Flexographic Expanded gamut printing with Proprietary and Nonproprietary Characterization Charts

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Abstract

Expanded gamut printing involves expanding the number of process colors by the three colors Orange, Green and Violet to create many spot colors with the new fixed CMYK-OGV ink set. The benefit of using expanded gamut printing is that the same inks can stay in the ink fountains of a printing press and only the printing plates need to be changed from job to job.

The authors conducted several studies with expanded gamut printing in digital printing, inkjet printing and offset printing. This study focuses on evaluating flexographic expanded gamut printing on a narrow web flexographic label press located at the School of Graphic Communications Management at Ryerson University, Toronto. Esko Equinox and GMG OpenColor expanded gamut software solutions were used, where each system was tested with its own proprietary characterization test chart. Idealliance ECG small v1 (2019) test target was also used in this study.

A verification test chart was created, with selected Pantone spot colors. The verification test chart was processed using the characterization data from the proprietary and nonproprietary characterization press runs. The build of the selected Pantone colors was analyzed and CIEDE2000 was calculated.

The main outcome from this study was that we conducted expanded gamut printing on a completely manual 7” narrow web label press and went through the step of optimization, curve calibration, characterization and verification. The average CIEDE2000 for the tested Pantone colors using the proprietary characterization charts was a CIEDE2000 of 2 and 3.2 with the Idealliance Small Chart. Both software solutions did better in regards to color accuracy with their proprietary

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characterization targets than using the data gathered from the Idealliance ECG small chart.

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 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 to the process colors Cyan, Magenta, Yellow, and Black 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 90-95% of Pantone® Plus book.

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. The history of this technology has been discussed and covered in several publications by John Seymour in two articles (Seymour, 2018) (Seymour, 2019), Habekost & Grusecki (Habekost 2019) and El Asaleh et al (El Asaleh, 2020).

In 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 additional ink to the standard CMYK process colors for wider colors reproduction on the press. Some common HiFi Color systems are Pantone®

Hexachrome (CMYKOG), Küppers (CMYKRGB) and DuPont's HyperColor™ & ColorBlind MaxCYM (CMYKCMY). This concept was widely used in offset printing (Hutcheson, 1990).

Expanded gamut as it is understood today goes beyond CMYK printing by adding Orange, Green and Violet (OGV) colors. The benefits of expanded gamut printing have been nicely summed up by Baldwin (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 savings)

At the 2019 TAGA conference, Hargrove (Hargrove, 2019) demonstrated with data from a print company that printed the same job(s) conventional and later with expanded gamut technology that there was a cost reduction of $845. 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 et al. (O'Hara, 2019) the research team reduced the chroma of Orange, Green and Violet (OGV) from 100% to 80% in 10% increments. The main points from the study were:

- The greatest chroma of the OGV inks 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 doesn't mean the most Pantone colors and
- 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 Politis et al's paper (Politis et al, 2020). The study also summarized research results from two latest studies in expanded gamut printing with Silk-Screen and Flexography 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 (FQC) researched to test the concept of expanded gamut technology in flexography printing. The study concluded that this concept has promising benefits and results especially if there are 10 or more stations available to handle CMYK+OGV 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. (Rich, n.d)

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 (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 (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 3, 4 or more colors. The study output the test charts on an Epson P9000 inkjet proofer and also 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, 2020).

In Europe, Fogra has also been active in the evaluation of expanded gamut solutions. In the Color Management Symposium in February 2019 and 2020 solutions for expanded gamut were shown. Participants in the Fogra study also had to process a test chart and the color accuracy of the rendered Pantone colors was compared.

Idealliance 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 (Idealliance, 2020). 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 4340 patches (35x31 patches on 4 pages).

The authors 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 and published in Color Research and Application. In response to interest from the community we now evaluate flexographic printing. In addition, equipment upgrades in the School of Graphic Communications Management, with additional printing units meant that we now had the means to conduct 7-color flexographic printing with CMYK-OGV stations.

