clemson University, Clemson, SC, using Esko Equinox color management software and separations, in conjunction with Esko HD screening and XPS Crystal platesetter. Printing was done on the seven-unit OMET VaryFlex 530 flexographic mid-web press with UV LED flexographic ECG process color inks and the coated paper label house stock. After the calibration and profiling of the press condition, the production run was prepared using the resulted profile to convert the special designed press form that contains spot colors into ECG process colors through ESKO Equinox system. The run was kept at a production speed and for more than 50 minutes continuously. At the completion of the run, the substrate roll was rewound then a sheet was cut and collected at every 150-foot length. A total of 35 sample sheets were collected for data analysis.

Without using any spot color inks, the accuracy of 25 chosen spot colors can be achieved to an average of ΔE_{00} 1.6, with no patches having an error greater than ΔE_{00} of 3. The average color variation through the press run was ΔE_{00} 0.4 for lead-edge vs. tail-edge and ΔE_{00} 0.33 from-sheet-to-sheet. Variation between left and right sides of the sheet is slightly higher with the maximum ΔE_{00} of 2.16 and average of 0.59. The variation on press was mainly caused by the repeatability of the black ink printing unit. The consistency can possibility be improved by resolving the repeatability issue on the black unit.

The study also confirmed that the variation on press for ECG printing was not caused by the color distance to the hue line of the process inks. It was not caused by adding orange, green, and violet inks into the color separation. It was not caused by the total area coverage of the inks. On the other hand, ECG process reduced the number of color inks needed and the ink coverage. ECG provides a way to an efficient production and reduces makeready time and the material waste.

For printers to implement ECG process printing for brand colors, the achievable colors can be reproduced in a consistent and accurate manner provided with a good and repeatable printing process condition and with proper calibration and profiling. If a printer has a repeatable system for a CMYK process printing or for spot color printing, the printer will have no issue to reproduce special colors consistently using the ECG workflow.

Introduction

“Brand colors” are a key component to a brand’s visual identity. Traditionally, the brand colors are defined with spot colors. The printing inks are formulated accordingly across a variety of process and substrates – carton, film, and coated paper, etc. to produce the required brand colors on the packaging. A package design commonly contains three or four spot colors including the brand colors. Over time, not only the print manufacture accumulates leftover spot-color inks, but also more waste was generated during make-ready and in the process of changing inks on press when dealing with multiple jobs that require various spot-color inks. With sustainability in mind, more and more printers are looking for ways to reduce waste and to optimize material management. The extended color gamut (ECG) process printing offers just the solution to achieve a sustainable production.

Conventionally, the process printing involves using cyan (C), magenta (M), yellow (Y), and black (K) inks for the image reproduction. The ECG printing is a print reproduction process that uses orange (O), green (G), and violet (V) inks in addition to the CMYK process inks. The three additional inks serve to expand the color gamut. The use of an ECG ink-set to replace spot colors reduces in press wash-up time and spot color ink inventory, by using ECG process, it improves productivity with the options to gang up different brand color jobs.

Yet brand owners and printers have doubts: how accurate and consistent can the press hold the ECG process colors through the production run? With one spot color ink, the press operator only needs to control that one color. After the spot color is converted to ECG process color, the same design element comprises multiple process colors, which seems to introduce more variables. They suspect the separated color can easily fluctuate on the press.

With a joint project between Sun Chemical and ESKO, a press trial was designed to investigate the following:

- How accurate can the predefined spot colors be reproduced in a SunECG workflow including the color at the edge of the gamut?
- How consistent are the ECG colors from “within the sheet” and from “sheet-to-sheet” throughout the run?

Methods

An ECG press trial was conducted at Sonoco Institute, Clemson University, Clemson, SC, using Esko Equinox color management software and separations, in conjunction with Esko HD screening and XPS Crystal platesetter. Printing was done on the seven-unit OMET VaryFlex 530 flexographic mid-web press with UV LED flexographic ECG process color inks from Sun Chemical and the coated paper label house stock.

With the selected screening system setting, plate, ink, and substrate, two press runs were conducted for calibration then for profiling. The third press run was prepared using the resulted profile to convert the special designed press form that contains 25 spot colors into CMYKOGV process colors through ESKO Equinox system. The third run was kept at a production speed and lasted for more than 50 minutes continuously. Sample sheets were collected from the third run and much of the color data was collected and analyzed.

This special designed press form contains a test chart “SunECG25” that was placed step-and-repeat, four across and six down, in an 18″ by 32″ form to mimic the production in label printing. In the center of the press form is ESKO SpotCheck 600 chart, which contains 600 PANTONE spot colors. Below it, the tone scales of seven process colors and the overprints of neighboring colors. The placement of the SunECG25 chart in the press form is labeled in a grid system as indicated in Figure 1.

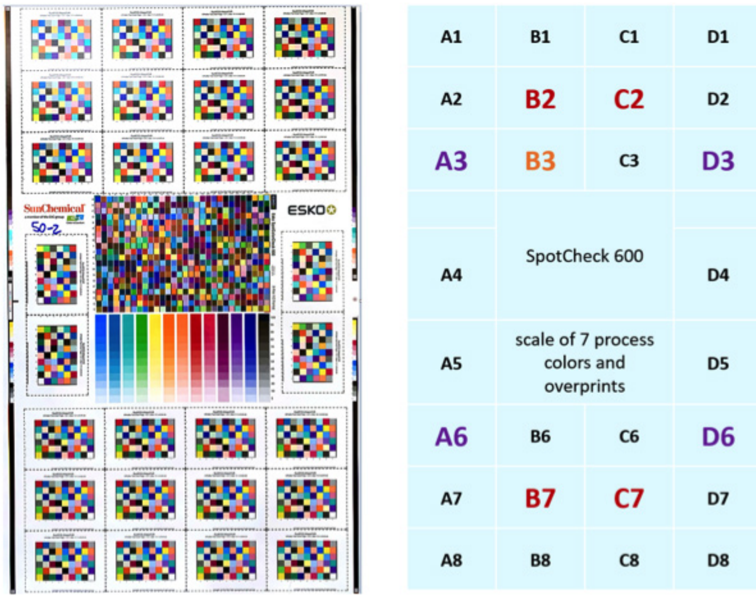

Figure 1: *Photograph of the press form and the placement identifier of the SunECG25 test chart.*

The first part of the SunECG25 test chart contains 25 spot color patches. These 25 PANTONE spot colors were identified as in the gamut for the trial condition and include in-gamut colors that are high in Chroma from 12 various hue angles, for testing near edge-of-gamut performance; 6 gray colors at various L* levels to test how well the separation software handles metamerism in grays; 7 pastel colors with various hue to check capabilities in the highlight area. The second part of the test chart contains 28 patches of process colors – there are CMYKOGV each at 25%, 50%, 75%, 100%. The last patch in the test chart has no color value assigned and is used for substrate color measurement.

