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Accuracy of spot color reproduction in a 7-color, expanded gamut, flexographic printing system

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Abstract

Expanded gamut printing involves expanding the number of process colors (cyan, magenta, yellow and black) by orange, green and violet colors to reproduce many spot colors with the new fixed ink set (CMYKOGV). This study focuses on evaluating flexographic expanded gamut printing on a narrow web flexographic label press located at Toronto Metropolitan University. Esko Equinox and GMG OpenColor expanded gamut software solutions were used, where each system was tested with its own proprietary characterization test chart. The Idealliance Expanded Color Gamut (ECG) test target was also used in this study. A verification test chart was created, with selected Pantone spot colors. The test chart was then processed using the characterization data from the proprietary and nonproprietary characterization press runs. The builds of the selected Pantone colors were analyzed and CIEDE2000 color difference was calculated. Both software solutions did better in regards to color accuracy with their proprietary characterization targets than using the data gathered from the Idealliance ECG small chart.

Keywords: extended color gamut, flexographic printing, Pantone spot colors, test chart, print contrast

1. Introduction

Flexography printing has been dominating the packaging industry for a decade due to its economical and fast process, ability to print on a wide variety of substrate materials such as corrugated cardboards, label stock, and metallic film, with minimal breakdowns and low maintenance cost.

Traditionally in flexography, printing a package with additional spot colors means setting four-color process units along with an additional one to three units dedicated for spot colors. This usually results in a loss in make-ready for changing the plates and loading spot color onto the press for the next run. This is time-consuming as additional time would be wasted just to make sure the spot colors are correct. This is also material intensive as any leftover ink needs to be stored for possible reuse in the future.

As flexography continues to develop methods and approaches to improve its productivity and quality, the challenge to overcome issues related to reducing cost, decrease make-ready time, and consistent reproducing spot colors becomes the new reality for many companies. Implementing expanded gamut technology would help to resolve such challenges.

Expanded gamut printing involves adding three colors, orange, green, and violet (OGV) to the conventional process colors cyan, magenta, yellow, and black (CMYK) to expand the gamut of a printing press. Thus, achieving more spot colors reproduction using the combination of these process colors set without the need of having the actual spot color in the printing unit. And therefore, improving production efficiency with less ink and material used, less make-up ready time on the press, and more press capacity while achieving up to 90 % of the Pantone Plus book (Ellis, 2017).

1.1 Historic developments of expanded gamut printing

The concept of expanded gamut printing has been around in the last century with different implementations and approaches until what we know today (Balasubramanian, 1999; Van De Capelle, 2006; Simoni, Butler and Deighton, 2017). The history of this technology has been discussed and covered in several publications – by John Seymour in two articles (2018a, 2018b), Habekost and Grusecki (2019) and El Asaleh, Habekost and Biga (2020).

In the early 1990's the High-Fidelity (HiFi) color printing technology was introduced by Mills Davis and Dan Carli. Similar to expanded gamut, HiFi color printing employs adding other inks to the standard CMYK process colors for wider colors reproduction on the press. Some common HiFi Color systems are Pantone Hexachrome (CMYKOG), Küppers (CMYKRGB), DuPont's HyperColor, and ColorBlind MaxCYM (CMYKCMY). This concept was widely used in offset printing (Hutcheson, 1999).

Expanded gamut as it is understood today goes beyond CMYK printing by adding OGV colors. The benefits of expanded gamut printing have been nicely summed up by Baldwin (2016). The benefits are as follows:

- Ink savings (only seven colors are needed, no spot colors)
- Reduced press characterizations
- Reduced wash-ups
- Ganging jobs
- Material savings (inks and substrates)

At the 2019 TAGA conference, Hargrove (2019) demonstrated with data from a print company that printed the same job(s) conventionally and later with expanded gamut technology that there was a cost reduction of $845 from the original cost of $2 285 to $1 440. The company needed half the make-ready time and half the press time. There were fewer wash-ups, less ink waste and the job had less of an environmental impact.

While most approaches were mainly focused on publication and commercial offset printing, other research focused on testing different approaches to implement expanded gamut printing in flexography. For instance, in the study by O'Hara, Congdon and Lindsay (2019) the research team reduced the chroma of OGV colors from 100 % to 80 % in 10 % increments.

The main points from the study were:

- The greatest chroma of the OGV colors does not mean the largest gamut volume.
- The greatest chroma does not mean the most Pantone colors. Low chroma inks can often make more Pantone colors.
- The greatest gamut volume does not mean the most Pantone colors.
- The ink film thickness appears to influence the gamut size beyond its influence on the chroma of solids.

A review of the latest technological and fundamental evaluations in multicolor printing was demonstrated in the paper of Politis, et al. (2015). The study also summarized research results from two latest studies in expanded gamut printing with silk-screen and flexographic printing. The study tested several color separation and screening techniques and it was concluded that the quality of expanded gamut would be achieved and standardized with a fixed set of six or seven colors.

The Flexo Quality Consortium group researched to test the concept of expanded gamut technology in flexography printing (Rich, 2012). The study concluded that this concept has promising benefits and results especially if there are 10 or more stations available to handle CMYKOGV inks with the addition of white ink, metallic inks, and clear coating. Moreover, it was concluded that using the CMYKOGV ink set would increase gamut across various tested substrates used in their study.

Since expanded gamut printing is a hot topic in the industry at the moment many premedia software solutions are available to implement seven color printing. All these software solutions require that characterization charts need to be printed on the press together with the inks and substrate that will be used for expanded gamut printing, so the software knows what the gamut of the process is. The number of test patches on these characterization charts is also a topic of discussion. For instance, Hoffstadt (2019) gave a presentation at the 2019 TAGA conference on the ideal number of test patches for expanded gamut printing. The study suggested that the ideal number of test patches should be between 1 000 and 5 000 patches.

In the summer of 2019 Sharma (2019) conducted an evaluation of spot color reproduction in multicolor printing. Several software vendors participated in the study. A test chart was created and processed through various software solutions. The aim of this study was not to determine which solution was the best, but how each software handled expanded gamut printing. One of the tests conducted in this study looked also at how a spot color was built using three, four or more colors. The study output the test charts on an Epson P9000 inkjet proofer and also on an HP Indigo 7900. There was no output of the test chart on a flexographic or offset press which is commonly used in the production of packaging using spot colors (Sharma and Seymour, 2020). In Europe, Fogra has also been active in the evaluation of expanded gamut solutions. In the research project on multiprimary printing in 2019 and at Color Management Symposium in February 2020 solutions for expanded gamut were shown (Li, 2021; Wessendorf, 2020). Participants in the Fogra study also processed a test chart and the color accuracy of the rendered Pantone colors was analysed.

Idealliance (n.d.) has also been quite active over the past few years and formed a committee to create a seven-color characterization target similar to the IT8.7/4 target used for four-color print characterization. This test target is available for free to anyone interested in expanded gamut printing. This project has a small 400 patch target and a large four-page target with 4 340 patches (35 × 31 patches on 4 pages).

Idealliance has created a task force that is part of the Print Properties Committee to come up with a standardized test chart that can be used by anyone with any color management software that can handle expanded gamut printing. In fall 2019 Idealliance (n.d.) released their test charts for expanded gamut printing. Version 1 of their test charts included a small test chart with 400 test patches and a large test chart with 4 340 test patches. Idealliance encourages the industry to test these charts and upload their measurement data to their website so the Print Properties Committee can evaluate the effectiveness of their two test charts.

The authors of the present paper have conducted earlier studies with expanded gamut printing in digital printing, inkjet printing and offset printing at the School of Graphic Communications Management and the results of these studies were presented at the 2019 and 2020 TAGA conferences (Habekost and Grusecki, 2019; El Asaleh, Habekost and Biga, 2020) and published in Color Research and Application (Sharma and Seymour, 2020). In response to interest from the community, we now evaluate flexographic printing.

2. Methods

The premise of this study was to get a better understanding of characterizing a press for expanded gamut printing with seven-color CMYKOGV process. The color press has only these seven process colors and is able to run even jobs with a number of spot colors on them.

Since printing with an expanded gamut is still relatively new there is no standardized test chart available like the IT8.7/4 for four-color offset printing except the above-mentioned test charts created recently by Idealliance. A number of premedia color management software vendors offer a solution for expanded gamut printing and use their own proprietary test chart that works with their software, but not with the software from another company.

2.1 Study parameters

In this study, the software solutions for expanded gamut printing from GMG Color and Esko were used. GMG's solution is called OpenColor. Esko's expanded color gamut technology is branded "Equinox" in which color measurements and transforms are made and stored in Curve Pilot and Color Pilot. In the current implementation, information from these two products was applied to PDF files via an Automation Engine workflow.

The School of Graphic Communications Management is in possession of a four-color narrow web 7" flexographic label press. In the summer of 2019, this press was extended by three additional print units and allows now to use the expanded gamut print process. Due to the limitations of the press, the Idealliance Small Chart (ISC chart) with 400 test patches was used in this study. The study consists of four main parts:

1. Optimization
   a. Determine the optimum combination of anilox rollers and ink viscosity for this study.

2. Curve Calibration
   a. Determine the curves for the seven process colors for optimum press performance.

3. Characterization
   a. Using the proprietary test charts from Esko and GMG and also ISC test charts
   b. Select up to 50 in-gamut Pantone colors for conversion to expanded gamut printing
   c. Create custom test charts for these 50 test colors
   d. Process this test chart with the color data from Esko, GMG and the ISC
   e. The data from the ISC chart will be processed with both software applications
   f. Create four PDF files of the 50 test colors that have been built with the data from the three characterization runs (see d.).

4. Verification run
   a. Print the four PDF files on one press sheet and measure the color data from them and compare for color accuracy with standard color values from Pantone for these colors.

2.2 Equipment used (software and hardware)

For this study a number of software and hardware was used, therefore the list is quite long.

Software:

- Esko Color Pilot v18.1.0
- Esko Curve Pilot v18.1.0
- Esko Automation Engine v18.1.0
- GMG OpenColor v2.4.1
- MS-Excel v16.45 for Mac

Hardware:

- Comco Cadet 700 – 7” narrow-web label press
- Inks: water-based flexographic inks from Siegwerk
- Anilox rollers with 1.8–2.5 billion cubic microns (BCM) volume and 800–1 000 lpi line count
- Media: Label Supply Extragloss LTR ‘Low Tack Removable’ 40#
- Plates: water-washable plates from Toyobo with a thickness of 0.067 inches were made to FIRST 6.0 specifications (Flexographic Technical Association, 2017)
- Micrometer: Mitutoyo Absolute digital micrometer
- Flexo plate analyzer: Betaflex system
- Flexo plate imager: Esko CDI Spark 2530
- Anderson & Vreeland Orbital X plate processor with CL-50 Whirl-A-Way AV Polymer Removal System
- Measurement instruments (spectrophotometers):
    - X-Rite eXact S/N 28618
    - X-Rite i1Pro2 S/N 1 104 522
    - Techkon SpectroDens S/N B312506

Measurement conditions: M1, D50 for all measurement instruments, status T. The pressroom had a relative humidity between 50 % and 55 % and the temperature was kept between 20 °C and 22 °C.