Premise of the study

The premise of this study was to get a better understanding about characterizing a press for expanded gamut printing. Expanded gamut printing uses three additional colors and the standard four process colors Cyan, Magenta, Yellow and Black. These additional colors are Orange, Green and Violet. This turns the CMYK four-color process into a seven-color CMYKOGV process. Adding these three colors to the four process colors expands the gamut significantly and is able to cover around 95% of Pantone book. This eliminates the need to have spot colors on press. The seven-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 expanded gamut is still relatively new there is no standardized test chart available like the IT8.7/4 for four color offset printing. 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.

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 released their test charts for expanded gamut printing. The version 1 of their test charts included a small test chart with 400 test patches and a large test chart with 4340 test patches. Idealliance encourages the industry to test these charts and upload their measurement data to their website so Print Properties Committee can evaluate the effectiveness of their two test charts.

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 limitations of the press the Idealliance Small Chart (ISC) 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. The selection process is outlined on page 16.
   c. Create a 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

Equipment used (hardware and software)

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

Hardware:

- Comco Cadet 700 - 7” narrow-web label press
- Inks:
  - Siegwerk EH033919 PS+ Yellow, Batch 2016
  - Siegwerk PSPX3320 PS+ Orange FR, Batch 2019
  - Siegwerk EH056923 PS+ Magenta, Batch November 2019
  - Siegwerk EH027556 PS+ Pro Cyan, Batch 2019
  - Siegwerk PSPX3600 PS+ Green, FR, Batch 2019
  - Siegwerk PSPX3240 PS+ Methyl Violet, Batch June 2019
  - Siegwerk PSPX3900 PS+ Dense Black FR, Batch 2019

- Target printed ink densities:
  - Yellow: 0.75
  - Magenta: 0.95
  - Cyan: 1.31
  - Orange: 1.17
  - Green: 1.63
  - Violet: 1.56
  - Black: 1.24

Anilox rollers:

- Yellow: 1.78 BCM, 1000 LPI
- Magenta: 1.79 BCM, 1000 LPI
- Cyan: 1.79 BCM, 1000 LPI
- Orange: 2.93 BCM, 550 LPI
- Green: 2.97 BCM, 550 LPI
- Violet: 2.18 BCM, 800 LPI
- Black: 1.78 BCM, 1000 LPI

- Media: Label Supply Extragloss LTR 'Low Tack Removable' 40#

- 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

- Plates: Toyobo Cosmolight water washable plate 0.067"
- Plate measurement:
  - Plate thickness: 0.0668"
  - Floor height: 0.0465"
  - Relief: 0.0203"
- Micrometer: Mitotoyo Absolute digital micrometer

- Plate QC: Betaflex system

- Esko CDI Spark 2530
- Anderson & Vreeland Orbital X plate processor with CL-50 Whirl-A-Way AV Polymer Removal System

- Measurement instruments:
  - X-Rite eXact S/N 28618
  - X-Rite i1Pro2 S/N 1 104 522
  - Techkon SpectroDens S/N B312506

Press runs

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

1. Optimization run
2. Curve calibration run
3. Characterization
4. Verification run

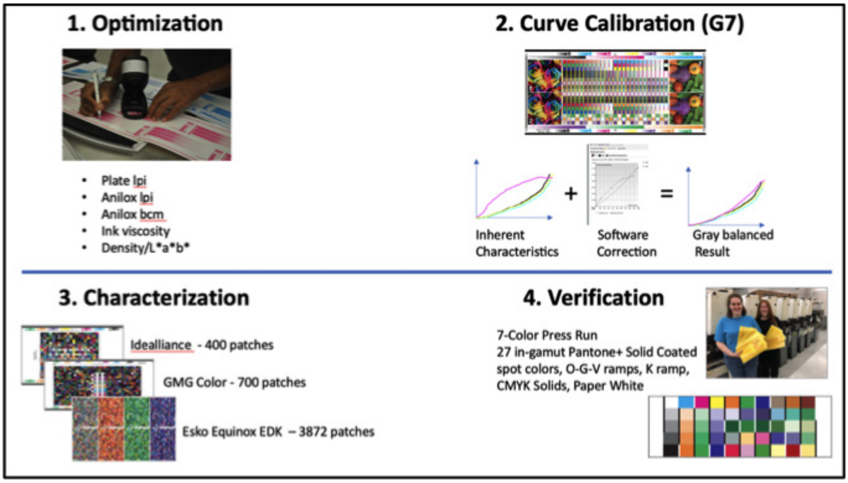

Figure 1: *Visual summary of the experimental process - Press Optimization followed by Curve Calibration are calibration steps "above the line". Characterization and Verification "below" the line form the conventional color management testing paradigm*