The patches were then randomized when placing into a format that is suitable for i1iO. (Figure 3)

iO-Patch	ColorName	iO-Patch	ColorName	iO-Patch	ColorName	iO-Patch	ColorName
A1	PANTONE 198 C	B4	PANTONE 9081 C	G2	Cyan 100	G5	Orange 100
B5	PANTONE 165 C	C1	PANTONE 413 C	E2	Cyan 75	I2	Orange 75
D2	PANTONE 1235 C	A4	PANTONE 7539 C	H3	Cyan 50	F2	Orange 50
A6	PANTONE 604 C	B6	PANTONE 2333 C	F4	Cyan 25	E6	Orange 25
A5	PANTONE 2269 C	C2	PANTONE 2336 C	H1	Magenta 100	I4	Green 100
C6	PANTONE 7724 C	D4	PANTONE 447 C	F6	Magenta 75	E3	Green 75
A2	PANTONE 7465 C	B2	PANTONE 9220 C	I3	Magenta 50	G6	Green 50
B1	PANTONE 632 C	C5	PANTONE 9160 C	G4	Magenta 25	G1	Green 25
B3	PANTONE 653 C	A3	PANTONE 9581 C	H2	Yellow 100	F3	Violet 100
D6	PANTONE 2117 C	D1	PANTONE 9504 C	G3	Yellow 75	I5	Violet 75
E1	PANTONE 2612 C	D3	PANTONE 9423 C	E4	Yellow 50	H4	Violet 50
C4	PANTONE 675 C	D5	PANTONE 9283 C	H5	Yellow 25	F5	Violet 25
		C3	PANTONE 9561 C	E5	Black 100	I6	Substrate
				H6	Black 75		
				F1	Black 50		
				I1	Black 25		

Figure 2: *Color name of each patch used in SunECG25 organized and grouped by their color values.*

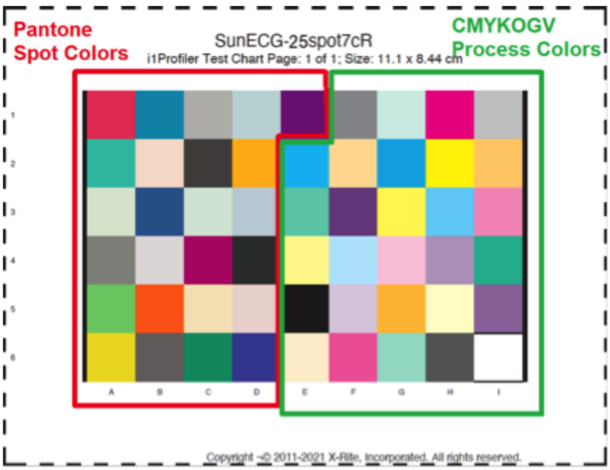

Figure 3: *The colors in figure 2 are randomized and put into a test chart format suitable for i1iO. The chart was then placed into the press form layout.*

Once the press was up to the color in the third press run, a length of 5250 linear footage was run at the speed of 100 feet per minute continuously, without stopping. Upon completion of the run, the printed roll was rewound, and one sheet was cut and pulled at every 150 feet, which gives a total of 35 sample sheets throughout the 5250-foot run. From these 35 sample sheets, SunECG25 charts at the placement of B2, C2, A3, B3, D3, A6, D6, B7, C7 in the form (see Figure 1.) were measured using an i1iO and the M0 spectral data was recorded for data analysis.

"Library value" and "achievable values" are used in the analysis. The "library value" is the original digital color value of the spot color that was specified in the PANTONE PLUS Library and were loaded into the prepress system for color separation. The "achievable value" is what theoretically achievable on the press with the printing condition including inks and substrates, etc.

In this study, the achievable values are what to be expected when producing using CMYKOGV process color and is therefore expected to report a lower ΔE when comparing the achievable value and the printed results. CIEDE2000 formula was used with all color difference calculation in this study.

Results and Discussion

Hue Angle Analysis: UV LED flexographic inks of CMYKOGV used in the press trial were within the guideline of Flexographic Image Reproduction Specifications and Tolerances (FIRST). CMYK colors are conforming to the ISO 12647 standard. The hue angle of the orange color was 53-degree, 183-degree for the green, and 308-degree for the violet.

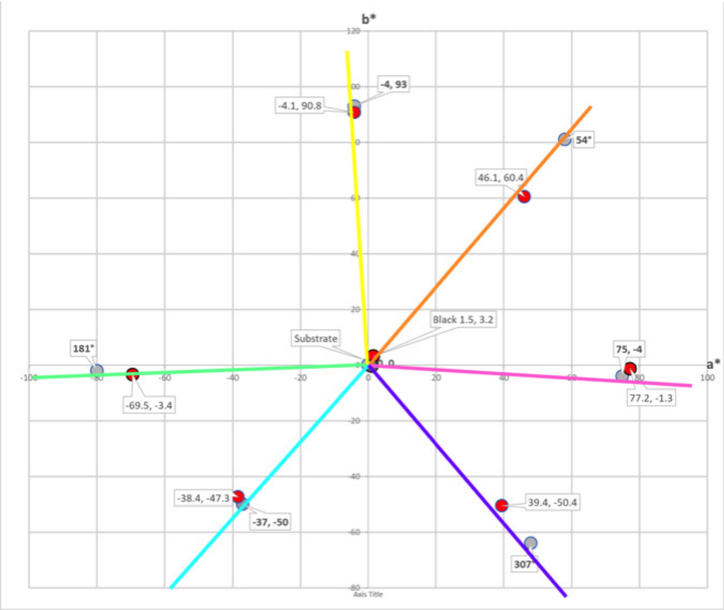

Figure 4: *Hue angles of CMYKOGV in comparison to the FIRST guideline.*

Gamut Analysis:

In figure 5, the substrate paper white and 100% solid color of CMYKOGV are plotted in the color space. The lines connecting the squares shows the extent of the gamut of the printing system. 25 SunECG colors are plotted as round dots and the figure shows these selected spot colors are in the gamut or at the edge of gamut of the printing system. From this view of color space, PANTONE 165 C, an orange color, appears to be out of gamut. This color has a ΔE_{00} color difference of 1.91 and is consider right at the edge of gamut in this printing system.