2.3 Press runs

It was mentioned earlier that this study needed four main press runs. These press runs were:

- Optimization run
- Curve calibration run
- Characterization run
- Verification run.

All press runs took place in the press lab of the School of Graphic Communications Management.

2.3.1 Optimization press run

This press run was designed to determine the best combination of ink viscosity and anilox rollers for each of the seven process colors. Two factors were taken into consideration for this evaluation. One was the printed color density that was achievable and the other one was which anilox volume can be used without causing dot bridging or other print defects. Another factor was also the available anilox rollers in the press lab. The dynamic ink viscosity was determined from measurements of efflux time with a Zahn cup #2. The optimum dynamic ink viscosities are listed in Table 1.

Table 1: Optimum ink viscosities for this study measured with a Zahn-Cup #2, converted to dynamic viscosity

Color	Viscosity (mPa·s)
Yellow	105
Magenta	90
Cyan	144
Orange	105
Green	105
Violet	90
Black	90

The press form used for this part of the study is a pre-made file that was supplied by Esko. An extended version of the actual calibration file that was used is shown in Figure 1.

2.3.2 Curve calibration press run

After the determination of the best combination of anilox rollers and ink viscosity for the seven process colors, a curve calibration run was required. This press run determines the plate curves for each color. Some colors might need cut-back curves, while others might require so-called bump curves.

The test chart used for this press run can be seen in Figure 2.

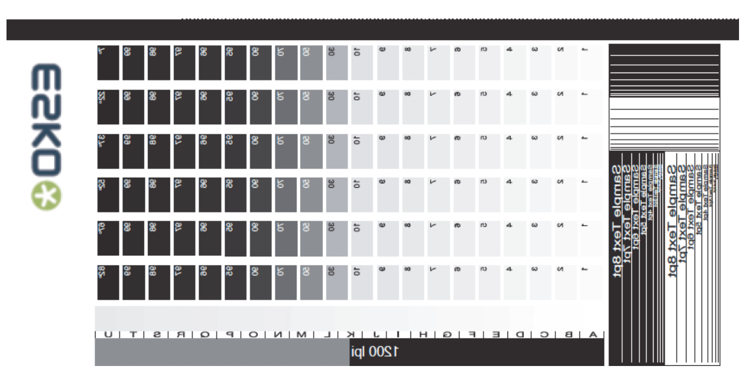


Figure 1: An extended version of the press form that was provided by Esko and used in the optimization run to determine the best combination of ink viscosity and anilox rollers for each of seven process colors

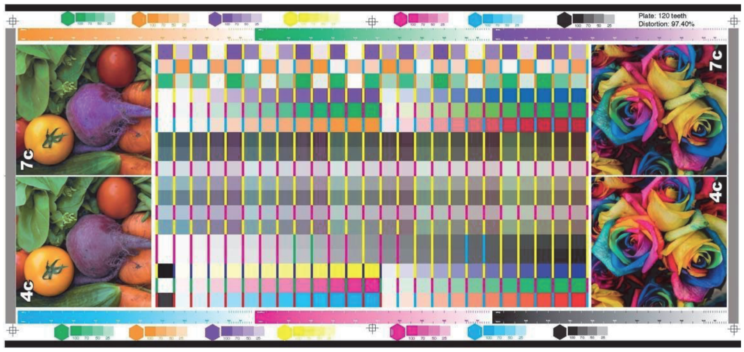


Figure 2: Test chart used for the determination of the tone value curves for all seven colors

The press run was conducted with the ink viscosities determined during the optimization run. Through the combination of ink viscosity and anilox roller used for each color, the target printed color densities were determined. For orange, green and violet the printed color density was measured using the Spot Color Tone Value (SCTV) mode on an X-Rite eXact according to ISO 20654 (International Organization for Standardization, 2017). Since the press used in this study is a manual press with no automatic doctor blade pressure settings and automatic setting of the ink fountain roller it took a couple of attempts to find the ideal settings. Once these settings were learned the following target printed color densities were established.

Table 2: Target printed color densities for all future press runs in this study

Color	Target printed color density
Yellow	0.75
Magenta	0.95
Cyan	1.31
Orange (λ = 450 nm)	1.17
Green (λ = 630 nm)	1.63
Violet (λ = 550 nm)	1.56
Black	1.24

Adjustment curves for all seven colors were determined using Color Pilot from Esko. It was also ensured that only opposing colors were placed on the same screen angle to avoid any moiré.

Three different characterization charts were used to evaluate the color behavior of the same printing process:

- Esko Equinox 4×4 EDK chart with 3 872 patches
- GMG OpenColor characterization chart with 700 patches
- ISC chart with 400 patches.

It is relevant to examine the color gamut that each of the three different characterization charts determines from the printing process. It is important that a characterization chart samples the color response of the system, not under sampling the color space with sparse data from which to create a color model, nor oversampling the color space wasting color patches that add no further information, all the while reaching the extremes of the gamut limits. In fact, the choice of the correct number of patches has been tested and evaluated ad infinitum in conventional literature (Deshpande, Green and Pointer, 2015).

At the 2019 Annual Technical Conference of TAGA Hoffstadt (2019) gave a presentation on the ideal number of test patches for expanded gamut printing. If the same 9-step resolution from CMYK would be applied to CMYKOGV about 5 million test patches would be needed and "...even with only 4 steps per ink, we have 4^7 = 16 384 patches at a rather poor grid resolution..." (Hoffstadt, 2019). Then the question was what can be done to reduce the number of test patches to a number between 1 000 and 5 000. At the time the number of patches used by GMG OpenColor was 4 200 (35 × 30 patches on 4 pages). At the same conference, a presentation by Braun and Alejandro (2019) showed that not much more accuracy is gained by test charts with many test patches. The number of test patches needed depends on the number of colorants used in the print process. For example, the number of test patches needed for GRACoL 2006 to achieve a 95th percentile of CIEDE2000 color differences of less than 1.0 is 150 (Figure 3).

For a seven-color print process, the optimum number of test patches to achieve a 95th percentile of a CIEDE2000 of 1.0 is around 3 000 (Figure 4).

The paper by Braun and Alejandro (2019) provides a formula (Equation [1]) that can be used to calculate the number of test patches that are needed to achieve a certain ΔE, for a specified printing system.

$$e = \frac{k}{n^g} \qquad [1]$$

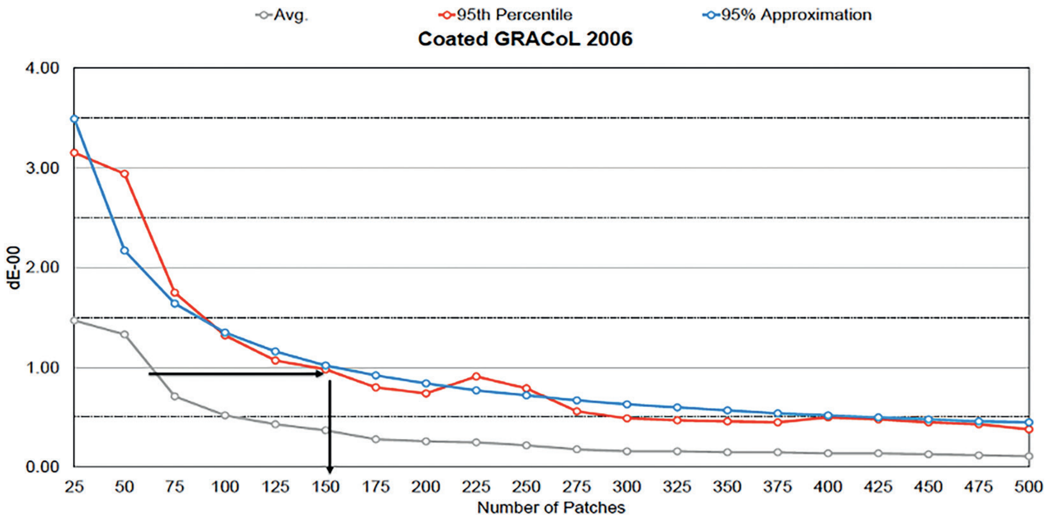


Figure 3: Number of test patches needed to achieve a 95th percentile of the test patches to have a CIEDE2000 of 1.0 according to Braun and Alejandro (2019)

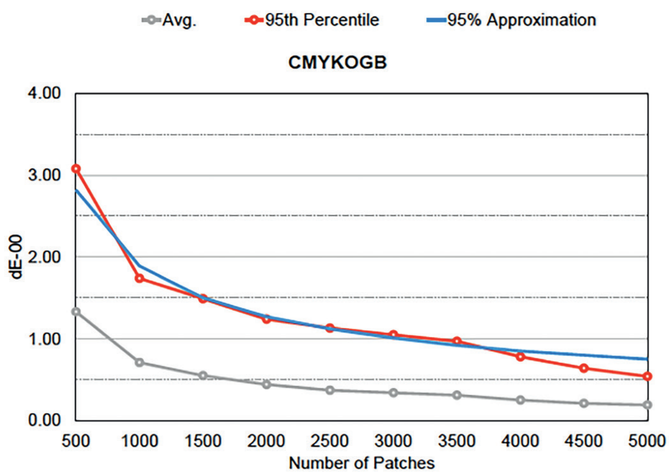
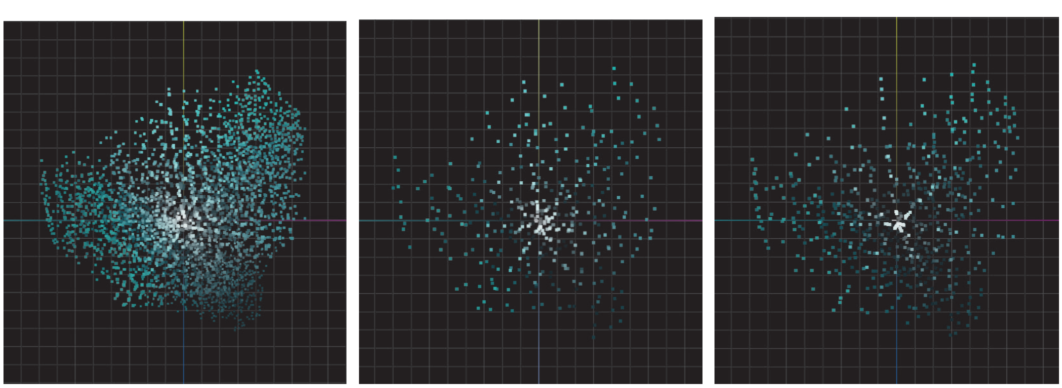


Figure 4: Number of test patches needed to achieve a 95th percentile of the test patches to have a CIEDE2000 of 1.0 according to Braun and Alejandro (2019)



a) b) c)

*Figure 5: Presentation of Esko EDK (a), GMG (b), and ISC (c) color gamuts; from the L*a*b* values in 2-dimensional color gamut presentation we see that the EDK (a) solution has many more patches while the ISC (c) appears to be missing data from some areas of the color space*

where the symbol e represents the ΔE value that one wants to achieve. Braun and Alejandro (2019) also provide numbers for k and g. For a seven-color system the factor $k = 100.00$ and the exponent $g = 0.57$. Solving the equation for n for a ΔE of 1 results in the number of patches needed to achieve a ΔE of 1 as 3227. A closer look at Figure 4 shows that the curve of the 95th percentile intersects with a y-axis value of 1 around this number of patches.