Optimization press run

The optimization run took place on August 18, 2020 in the press lab of the School of Graphic Communications Management. 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 ink 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 best anilox roller for each color has been listed in the "Materials used" portion of this research paper. The ink viscosity were determined with a Zahn cup #2. The optimum ink viscosities are listed in the table below.

	Yellow	Magenta	Cyan	Orange	Green	Violet	Black
Viscosity (time/sec)	31	28	39	31	31	28	28

Table 1: *Optimum ink viscosities for this study measured with a Zahn-Cup #2 in seconds*

The press form used for this part of the study is a pre-made .LEN file that was supplied by Esko. This calibration file printed with Cyan and Magenta is shown in Figure 2.

Figure 2: *Press form used for the optimization run*

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 is required. This press run will determine the plate curves for each color. Some colors might need cut-back curves, while others might require so-called bump curves. This fingerprinting press run took place on August 19, 2020 in the press lab of the School of Graphic Communications at Ryerson University.

The press form used for this press run can be seen in the image below.

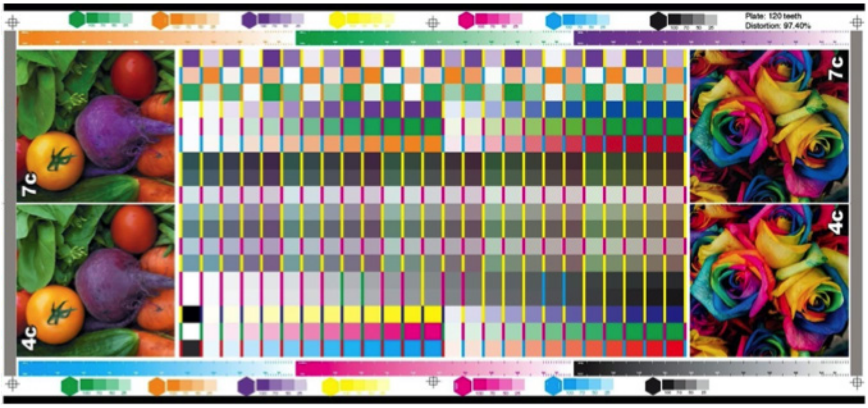

Figure 3: *Press form used for the determination of the tone value curves for all seven colors*

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 ink densities were determined. For Orange, Green and Violet the printed ink density was measured using the SCTV mode on an X-Rite eXact. 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 ink densities were established.

	Yellow	Magenta	Cyan	Orange	Green	Violet	Black
Target printed ink density	0.75	0.95	1.31	1.17	1.63	1.56	1.24

Table 2: *Target ink densities for all future press runs in this study*

The test patches located in the middle of the press form shown in Figure 3 were read in Esko’s Color Pilot to determine the plate adjustment curves. A screenshot of one the curves and the name of the other curves as determined by Color Pilot can be seen in the image below.