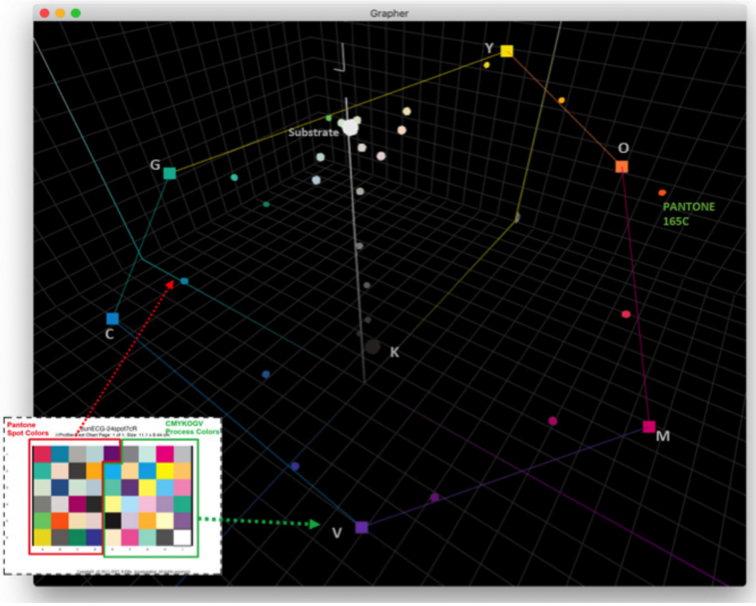

Figure 5: *Gamut plot vs. 25 chosen spot colors.*

In figure 6, both the library and the achievable values from ESKO SpotCheck 600 and Sun ECG25 were plotted in the CIELAB space with a line connecting from the Library to the Achievable of each color. In-gamut colors are expected to have a lower ΔE between the two values and appear as dots in the graph. The farther outside the gamut the library value is, the longer the line appears in this graph. Gamut size is more limited in the purple/violet area just the same as in CMYK process printing and in spot color ink formulation. Out of the 625 spot colors, the maximum ΔE_{00} is 10 for PANTONE 252 C.

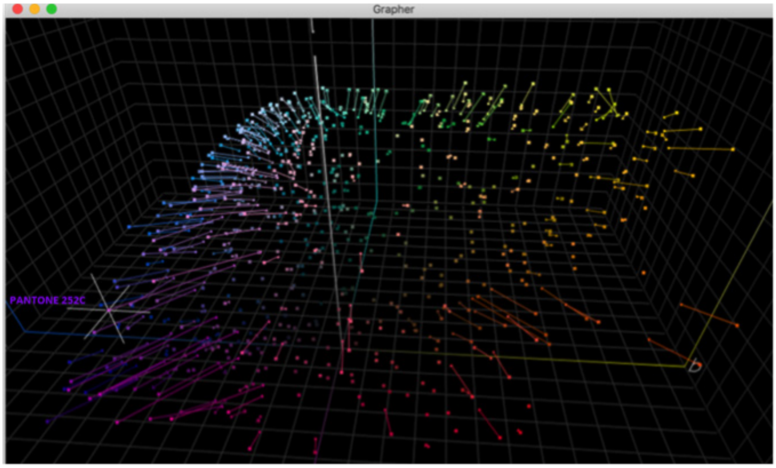

Figure 6: *Movement of 625 spot colors converted to CMYKOGV process colors.*

Color Accuracy:
The SunECG25 chart at the B3 placement (figure 1) from 35 sample press sheets were spectrally averaged to compare to the color values from the PANTONE PLUS Library and to that of the achievable values calculated from Equinox. Figure 7 shows the accuracy of the seven-color simulation of spot colors comparing to library values and to achievable values.

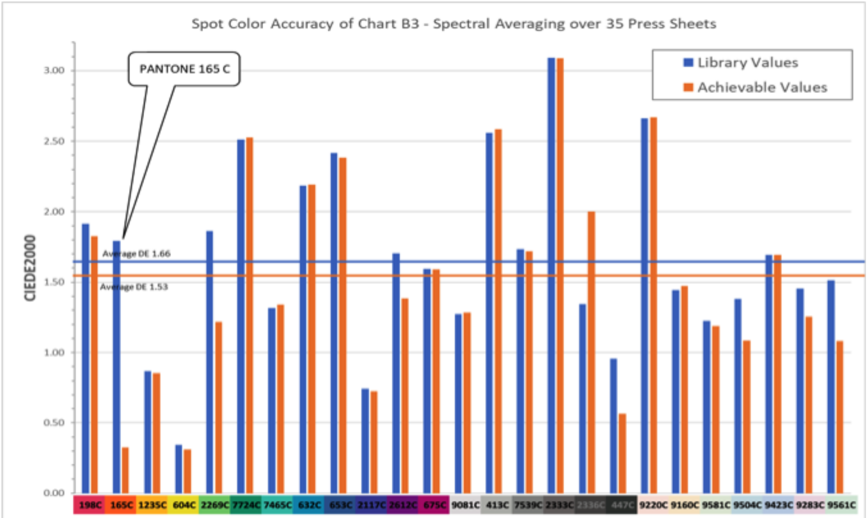

Figure 7: *Spot color accuracy of chart location B3 – spectral averaging over 35 sample sheets.*

Both datasets produce reasonable average ΔE values. The maximum error is identical for both datasets at ΔE_{00} 3.09 CIEDE2000 with PANTONE 2333 C, which is a near exact mid-tone gray with L*a*b* of 46.5, 1.05, 2.54. Average ΔE_{00} drops from 1.66 to 1.53 when switching from library to achievable values. ΔE_{00} for the out-of-gamut color PANTONE 165 C drops from 1.8 to 0.33 when using its achievable value. This shows the benefit of specifying an achievable value and confirms the role and purpose of the achievable value. For a printer, it's important to manage customer expectations.

In addition to Sun ECG25 color from the B3 placement, three sheets were pulled from the beginning, the middle, and the end of the third run and SpotCheck 600 was measured and averaged. Figure 8 shows the color accuracy of the printed results versus the library and the achievable for both Sun ECG25 and SpotCheck 600.

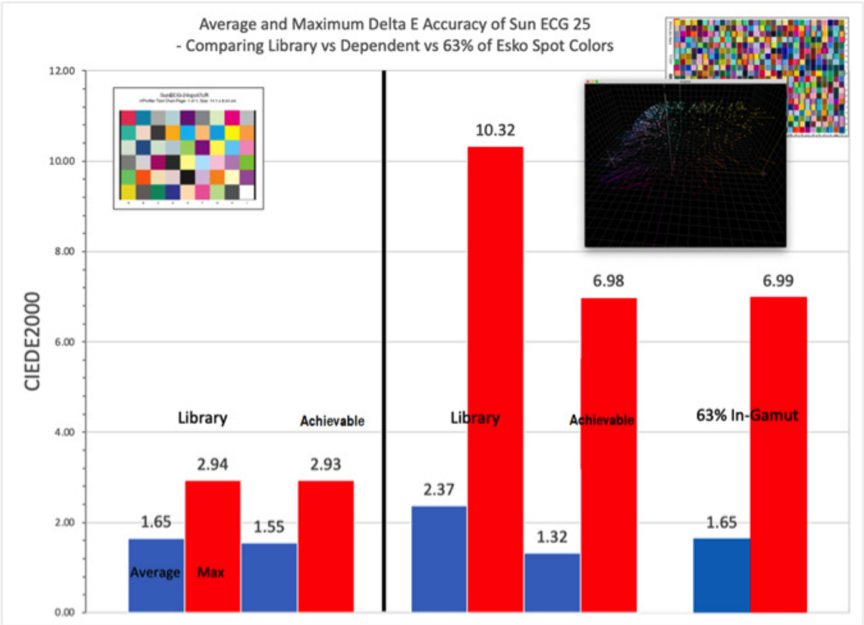

Figure 8: *Spot color accuracy of chart location B3 – spectral averaging over 35 sample sheets.*

Sun ECG25 was designed with in-gamut spot colors so it shows similar result, not changing as much for library vs. achievable values. SpotCheck 600 chart is a standard test set and are improved by consideration of achievable values. Both datasets produce reasonable average ΔE_{00} values of 1.55 or 1.32 with the achievable values. 63% or 377 of SpotCheck 600 are in-gamut colors with the $\Delta E_{00} < 1$ between library and achievable. Considering only these in-gamut spot colors, the result on press showed the average of ΔE_{00} 1.65 and the maximum of ΔE_{00} 6.99. The error for this in-gamut subset represents the accuracy of the overall process (software, printing, measuring, etc.) for the larger data set. Further investigation was done to identify the root cause of this large error on the in-gamut color. The result is reported in the section about press consistency.