2.3.3 Characterization press runs

After the successful creation of the plate curves for the output of plates for any future press runs in this study the plates for the characterization press runs were made. The ink viscosities for the characterization press runs were kept within a variance of ± 5 % from the target ink viscosity values listed in Table 1.

The test chart for the Esko characterization press run consists of all seven colors, but not all seven colors are printed at once. The press run is split up into four different runs:

- CMYK
- OMYK (Orange)
- CGYK (Green)
- CMVK (Violet)

The Esko EDK four test charts can be seen in Figure 6.

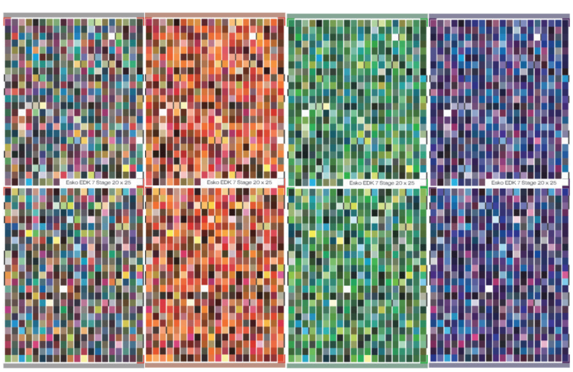


Figure 6: Esko EDK test charts with a total of 3872 patches; the four charts have been used to sequentially explore different parts of color space

The test charts were read into the Color Pilot software so the Pantone Plus Solid Coated v3 M1 color library can be built using the seven process colors.

The next characterization press run took place on day two of the experiment. On this day two characterization press runs took place. The first press run of that day was used to print the proprietary test chart from GMG and the second press run was used to print the ISC chart.

An image of the GMG test chart can be seen in Figure 7. The chart is an exact fit for our printing plate and measurable with our measuring instrument (i1IO table) without further cutting. The test chart has a total area coverage limit of 300 %.

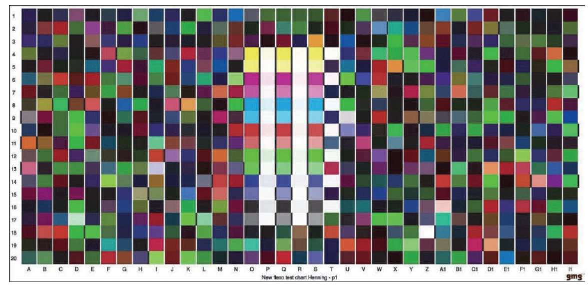


Figure 7: GMG test chart with 700 patches; the number of patches is user-defined for our printing process and it covers the whole gamut in a single chart

After the press run the test chart was measured with the i1Pro2 listed above and imported into GMG's OpenColor software to build teh Pantone Plus Solid Coated color library using the seven process colors.

The last test chart that needed to be printed was the ISC chart (Figure 8). This chart was measured in the expanded gamut software solutions from Esko and GMG; again, so the Pantone Plus Solid Coated color library can be built using the seven process colors.

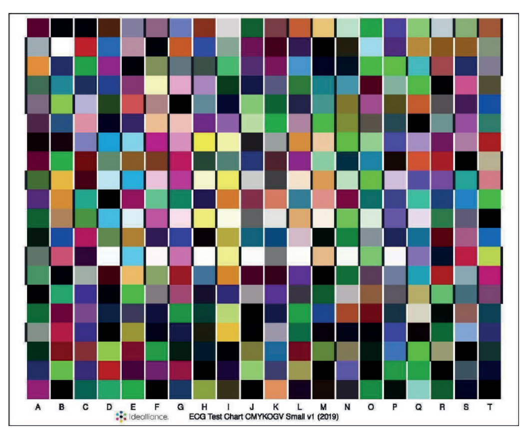


Figure 8: Idealliance Small Chart with 400 patches; it is an exact fit for the printing plate and measurable in our measuring instrument without further cutting

From Figures 6 to 8 it can be seen that the size of the test chart varies greatly. The Esko test charts have a total of 3872 patches, the GMG test chart has 700 patches and the ISC chart contains 400 patches.

One of the questions is, "Do more test patches result in a more accurate prediction of the color builds of the Pantone?"

It needs to be said also, that the data from the characterization test charts were read in with the same measurement instrument using the respective measurement tools from either Esko and GMG and test measurements from each test chart were sent to their respective vendor. The only measurement data that was sent to both vendors was the data from the ISC chart.

2.3.4 Verification runs

Using the Check Gamut tool in Esko's Color Pilot, we were able to check how each ink in the Pantone Plus Solid Coated ink book will be reproduced with the percentage of each output ink. Also, the tool would show how close the converted color would be to the original via CIEDE2000 information. The conversion was conducted using the Equinox profile and color strategy information that was generated using Esko's characterization data.

Out of the tested Pantone Plus Solid Coated book with 2139 colors, 1037 Pantone colors were selected with a CIEDE2000 of less than one. This represents 48.5 % of the Pantone Plus Solid Coated colors. These colors would be considered "in-gamut" colors. We then extracted 27 colors from that list that will be used in the verification target. The selected colors were closely distributed in lightness, hue and chroma. In Figure 9 the selected colors and their respective hue values are shown.

In addition, the verification target included CMYKOGV solids, black tint (0 %, 25 %, 50 %, 70 % and 100 %), and three additional tint ramps for spot colors that were chosen to be close to the OGV colors of the printing process as follows:

- PANTONE 151 C: 25 %, 50 %, 70 %, 100 % (orange)
- PANTONE Green C: 25 %, 50 %, 70 %, 100 % (green)
- PANTONE 2091 C: 25 %, 50 %, 70 %, 100 % (violet)

The final verification target with all the selected patches plus the tint ramps of the three Pantone colors P151 C, Green C and P2091 C is shown in Figure 10.

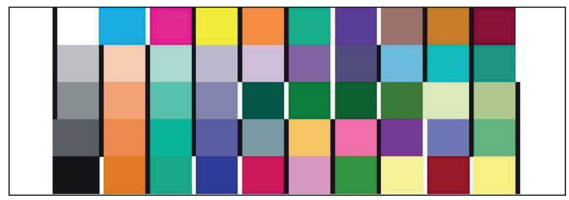


Figure 10: Custom test chart for the verification press runs showing the selected 27 test Pantone patches with tint ramps for black and three Pantone colors P151 C, Green C and P2091 C

For the verification test run to take place, the small custom test chart needed to be placed onto the plate template that was used during this study. The custom test chart was placed four times onto the plate template.

Two of the custom test charts had been processed by Esko using the data from the EDK test chart (Figure 6) and ISC chart (Figure 8) and the other two test charts

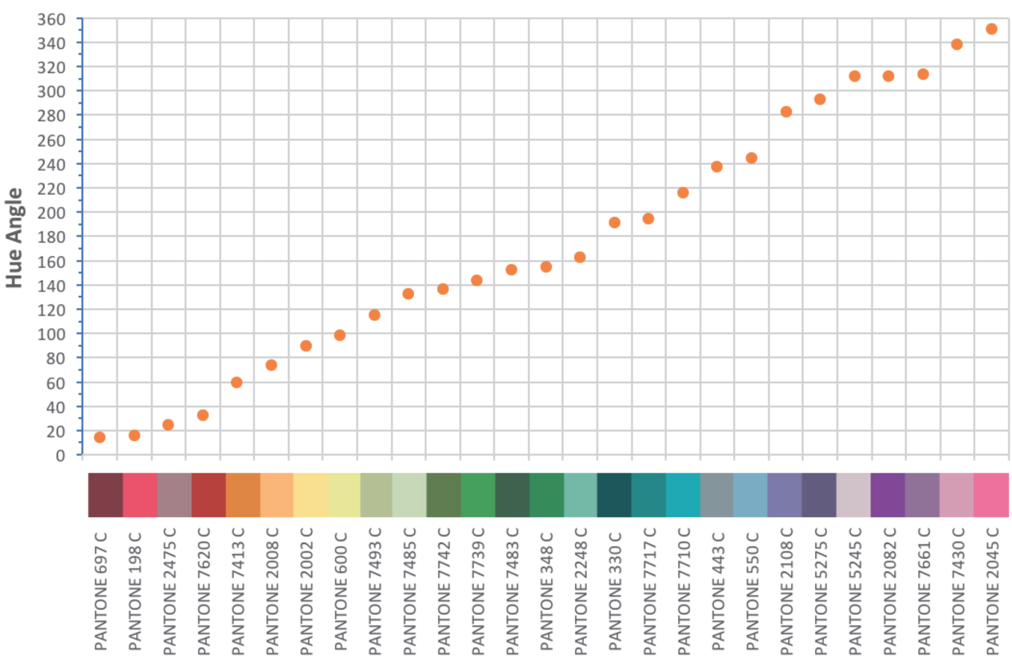


Figure 9: Hue angle distribution for the 27 selected verification Pantone targets; the selected colors cover the whole gamut and are closely distributed in lightness, hue and chroma

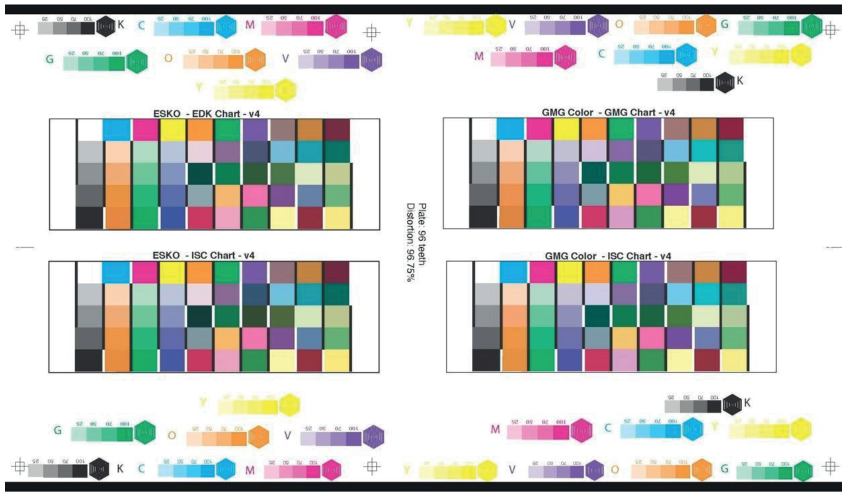


Figure 11: Layout of the test chart used in the verification run; the left charts were processed with Esko software using data from Esko property target (top left) and ISC target (bottom left). The right charts were processed with GMG software using data from GMG property target (top right) and ISC target (bottom right)

were processed by GMG using the data from their characterization test chart (Figure 7) and the ISC chart (Figure 8). The verification press run took place two months after the characterization run. The layout of the test charts can be seen in Figure 11.