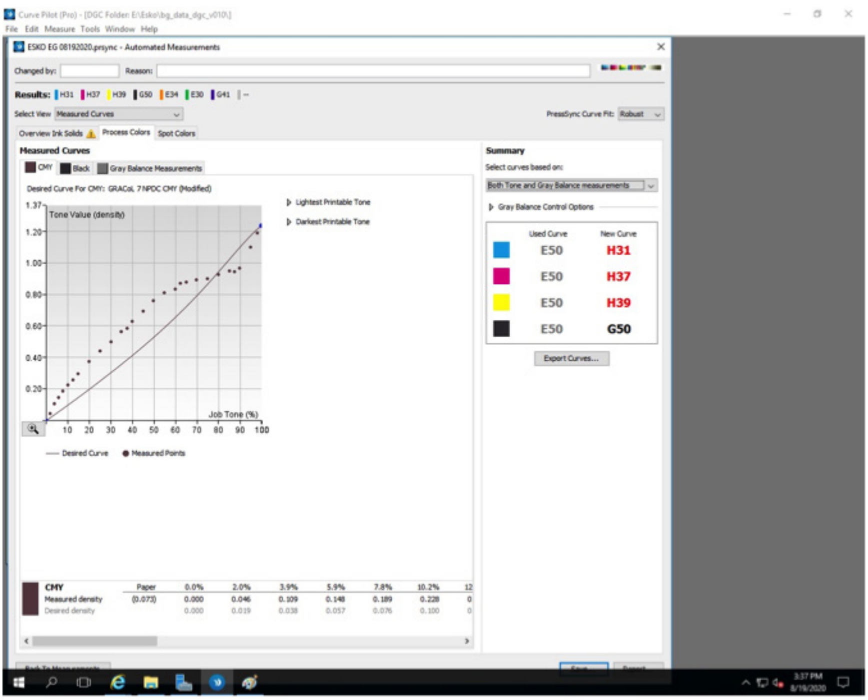

Figure 4: *Plate tone value curve as determined by Esko’s Color Pilot*

The purpose of these curves is to achieve gray balance from a low to a high tint percentage. The results from Color Pilot were saved in a so-called "Curve strategy" which will be applied to all subsequent plate output files so there is consistency. The application of this curve strategy can be seen in the image below.

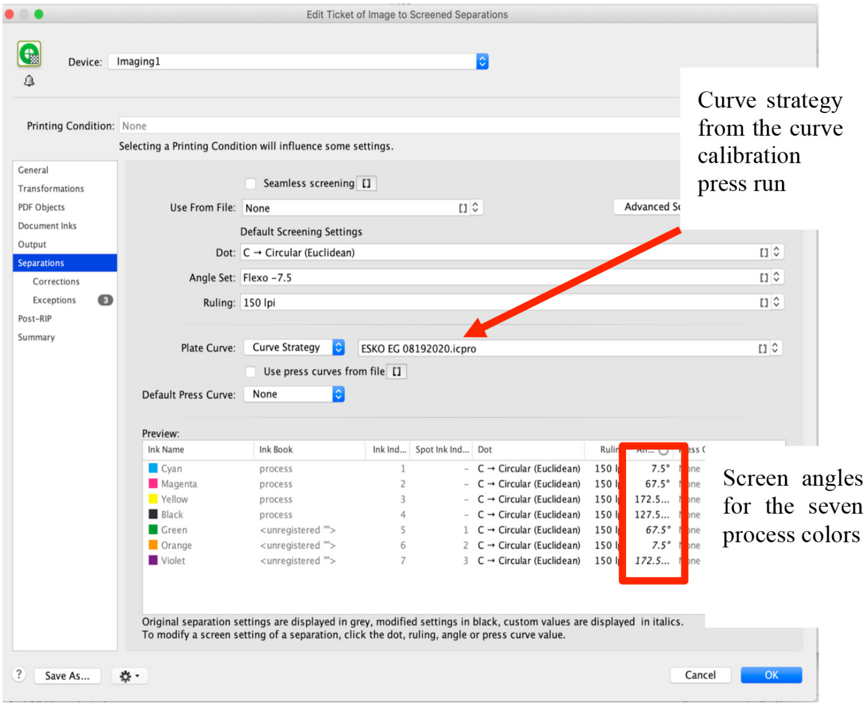

Figure 5: *Screen angles for the seven process colors and the curve strategy derived from the curve calibration press run*

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 ± 1 second from the target ink viscosity values listed in the equipment used portion of the study.

The press form for the Esko characterization press run consists of all seven colors, but not all seven colors print at once. This press run took place on September 9, 2020. The press run is split up into four different runs and these runs are:

1. CMYK
2. OMYK (Orange)
3. CGYK (Green)
4. CMVK (Violet)

The four test charts can be seen in the images below.