Variation within a Sheet – Upper vs. Lower: The result of within-sheet variation includes the analysis for upper vs. lower (or lead-edge vs. tail-edge) and left vs. right. Out of the 35 pulled sample sheets, the averaged spectral data of B2 and C2 locations was compared to the averaged spectral data of B7 and C7 locations to show the upper versus lower variation within a sheet. The average ΔE_{00} of upper-lower variation was 0.4 with the maximum of 1.03, which is normal press variation. The largest ΔE's are the neutrals, which is likely a manifestation of how CIEDE2000 perceptually weights neutral colors.

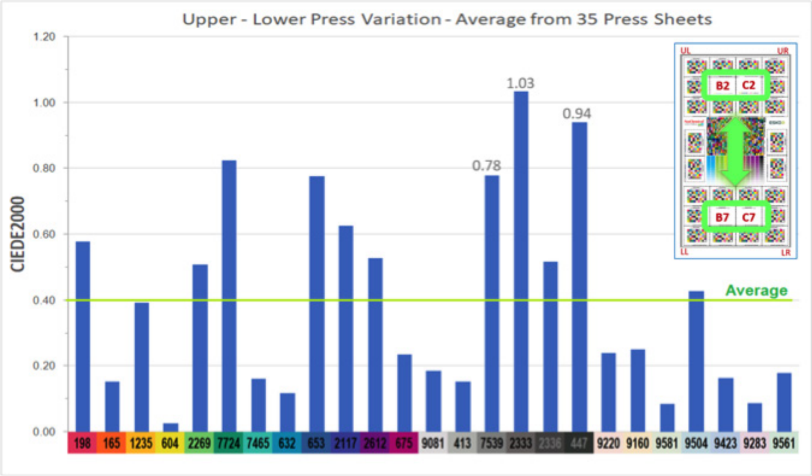

Figure 9: *Upper-Lower press variation – average from 35 press sheets.*

<u>*Variation within a Sheet – Left vs. Right:*</u> The averaged spectral data of A3 and A6 locations was compared to the averaged spectral data of D3 and D6 locations to illustrate the left versus right variation within a sheet. The average ΔE_{00} of left-right variation was 0.59 with the maximum of 2.16 – the largest ΔE's are the blues and the neutrals.

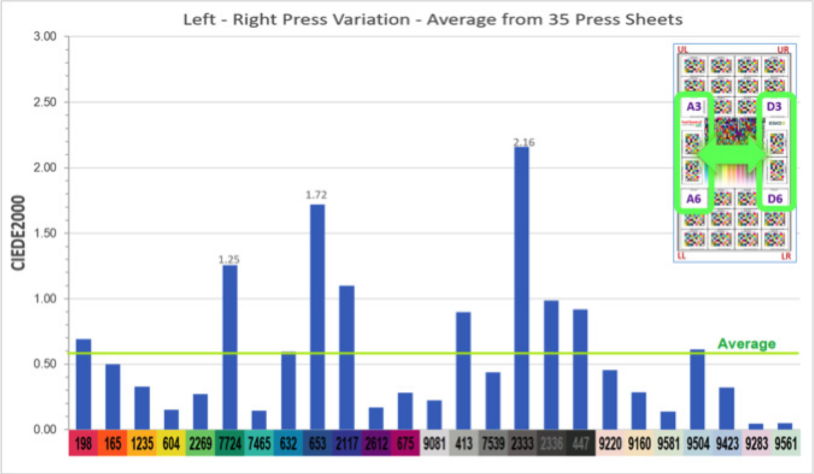

Figure 10: *Left-Right press variation – average from 35 press sheets.*

<u>*Variation from Sheet to Sheet – MCDM:*</u> The mean color value of B3 location from 35 sample sheets was calculated and compared to each of the 35 sheets. By using Mean Color Difference from the Mean (MCDM) of each color, it shows the repeatability throughout the run. The average MCDM is ΔE_{00} 0.33 with the maximum of 0.64 for PANTONE 7539 C. Lighter colors show more consistency from sheet to sheet.

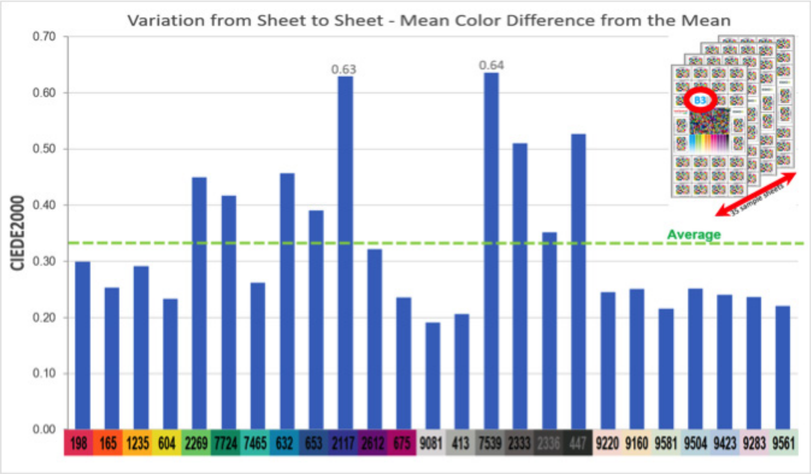

Figure 11: *Variation from sheet to sheet – Mean Color Difference from the Mean.*

<u>*Consolidated – Consistency & Accuracy:*</u> Combining all the analysis result for consistency and accuracy of Sun ECG25 into one single chart, figure 12 shows that pastel colors have average accuracy and great stability. PANTONE 2117 C and PANTONE 447 C are very accurate but very variable on press. PANTONE 2333 C is both inaccurate and unstable during printing. Followed by PANTONE 653C and PANTONE 7724 C.