From Figure 11 it can be seen that the test charts have been labelled clearly to indicate which software was used to process the custom test chart shown in Figure 10.

2.4 Press variation

After having looked at the accuracy of the color reproduction of the selected in-gamut test colors and seeing that test color builds done by Esko resulted in higher CIEDE2000 values compared to the Pantone Plus Solid Coated reference values than the color builds done by GMG raised the question about variations between the various characterization press runs.

A good tool to look at press variation is to examine the tone value curves from the various characterization runs. Measurements of the characterization and verification runs (Esko verification run, GMG verification run) were done in December 2020.

The following charts were measured with a Techkon SpectroDens listed in the chapter 2.2:

- Esko EDK target with the following sub-targets:
  - CMYK
  - OMYK (orange)
  - CGYK (green)
  - CMVK (violet)
- GMG characterization target
- ISC chart

All data were measured with a Techkon SpectroDens in M1 mode, status T. The following parameters were measured:

- Printed color density
- $L^*a^*b^*$ values
- Tint densities of the 70 %, 50 %, and 25 % patches
- Tint value measurements were performed using the SCTV function for all colors

The purpose of these measurements was to determine if there were differences between the press runs of the various targets. The results are split between the gear and drive side of the press. Besides generating the tone value curves for each of the runs, the color difference for the seven colors between characterization run(s) and verification run was also determined and expressed in CIEDE2000 values. Another quality measure for press runs is the calculation of print contrast.

2.5 Print contrast

According to Breede (1999), Handbook of Graphic Arts Equations, “Print contrast measures the ratio of a shadow area density to solid ink density.” A high print contrast ratio can be used as a measure for superior print quality. In offset printing, the 75 % tint patch is used to determine the print contrast, but in flexography, the 70 % tint patch is being used for this determination. For the determination in our study, the print contrast on the CMYK colors was only used and calculated using the following formula (Breede, 1999):

$$\text{Print contrast} = \frac{(\text{Solid ink density} - \text{density of 75 \% tint})}{(\text{Solid ink density})} \qquad [2]$$

3. Results and discussions

3.1 Color differences of the tested Pantone colors

Figure 12 shows the average CIEDE2000 between the expected $L^*a^*b^*$ values of 27 in-gamut spot colors based on the Pantone Plus Solid Coated library and the printed and measured $L^*a^*b^*$ values for that spot colors. Figure 12 shows two columns with results for the Esko solution when using the proprietary Esko Equinox 4 × 4 EDK characterization chart (Esko-EDK) and the results when Esko created a color characterization with the non-proprietary, ISC chart (Esko-ISC).

In general, we see that many colors can be reproduced to < 2 CIEDE2000 (a typical tolerance in package printing), and we see that Equinox generally produces lower ΔE (better results) when using the 4 × 4 EDK chart (3 872 patches) compared to the ISC chart (400 patches). Lower CIEDE2000 reflects better matching, thus, overall Esko achieved better matching when using its proprietary data over non-proprietary Idealliance data.

In the same way, Figure 13 presents results for GMG Color, showing data for OpenColor when using the proprietary OpenColor characterization chart (GMG-GMG) and the results when OpenColor used the non-proprietary, ISC chart (GMG-ISC).

In general, we again see that many colors can be reproduced to < 2 CIEDE2000, and that OpenColor produces much lower CIEDE2000 when using the OpenColor chart (700 patches) compared to the ISC chart (400 patches). As in the case of Esko, overall GMG achieved better matching when using its proprietary data over non-proprietary Idealliance data.

Table 3: The CIEDE2000 statistics for the 27 spot colors for the Esko Equinox solutions with the 4 × 4 EDK chart is compared to the same solution when using the ISC chart

Color differences	Esko-EDK	Esko-ISC
Minimal	0.82	0.99
Standard	1.29	1.92
Average	2.45	3.49
95th percentile	4.77	6.15
Maximal	5.08	9.93

Table 4: The CIEDE2000 statistics for the 27 spot colors for the GMG OpenColor solutions with OpenColor characterization chart is compared to the same solution when using the ISC chart

Color differences	GMG-GMG	GMG-ISC
Minimal	0.69	0.96
Standard	0.75	1.15
Average	1.55	2.94
95th percentile	3.22	4.58
Maximal	3.87	5.49

The average CIEDE2000 values over the 27 in-gamut spot colors are shown in Tables 3 and 4, for Esko Equinox and GMG OpenColor, respectively. We see that both vendors have a lower average CIEDE2000 when using their own proprietary characterization chart compared to the generic ISC chart.

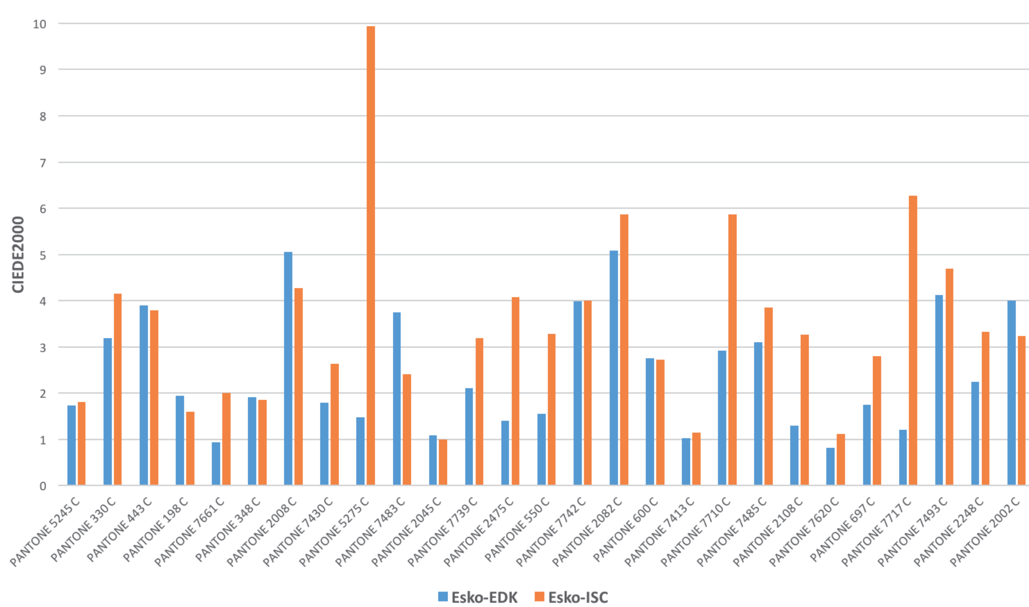


*Figure 12: Average CIEDE2000 values between the Pantone Plus Solid Coated L*a*b* library values and the printed and measured values for Esko when using the 4 × 4 EDK chart (marked blue) and the ISC chart (orange)*

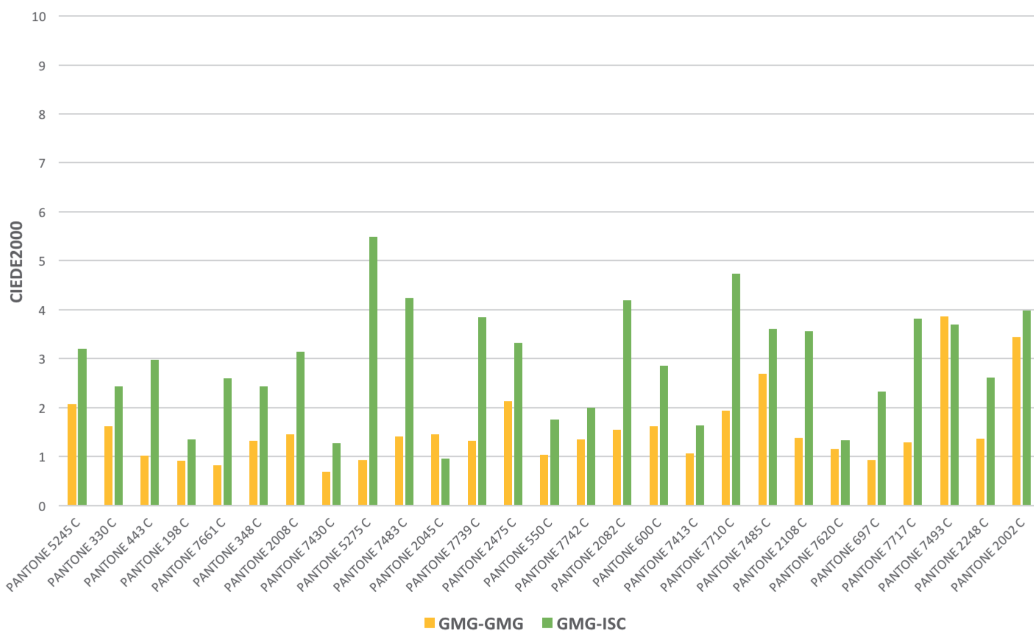


*Figure 13: Average CIEDE2000 values between the Pantone Plus Solid Coated L*a*b* library values and the printed and measured values for GMG Color when using the OpenColor chart (marked yellow) and the ISC chart (green)*

The separation build for the spot colors was analyzed between the vendor solutions. In particular different spot color builds were analyzed in terms of CMYKOGV inking values.

As it is shown in Figure 14, Pantone 2108 C was reproduced with similar CIEDE2000 accuracy by both vendors, however, analysis of the inking showed Esko using violet while GMG favored a CMYK-only build. In analyses of the separations, in general, we saw that GMG frequently favored a CMYK-only build.

Pantone 443 C was reproduced inaccurately by Esko, but accurately by GMG OpenColor. The human observer is very sensitive to this mid-tone, neutral color ($L^*a^*b^*$ = {64, −4, −6}) and a small shift in printed color

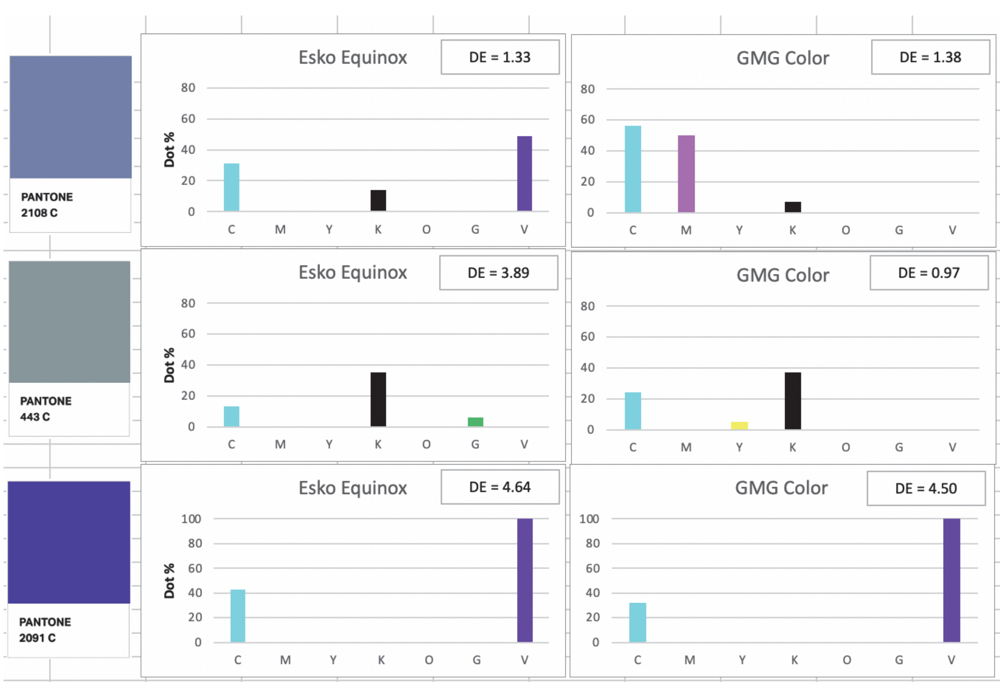


Figure 14: The separation build for three different spot colors was analyzed between the vendor solutions

can create a large CIEDE2000. Pantone 2091 C used a similar separation in both vendors' software, and was out of gamut and was subsequently reproduced with a high CIEDE2000 by both solutions. Pantone 2091 C was not part of the testing set of 27 spot colors, instead, it represented a spot color very close to the violet ink used on press and was used to "tempt" the vendor solutions to use an expanded gamut colorant in the separation, and indeed OpenColor was forced to use a non-CMYK colorant – violet.

3.2 Results from the color gamut and test charts patches number

In the analysis of the $L^*a^*b^*$ two-dimensional projection of the characterization measurements, Figure 5, we see that the Esko EDK solution has many more patches and therefore a much denser color cloud. A large number of patches appear to needlessly oversample the color space as it does not lead to lower ΔE in the analysis. Furthermore, the larger number of patches requires four press runs on a narrow web flexo press as used in this project and also by a typical packaging customer. A large number of patches could be useful in a very "noisy", unstable printing process, as the large number of patches can provide a smoothing function and the solution is expected to be very robust in the presence of press variations. The fact that four press runs are used to create this single dataset is somewhat self-defeating as each press run necessarily introduces its own variations. See the section 3.7 on press variation.

At the other extreme, the ISC chart has so few patches (or patches with poorly chosen inking values) that some areas of the color space remain unsampled, thus a color algorithm receives no colorimetric information from these colors with which to develop a color model and lookup table, supporting the findings where both vendor solutions created the least accurate separations when using the ISC chart characterization data.

3.3 Printed color densities

The average printed color densities for all the press runs were compared to determine if there was considerable variation for these values. The results of these measurements can be seen in Figure 15, where you can see the average printed color densities for all seven process colors. The ink densities that stand out the most are the densities for orange, green and violet in the verification run that are a little bit higher than the average printed color densities printed in the previous runs, and the density for cyan in the GMG characterization run.

From Figure 15 one can conclude that there were some printed color density variations. Overall, these variations were only somewhat significant for the OGV inks in the verification press run. Since these values do not show a great difference, it is important to also examine the tone value curves of all the press runs conducted in this study.

3.4 Spot color tone value curves

A point of interest is the tone value curves since tint values of CMYKOGV are used to build the Pantone colors. Differences between the characterization runs and the verification run in the tone value curves are a possible source of error. The tone value curves were measured with the Techkon SpectroDens in SCTV mode. Typical examples of the curves are shown in Figures 16 and 17 and detailed curves from all the runs can be found in the Appendix.

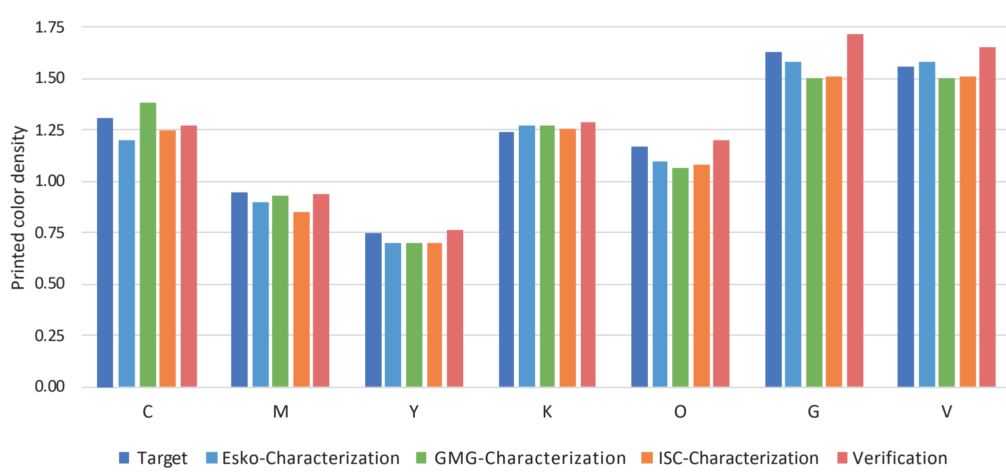
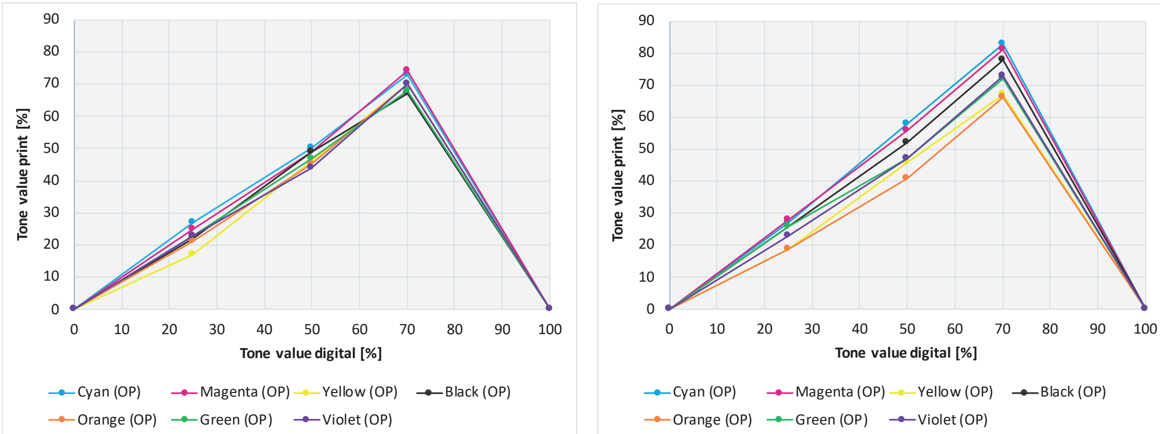
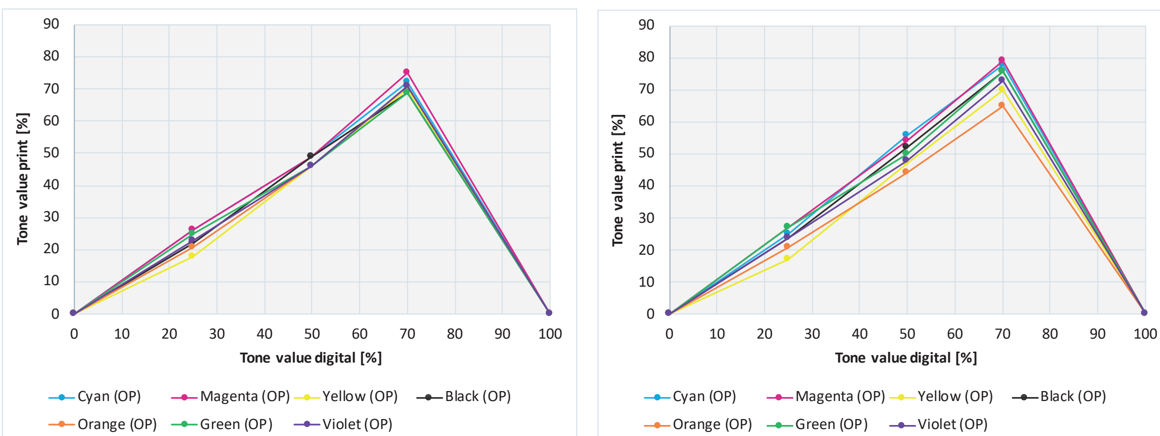


Figure 15: Average printed color densities for the seven process colors for all press runs; while print ink densities variation exists in all seven colors, OGV colors score higher ink densities in the verification run compared to other runs



a) *b)*

Figure 16: The SCTV tone value curves from the Esko verification run for the gear (a) and operator (b) side; variation in tonal values is noticeable between the two sides



a) *b)*

Figure 17: The SCTV tone value curves from the GMG verification run for the gear (a) and operator (b) side; variation in tonal values is noticeable between the two sides

From Figures 16 and 17 it can be seen that there is a difference in the SCTV curves between the gear and the operator side. Most likely this is due to the purely mechanical and analog setting of the printing plate against the anilox roller, but the behavior is consistent between the different press runs. The curves are different from the traditional dot gain curves as they used spectral reflectance values to calculate tonal value. There is more spread in tonal values on the operator side than on the gear side. On some occasions, some colors scored more or less tonal values from one side to another which reflects press variation across a different side of the press.

3.5 Color differences between the runs

For the determination of the color differences between the characterization and verification runs the *L*a*b** values of the 100 % solids of the seven process colors CMYKOGV were averaged from the measured press sheets and the CIEDE2000 was calculated. The results are shown in Figures 18 and 19. While overall variations between press runs are small, the color differences between the press runs are noticeable in cyan, black and violet colors.