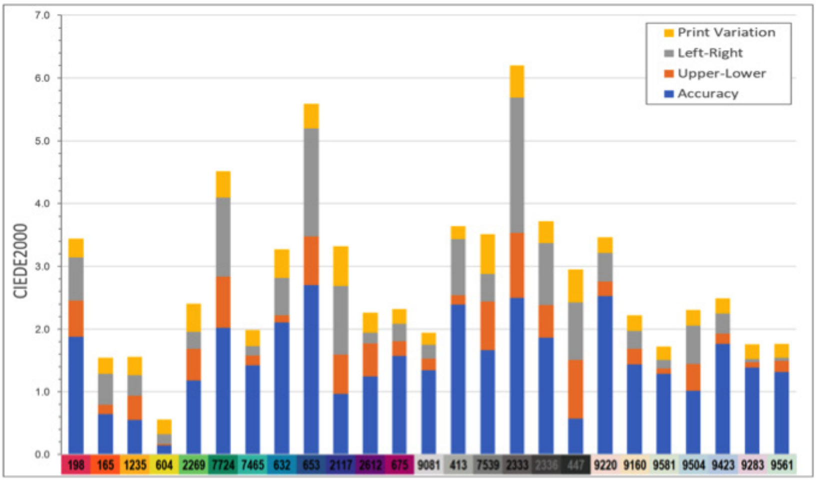

Figure 12: *Consolidated – consistency & accuracy of ECG colors*

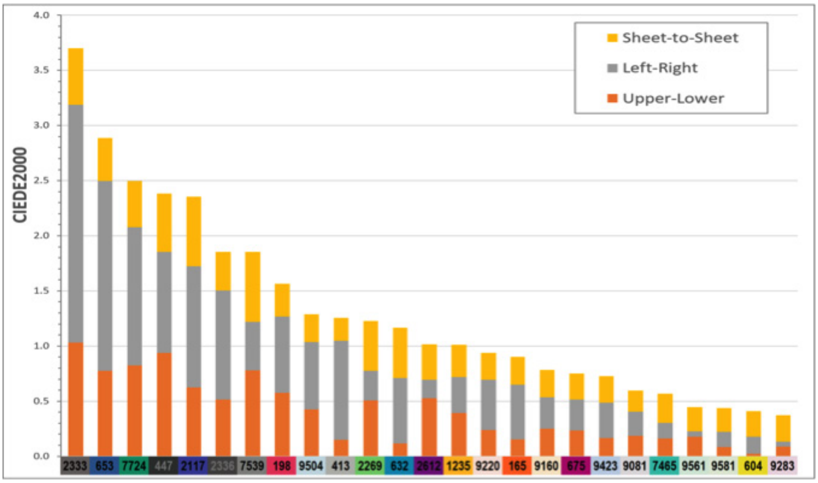

Figure 13: *On press variation*

Figure 13 has the data or accuracy removed from the chart in figure 12 and shows only the ΔE's of on-press variation that include sheet-to-sheet, left versus right, and upper versus lower. The results are sorted by ΔE from high to low.

These 25 colors were identified as in-gamut colors, what is the cause of high ΔE? Here are some hypotheses.

- They are dark green, dark gray, dark blue, or neutral colors.
- One or more printing units were unstable.
- The hue angle of the color is farther away from the closest hue line out of CMYOGV.
- The use of orange, green, violet introduces variables.

<u>*Press Variation:*</u> The mean color value for each of the 25 colors were calculated from nine placements of the press form for all 35 sample sheets. Using the mean color value as the standard, the time series plot of each color is shown in figure 14, which includes all the data from within sheet and from sheet-to-sheet. A stable color would show very little movement in this plot. A color with ΔE bouncing up and down would indicate higher variation. In figure 14, PANTONE 2333 C, PANTONE 2336 C, PANTONE 653 C, and PANTONE 2117 C are showing higher variation, or less stable. Especially for PANTONE 2333 C and PANTONE 653 C, there seems to be a pattern for their variations. To make it more comprehensible visually, the color patch in a color that approximates the named spot color is placed in its own section for the time series plot. In figure 15, only the color patches with low variation are displayed. They include colors that are higher in Chroma, or higher in Lightness. Colors in various hue areas can be produced consistently. Not only the yellow, orange, red, and purple, but also the blue, and green colors. So, the high variation is not due to the hue angle.

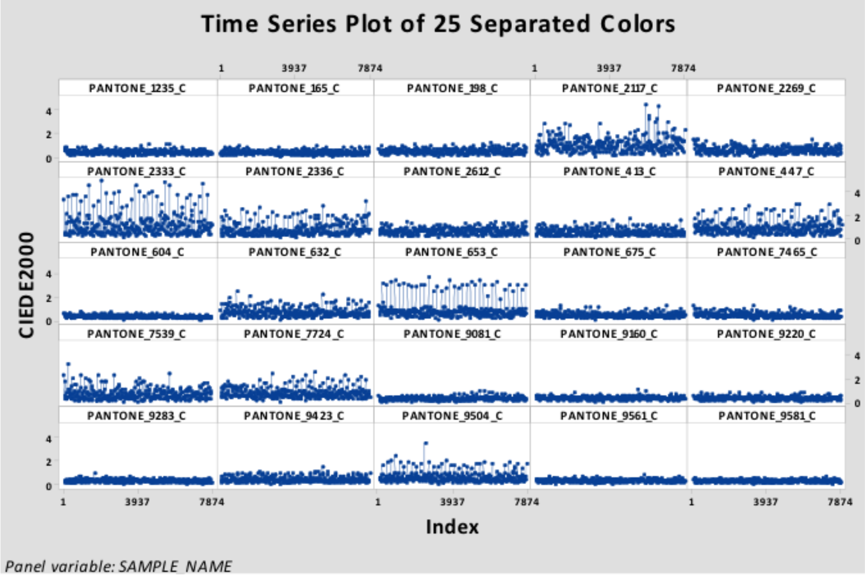

Figure 14: On press variation for each of the 25 chosen colors.

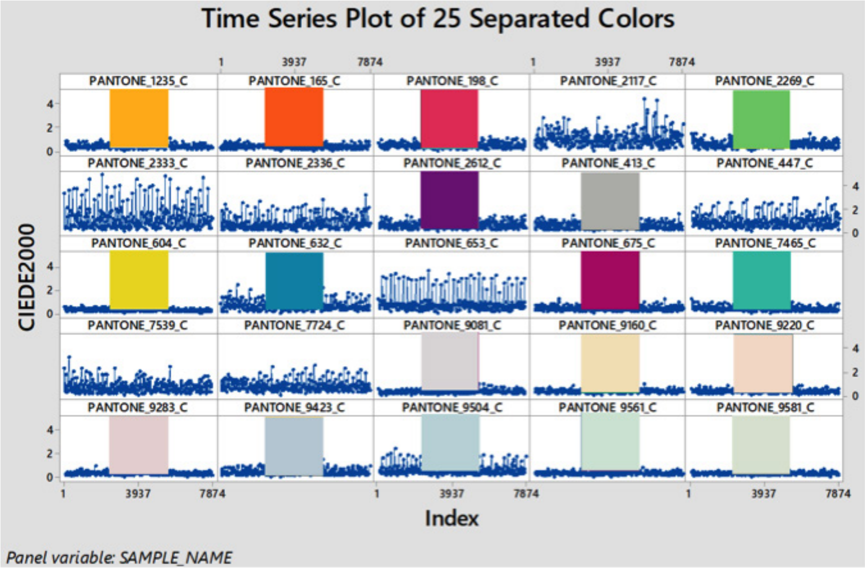

Figure 15: Color patches with low press variation.