The biggest color differences were determined for cyan and black colors between the Esko EDK characterization run and the verification run. Surprisingly the color differences between the ISC characterization run and the Esko verification run for ISC are in general smaller. The largest color differences were determined for cyan, black and violet colors with a maximum value of CIEDE2000 of 2.91 for cyan, followed by 2.61 for black and 2.07 for violet. The average CIEDE2000 between the Esko characterization runs and the verification run was 1.67. For the color differences between the ISC characterization run and verification run the

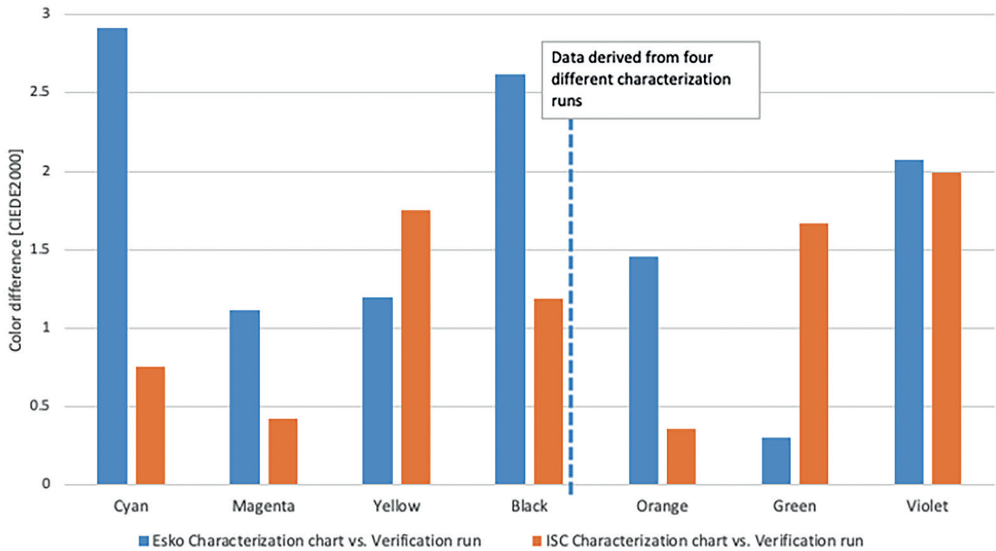


Figure 18: CIEDE2000 values between the Esko characterization and verification run and the ISC characterization run and the Esko verification run; a lower CIEDE2000 is better

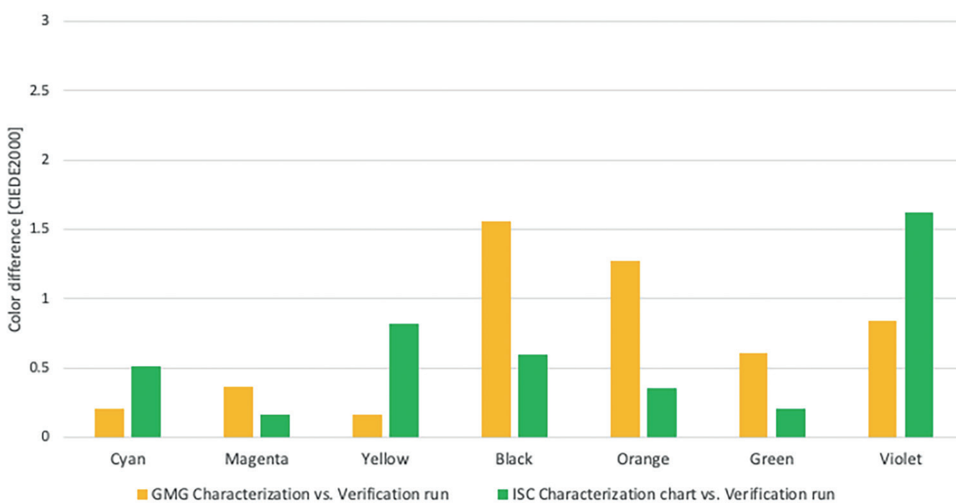


Figure 19: CIEDE2000 values between the GMG characterization and verification run and the ISC run and the GMG verification run; a lower CIEDE2000 is better

largest differences were determined for violet, yellow and green. The maximum value of 1.99 was determined for violet, followed by 1.75 for yellow and 1.67 for green color. The average CIEDE2000 between the ISC characterization run and the Esko verification run was 1.16.

The same evaluation was done for the press runs associated with the GMG characterization and verification run. Figure 19 paints a slightly different picture. While overall variations between press runs are small, the color difference between the press runs are noticeable in black, orange and violet colors. The largest color differences between the characterization and the verification run have CIEDE2000 values of 1.56 for black, followed by 1.27 for orange and 0.84 for violet. The average color difference was 0.72. The largest color differences between the ISC characterization run and GMG verification run for ISC were determined for violet, yellow, and black colors. The maximum value of 1.62 was determined for violet, followed by 0.82 for yellow and 0.6 for black. The average CIEDE2000 between the ISC characterization run and the GMG verification run was 0.61.

3.6 Print contrast results

Figure 20 shows the print contrast for all the print runs. Aside from the outlier values in cyan in GMG runs, yellow in ISC run, the remaining runs have close print contrast values. Noticeable variation still occurs between Esko EDK and verifications runs.

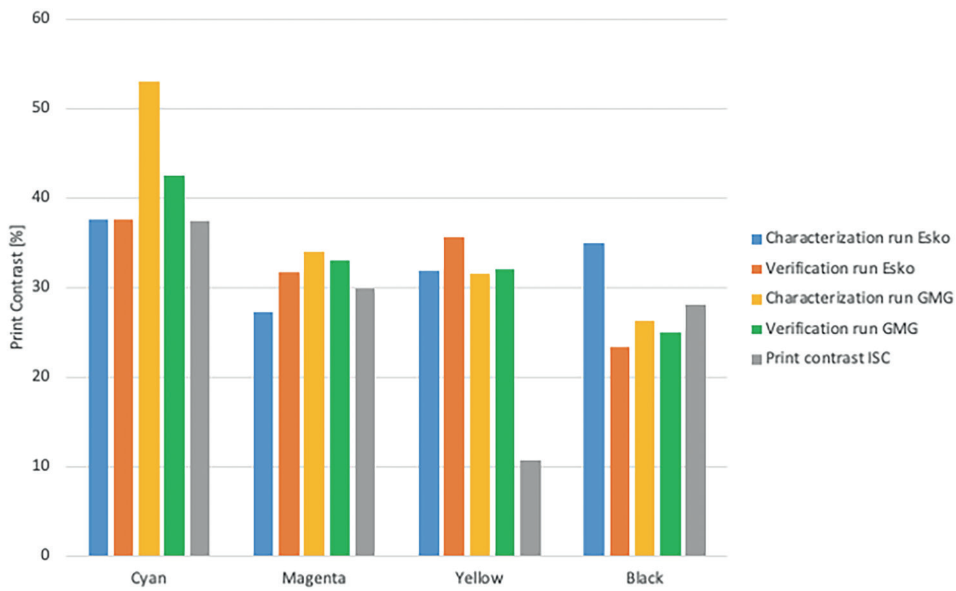


Figure 20: Print contrast percentage values for all print runs; a higher print contrast percentage is more desirable

3.7 Variations between print runs

Overall, it can be said that there was some variation between the characterization and the verification press runs. The biggest variations were found in the four Esko EDK runs and the verification run. The variations between the four characterization press runs for the EDK target were expected, because there were basically four different press runs. Print units were manually taken of impression and put on impression. Even though great care was taken to minimize printing pressure variations due to the fully manual nature of the press used in this study these variations manifested themselves in the variations of the tone value curves and also in the color differences between the characterization runs and the verification runs. The color differences were larger for the press runs conducted for the Esko workflow solution than for the press runs conducted for the GMG workflow solution.

4. Conclusions

One of the main outcomes of this study was that it is possible to print Pantone spot colors using expanded gamut print technology on a more than 20-year-old narrow-web printing press. Another outcome was that it is possible to get quite accurate color build results using 700 test patches to create the characterization of the press. The biggest variations were found in the four Esko EDK runs, and the verification run. The variations between the four characterization press runs for the EDK target were expected, because there were basically four different press runs. It is also important to correctly record all press run parameters so they can be recreated at future press runs. The process comprising an optimization run to determine the best combination of anilox roller and ink viscosity, a curve calibration run to determine the tone value curves for each of the seven process colors, a characterization run to map the color gamut of the printing press, and inks used on press and verification run to validate all the previous steps results in quite an accurate color build of the tested Pantone colors.

In label and package printing, the typical color difference tolerance for reproducing spot colors is < 2 CIEDE2000. In this study, many colors were reproduced to that tolerance as we see, in essence, the average CIEDE2000 that was achieved when reproducing the 27 tested spot colors was 2.45 when using Esko Equinox solutions with Esko EDK chart compared to 3.49 when using the same solution with Idealliance Small Chart. In addition, we achieved an average of CIEDE2000 of 1.55 with GMG Open Color solutions with OpenColor characterization target compared to 2.94 when using the same solution with Idealliance Small Chart.

Color management software plays a significant role in achieving accurate color metrics at different stages of this process. In expanded gamut technology, the software must come with the best ink separation build algorithm to modulate a 7-color printing system using the provided gamut generated from printed characterization charts. In addition, this study demonstrates the correlation between the number of patches and the effective sampling of color responses of the printing system. While a large number of patches would better suit a very noisy, unstable printing process, it does not result in lower ΔE. Lower number of patches, on the other hand, would result in missing color sampling information and thus less accurate separation which was the case with Idealliance Small Chart. Both color management software used in this study showed better results with their own target compared to generic Idealliance Small Chart.

A future project emanating from this study can be to optimize the ink set and even the substrate used on the press to achieve a wider gamut, so more of the Pantone colors can be reproduced using expanded gamut technology.

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- Charlotte Curphey, GCM student
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Appendix