Figure 16 shows only the color patches with high variation. These are dark gray, dark blue, and darker green colors. From here, we speculate the variation was caused by the black ink printing unit. Or maybe the cyan ink unit or the green ink unit depending on the color separation for the blue and green PANTONE colors.

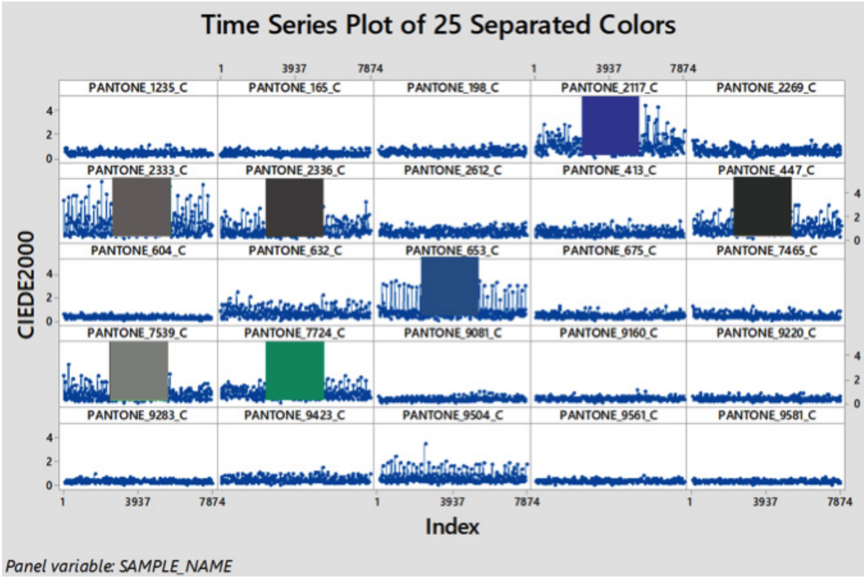

Figure 16: *Color patches with higher press variation.*

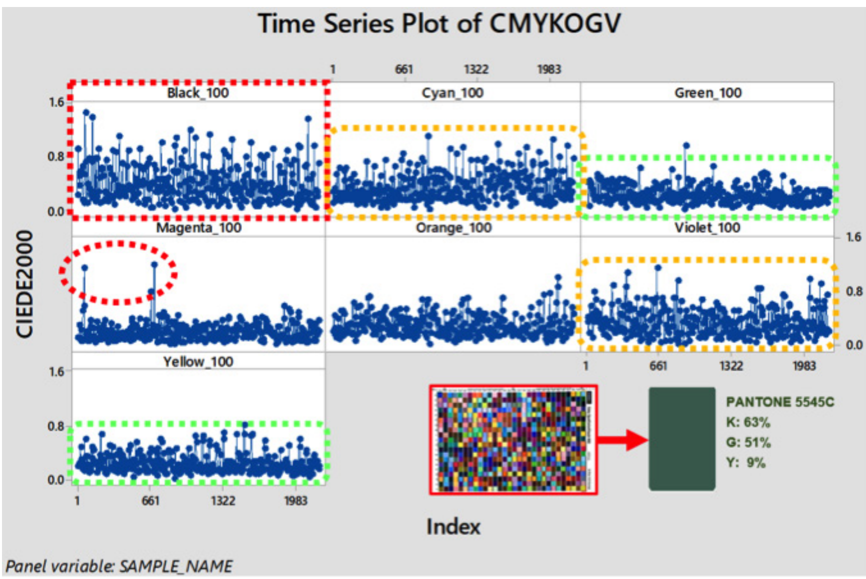

Figure 17: *Color variation of each printing unit.*

Using the same method to calculate the mean color value for each of the CMYKOGV process colors, the time series plot was created, figure 17, to show the variation of each printing unit. The yellow and the green units look very stable. The magenta unit is considered stable with a couple hiccups. The violet and the cyan units show more variation, but the black unit has the highest variation among the seven process colors with multiple ΔE above 1.

As mentioned previously in color accuracy analysis, PANTONE 5545 C from SpotCheck 600 is an in-gamut color but produced a ΔE_{00} of 6.98. The color was separated into black, green, and some yellow. The variation in the black unit certainly affected the color accuracy of this in-gamut color.

Further looking into the variation on the black printing unit, using the location on the press form as the variable, both ΔE_{00} values (figure 19) and density values (figure 20) are plotted to show the variation for each location on the press form. We can see the density difference can be as high as 0.14. By using ΔE_{00} though, the color difference displays the variation in a more sensitive way. For the black ink for this press run, there are more variation at the "lead" edge (position 1 and 2) than the "tail" edge (position 8 and 9). The right side (position 5 and 7) is more stable than the left side (position 3 and 6). This variation has the same result as what was observed in the within-sheet analysis. Therefore, the conclusion is: the within-sheet variation during this press run was mainly caused by the variation of the black ink printing unit.

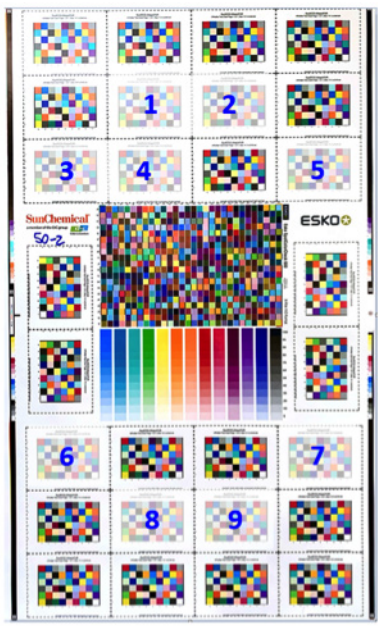

Figure 18: *Location identifier (1-9) in a press form used in variation analysis.*