Detailed SCTV curves from the Esko characterization press runs

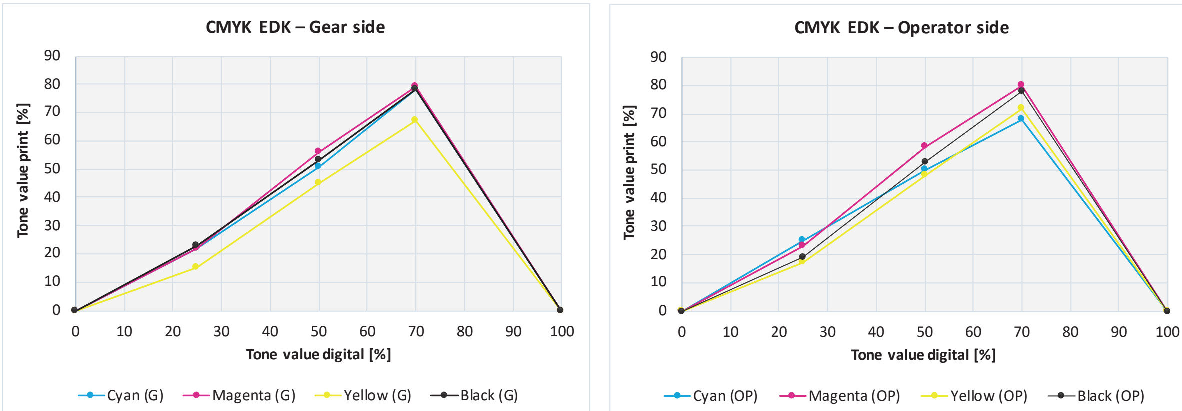


Figure A1: CMYK EDK tone value curves

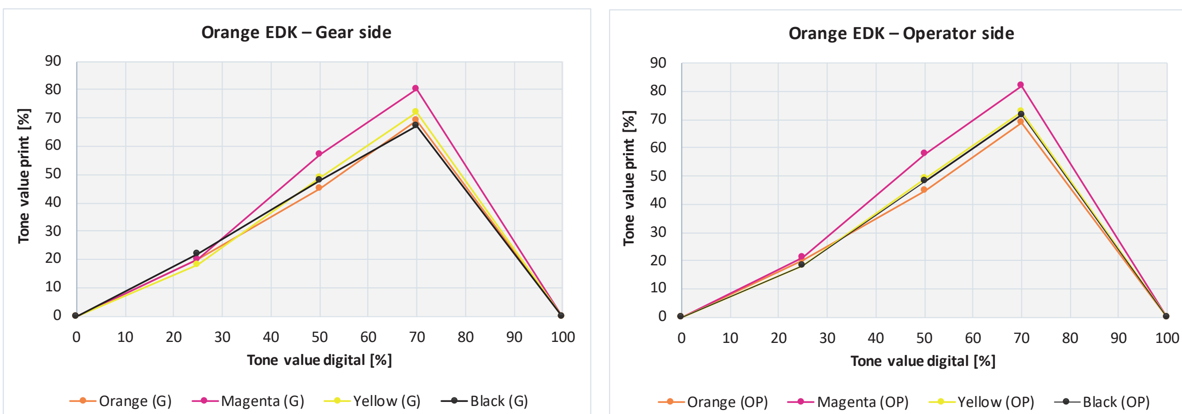


Figure A2: OMYK (Orange) EDK target tone value curves

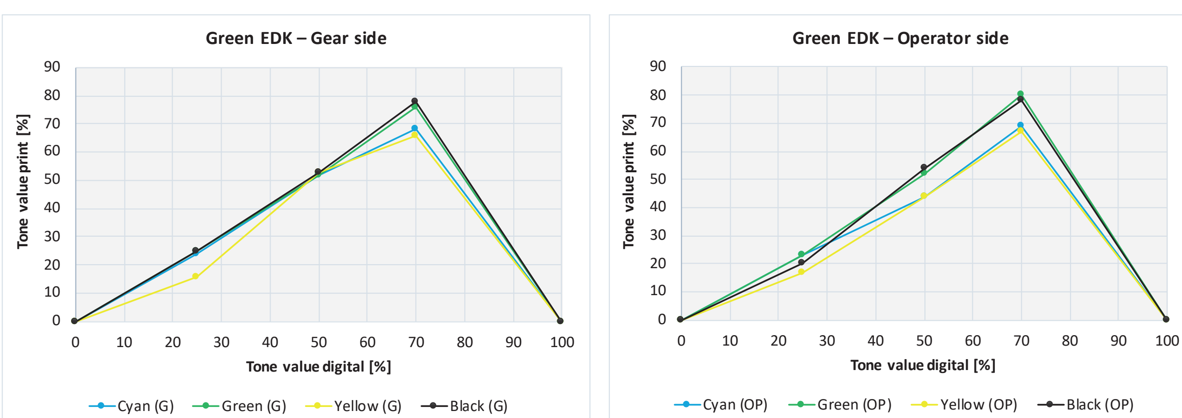


Figure A3: CGYK (Green) EDK target tone value curves

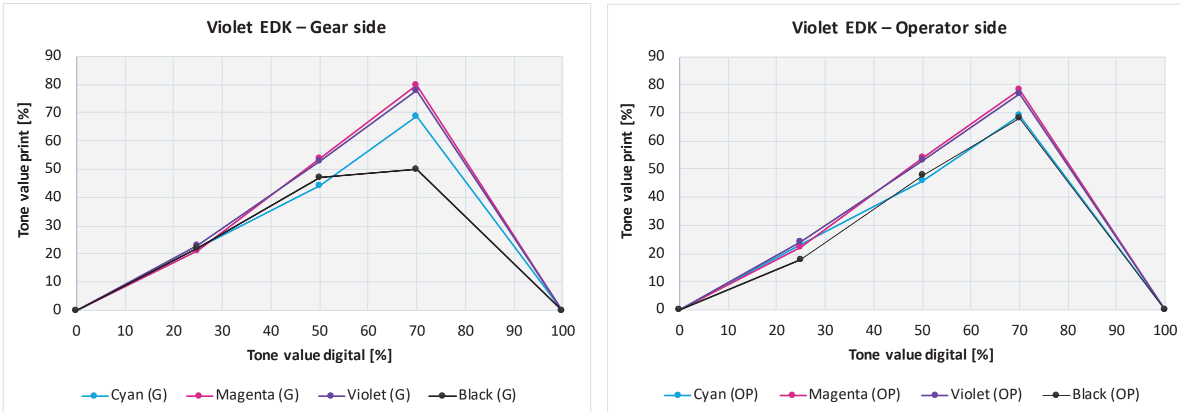


Figure A4: CMVK (Violet) EDK target tone value curves

Detailed SCTV curves from the GMG characterization press run

Figure A5: Tone value curves for the GMG characterization run

Detailed curves from the ISC chart characterization run

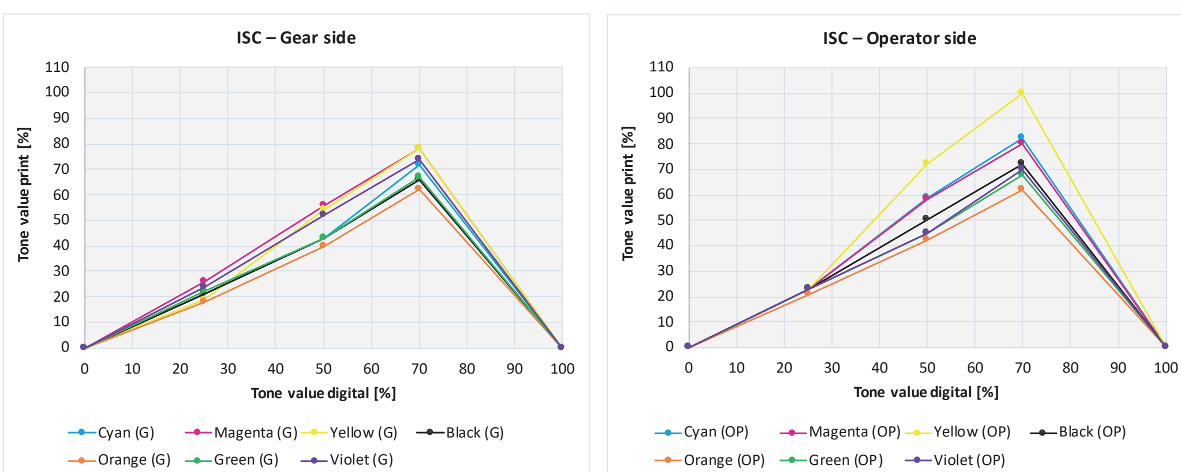


Figure A6: Tone value curves for the ISC characterization run

A detailed list of the selected Pantone patches for the verification target

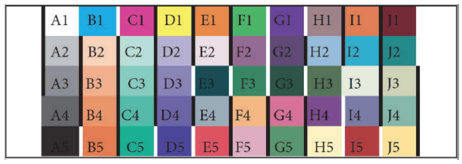


Figure A7: Verification target

#	ColorName	%	
A1	Black	0	
A2	Black	25	
A3	Black	50	
A4	Black	75	
A5	Black	100	
B1	Cyan	100	
B2	PANTONE 151 C	25	
B3	PANTONE 151 C	50	
B4	PANTONE 151 C	75	
B5	PANTONE 151 C	100	
C1	Magenta	100	
C2	PANTONE Green C	25	
C3	PANTONE Green C	50	
C4	PANTONE Green C	75	
C5	PANTONE Green C	100	
D1	Yellow	100	
D2	PANTONE 2091 C	25	
D3	PANTONE 2091 C	50	
D4	PANTONE 2091 C	75	
D5	PANTONE 2091 C	100	
E1	Orange	100	
E2	PANTONE 5245 C	100	
E3	PANTONE 330 C	100	
E4	PANTONE 443 C	100	
E5	PANTONE 198 C	100	

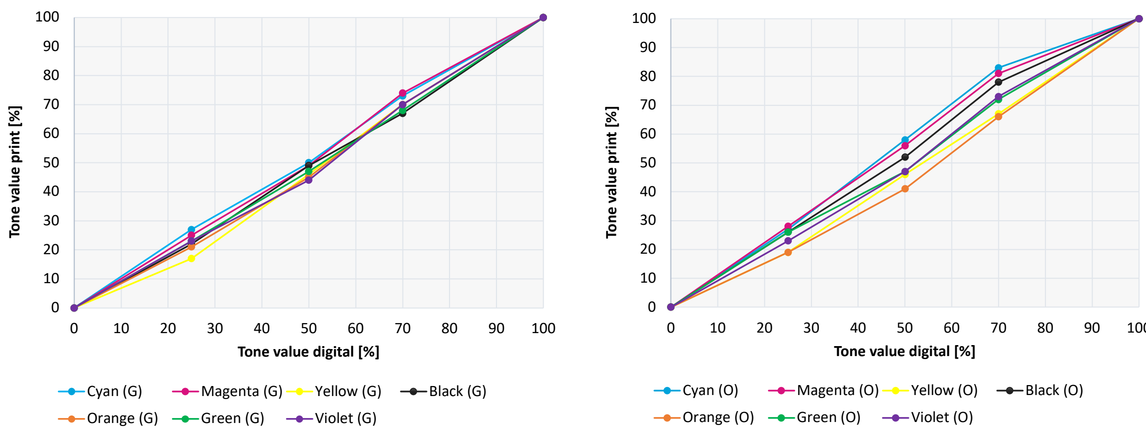
#	ColorName	%	
F1	Green	100	
F2	PANTONE 7661 C	100	
F3	PANTONE 348 C	100	
F4	PANTONE 2008 C	100	
F5	PANTONE 7430 C	100	
G1	Violet	100	
G2	PANTONE 5275 C	100	
G3	PANTONE 7483 C	100	
G4	PANTONE 2045 C	100	
G5	PANTONE 7739 C	100	
H1	PANTONE 2475 C	100	
H2	PANTONE 550 C	100	
H3	PANTONE 7742 C	100	
H4	PANTONE 2082 C	100	
H5	PANTONE 600 C	100	
I1	PANTONE 7413 C	100	
I2	PANTONE 7710 C	100	
I3	PANTONE 7485 C	100	
I4	PANTONE 2108 C	100	
I5	PANTONE 7620 C	100	
J1	PANTONE 697 C	100	
J2	PANTONE 7717 C	100	
J3	PANTONE 7493 C	100	
J4	PANTONE 2248 C	100	
J5	PANTONE 2002 C	100	

Figure A8: Description of color patches of the verification target

Errata

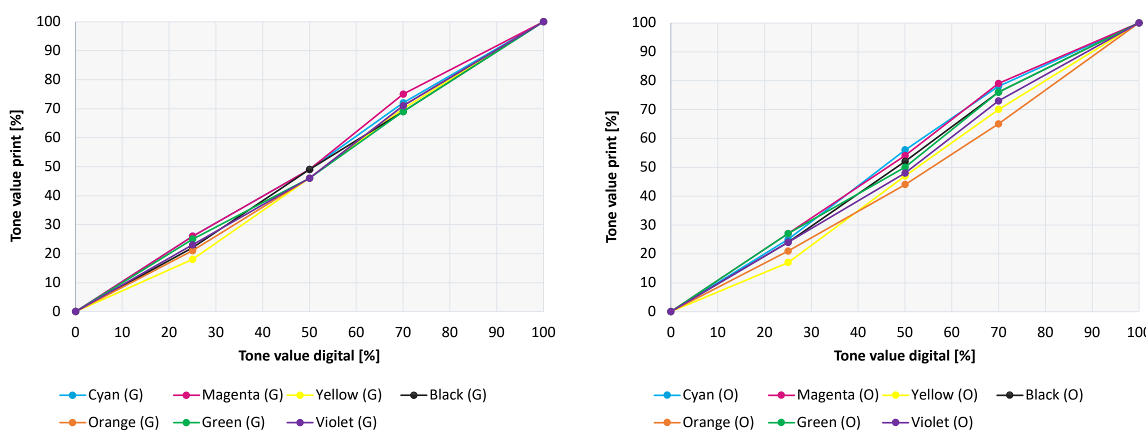
The following corrections are to be made:
J. Print Media Technol. Res. Vol. 10 No. 2 (2022), paper JPMTR-2119, pp. 99–118.

Page 111: The Figures 16 and 17 are incorrect and should be replaced with the correct figures below.



a) *b)*

Figure 16: The SCTV tone value curves from the Esko verification run for the gear (a) and operator (b) side; variation in tonal values is noticeable between the two sides



a) *b)*

Figure 17: The SCTV tone value curves from the GMG verification run for the gear (a) and operator (b) side; variation in tonal values is noticeable between the two sides

Pages 116 and 117 (Appendix): the Figures A1 to A6 are incorrect and should be replaced with the correct figures below.

Detailed SCTV curves from the Esko characterization press runs

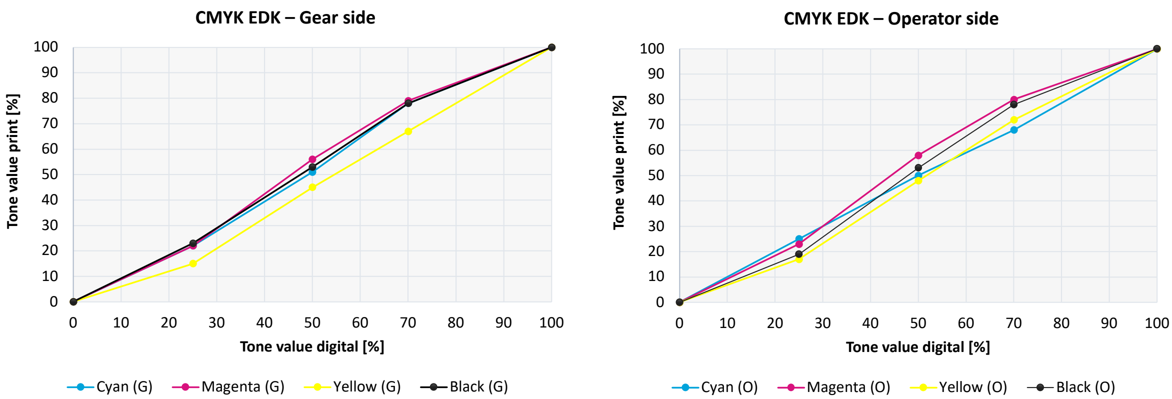


Figure A1: CMYK EDK tone value curves

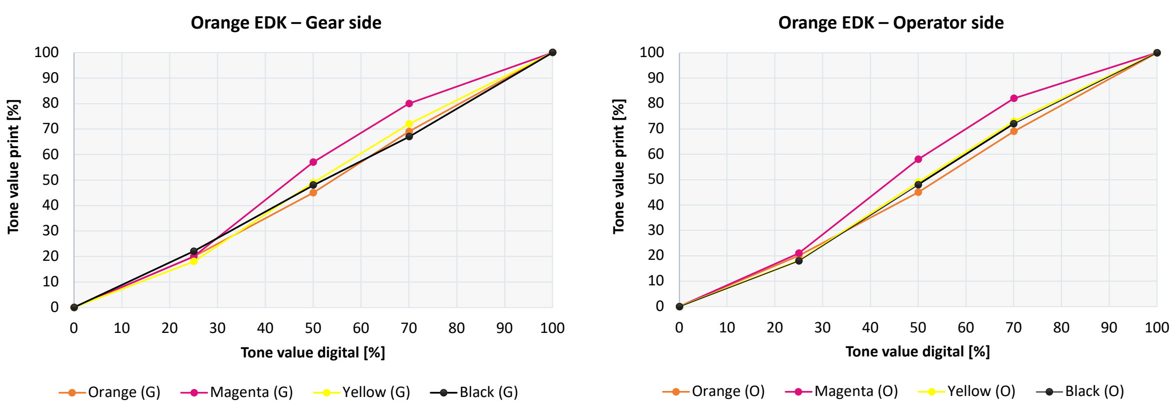


Figure A2: OMYK (Orange) EDK target tone value curves

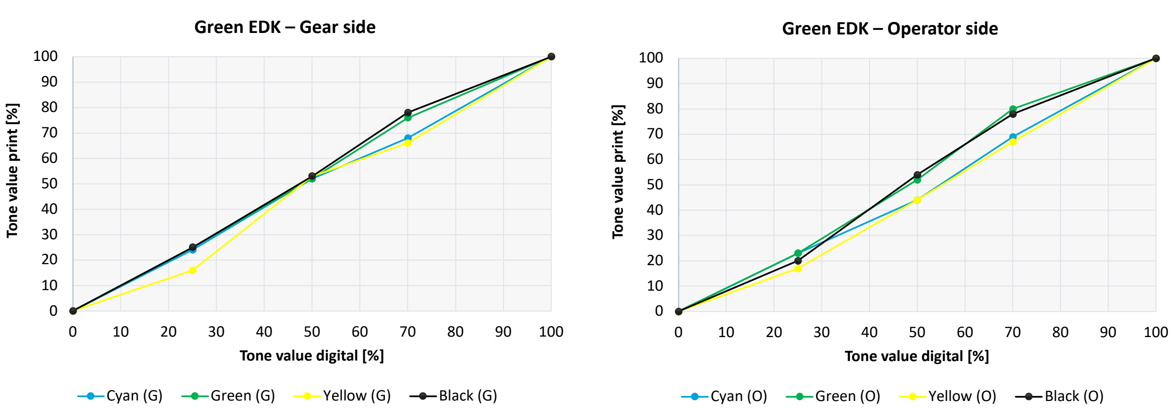


Figure A3: CGYK (Green) EDK target tone value curves

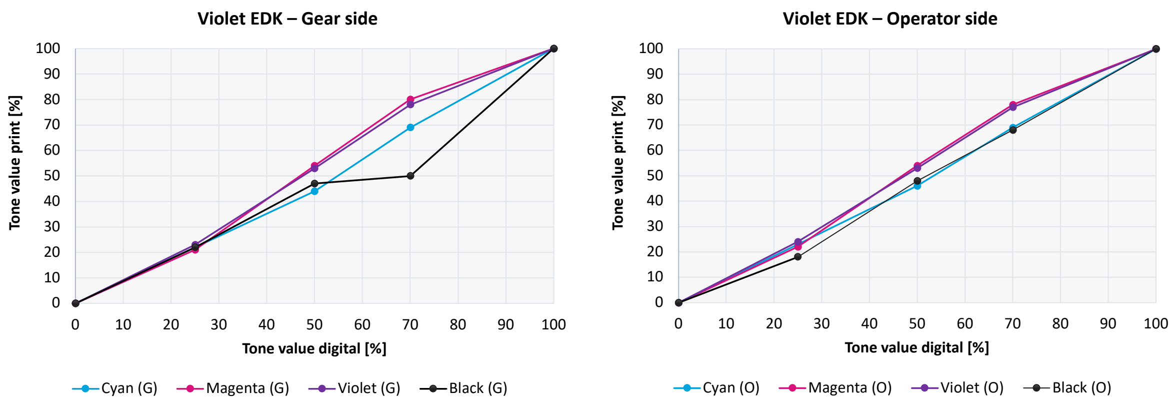


Figure A4: CMVK (Violet) EDK target tone value curves

Detailed SCTV curves from the GMG characterization press run

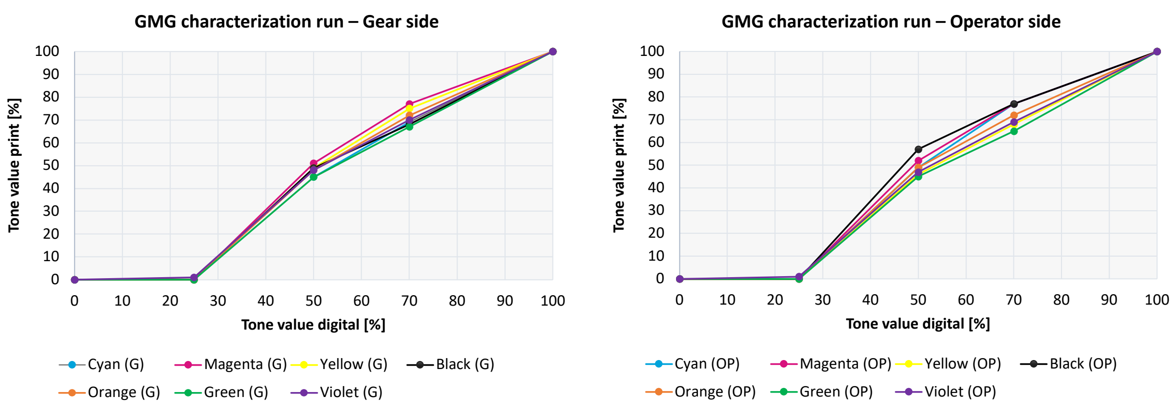


Figure A5: Tone value curves for the GMG characterization run

Detailed SCTV curves from the ISC chart characterization run

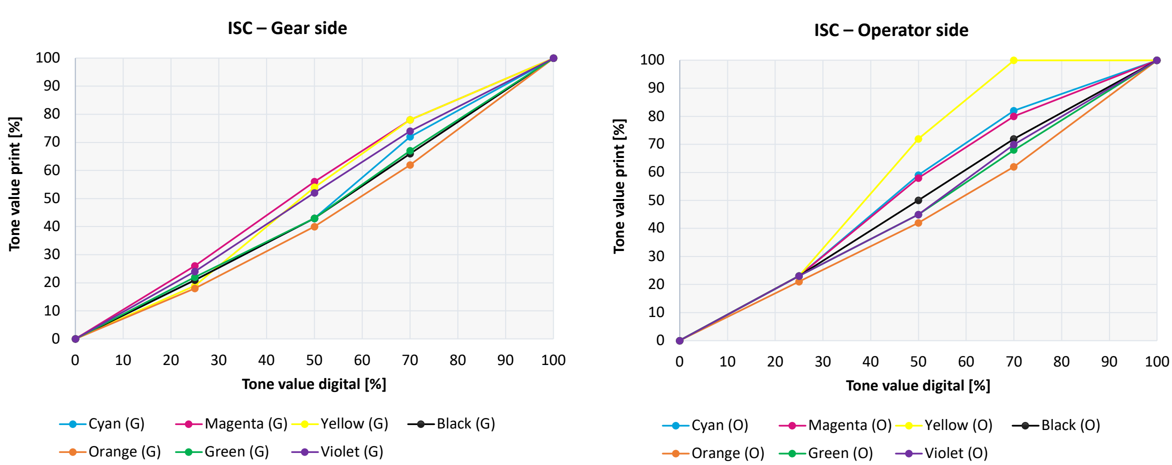


Figure A6: Tone value curves for the ISC characterization run