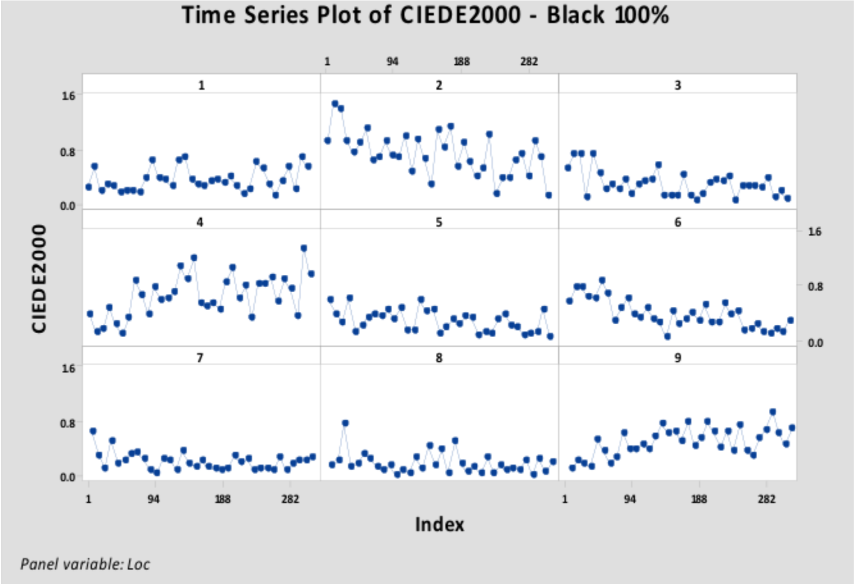

Figure 19: *Color variation of the black printing unit based on locations.*

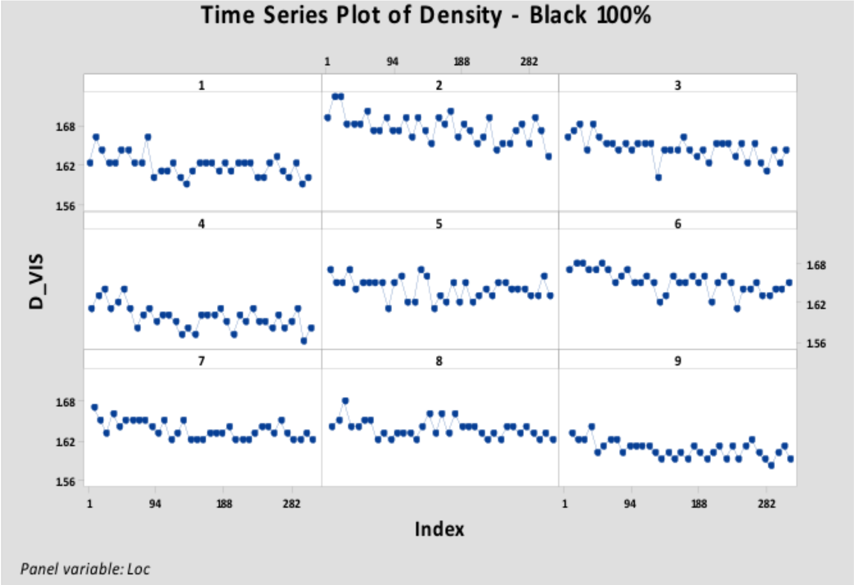

Figure 20: *Density variation of the black printing unit based on locations.*

Distance to the Hue Line of the Process Colors: One of the hypotheses for the cause of variation in ECG printing is that the hue angle of the color is further away from the hue line of the process color that's closest in hue. In figure 21, hue lines of the process colors yellow, green, cyan, violet, magenta, and orange are plotted in the CIELAB space, along with the coordinates of 25 chosen colors. If this hypothesis is true, PANTONE 198 C, PANTONE 2269 C, and PANTONE 1235 C, should have very high ΔE, colors that have very small distance from these hue lines should produce very small ΔE.

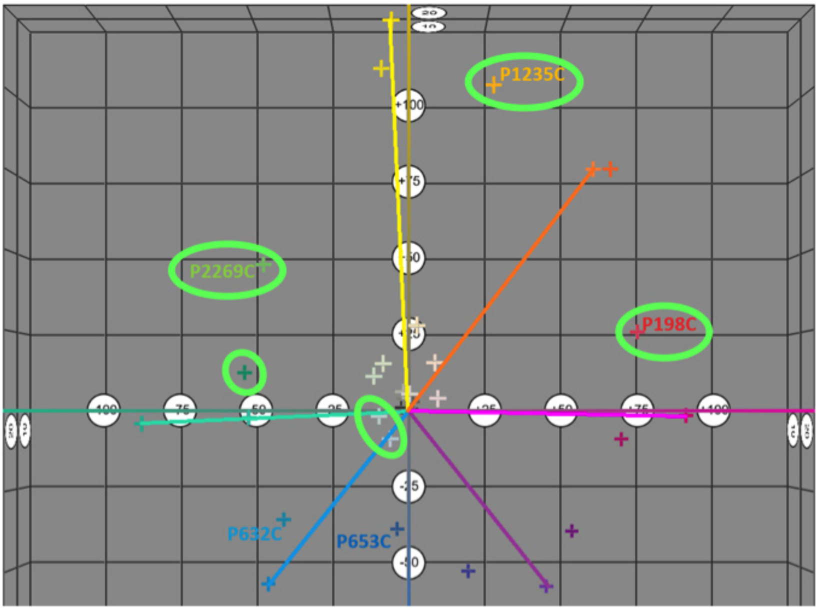

Figure 21: *SunECG 25 colors are plotted in the CIELAB space with the hue lines of CMYOGV process colors.*

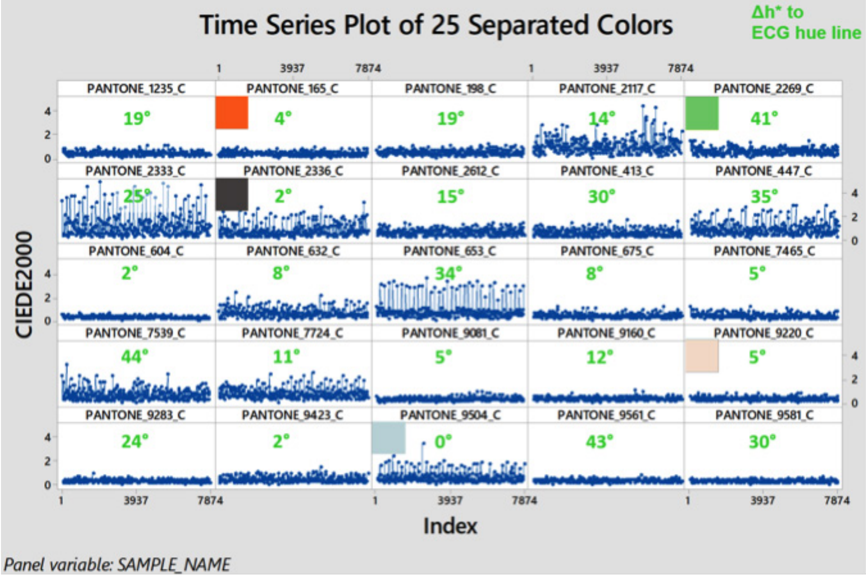

Figure 22: *Color variation of 25 separated colors with the info of its Δh° (in green) to the ECG color that is closest to it in hue angle.*

Figure 22 includes the Δh° of the color to the closest hue angle out of the CMYOGV process colors. PANTONE 2269 C is 41° from the hue line of the green ink but has very stable ΔE appearance. PANTONE 9504 C has almost the same angle as the green ink but shows much higher ΔE variation. Another example is based on the hue line of the orange ink. PANTONE 2336 C, PANTONE 165 C, and PANTONE 9220 C are all within 5° from the hue line of the orange ink. The latter two are very stable but PANTONE 2336 has a lot of variations. Therefore, the hypothesis of the color distance to the hue line is false. The variation of the color is not related to the hue angle difference to the process color.

Color Separation Using OGV: Figure 23 plotted the ΔE variation of each color along with the separation used at the bottom of the graph. PANTONE 2333 C has the highest variation and used only orange and black. PANTONE 653 C also has high variation, but it used cyan and magenta, without orange, green, nor violet. On the other hand, on the right side of the graph, there are several colors that used violet, orange, or green in their separation, but their performances were quite stable. Therefore, introducing orange, green, and violet to the color separation does not increase the color inconsistency. Another thing to be noted here is the cost and efficiency. Five out of the 25 chosen colors can be reproduced using the CMYK process. If the printer had decided to run a job like this, they would need to have 20 spot color inks. It will cost more to order four color process plus 20 spot color inks than order just 7 ECG process color inks, which is also more manageable for material management. In addition, the ECG workflow makes it possible to put 25 brand colors in one job, making it a more efficient production workflow.

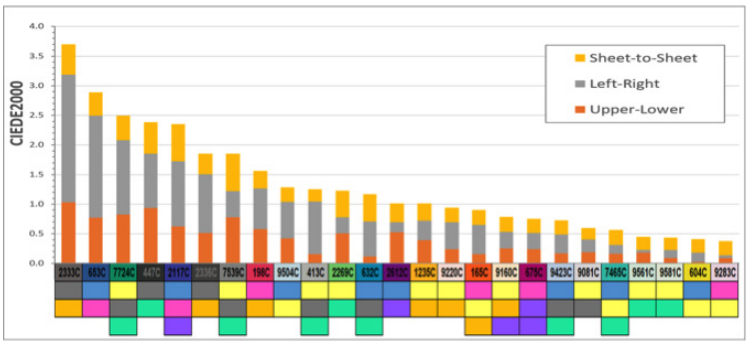

Figure 23: *Color separation used when converting the 25 spot colors into ECG.*

ECG 7-Color vs. 4-Color Process: CMYK color data was extracted from the profiling chart in the second press run and a CMYK ICC profile was generated from the extracted data. In figure 24, the lower part of the table shows how the color would have been separated in a CMYK workflow. Notice many of the darker colors use all four separation colors. When the same color is separated through Equinox ECG workflow, the example here shows mostly two or three separation colors were used. PANTONE 2333 C used only black and orange in the ECG workflow but would need all four separation colors in the CMYK workflow; PANTONE 675 C used only magenta and violet to achieve the color in the ECG workflow. (93% magenta, 29% violet.) But in the CMYK workflow, it would have needed all four separation colors (25% cyan, 93% magenta, 12% yellow, 7% black). At the first glance, ordering seven process inks would cost more than ordering for four process inks. However, ECG workflow can be implemented in a very efficient way. For example, a purple color might only need some violet and magenta in the ECG workflow. But in the CMYK workflow, it would need a lot more cyan and magenta to achieve that purple color.

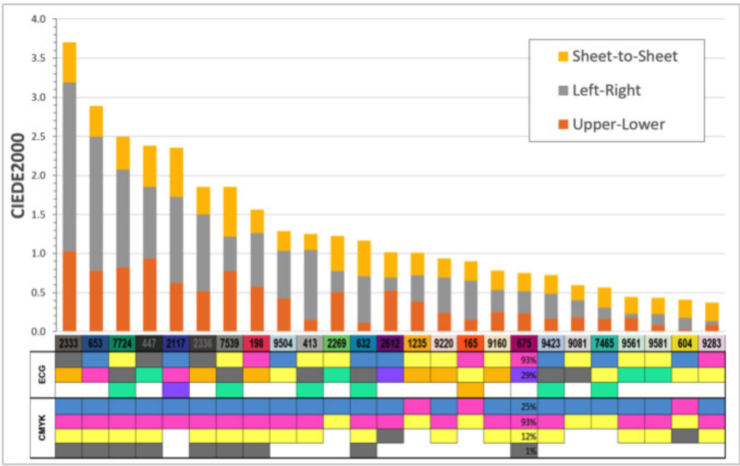

Figure 24: *Color separation using ECG versus CMYK.*

When looking at the Total Area Coverage (TAC) for each of the 25 chosen colors as shown in figure 25, in average it is 67% more when separated colors into the CMYK process. Examples here are PANTONE 2269 C, PANTONE 198 C, and PANTONE 653 C. When separated these spot colors into the ECG process it requires less ink and use the color more efficiently.

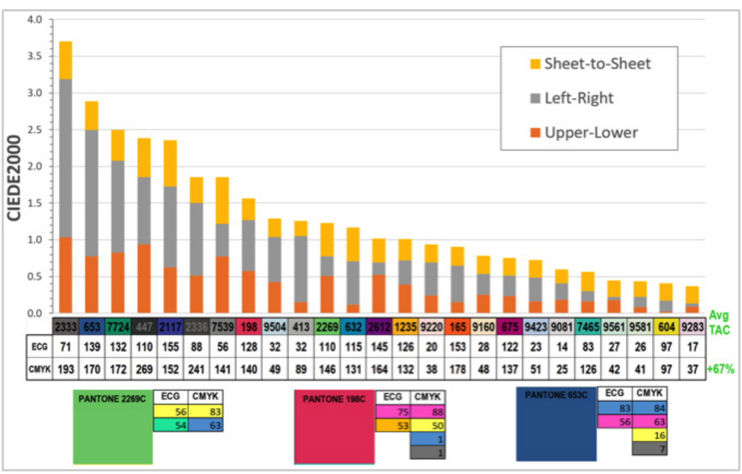

Figure 25: *ECG cost benefit from the perspective of TAC.*

Conclusion:

Without using any spot color inks, the accuracy of 25 chosen spot colors can be achieved to an average of ΔE_{00} 1.6, with no patches having an error greater than ΔE_{00} of 3. The average color variation through the press run was ΔE_{00} 0.4 for lead-edge vs. tail-edge and ΔE_{00} 0.33 from-sheet-to-sheet. Variation between left and right sides of the sheet is slightly higher with the maximum ΔE_{00} of 2.16 and average of 0.59. The variation on press was mainly caused by the repeatability of the black ink printing unit. The consistency can possibility be improved by resolving the repeatability issue on the black unit.

The study also confirmed that the variation on press for ECG printing was not caused by the color distance to the hue line of the process inks. It was not caused by adding orange, green, and violet inks into the color separation. It was not caused by the total area coverage of the inks. On the other hand, ECG process reduced the number of color inks needed and the ink coverage. ECG provides a way to an efficient production and reduces makeready time and the material waste.

For printers to implement ECG process printing for brand colors, the achievable colors can be reproduced in a consistent and accurate manner provided with a good and repeatable printing process condition and with proper calibration and profiling. If a printer has a repeatable system for a CMYK process printing or for spot color printing, the printer will have no issue to reproduce special colors consistently using the ECG workflow.

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