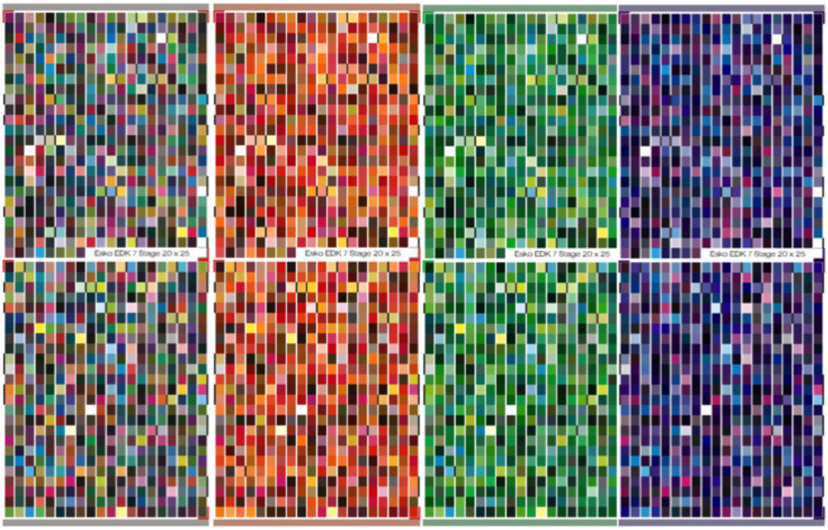

Figure 6: *Esko EDK test charts*

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

The next characterization press run took place on September 30, 2020. 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 Idealliance small test chart (ISC).

An image of the GMG test chart can be seen below. The test chart has a total area coverage limit of 300%.

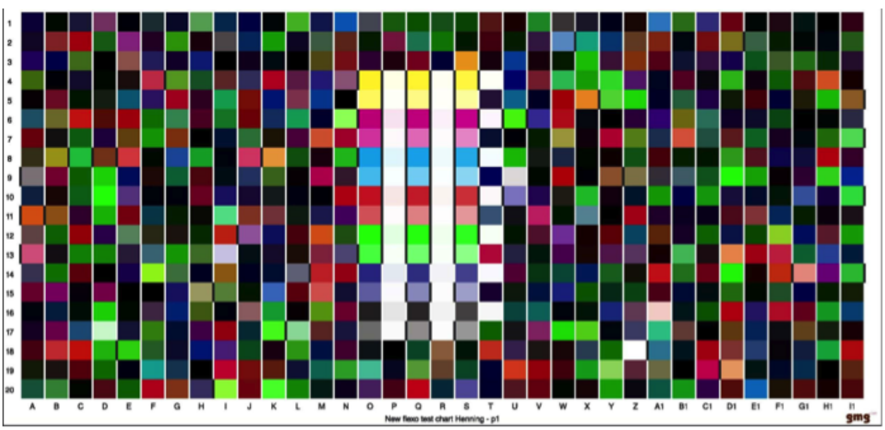

Figure 7: *GMG test chart*

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

The last test chart that needed to be printed was the Idealliance Small Chart (ISC). This chart will be measured in the expanded gamut software solutions from Esko and GMG so the Pantone Plus Solid Coated color library can build using the seven process colors. An image of the ISC chart can be seen below.

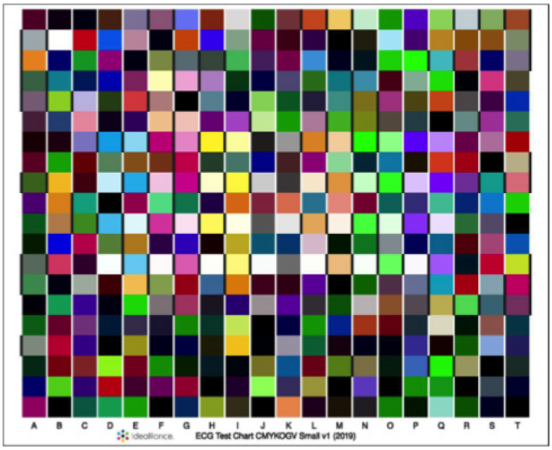

Figure 8: *Idealliance Small Chart (ISC)*

From the Figures six to eight 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.

Preparation of the test target of 27 test colors

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 percentages 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 the Figure below the selected colors and their respective hue values are shown.

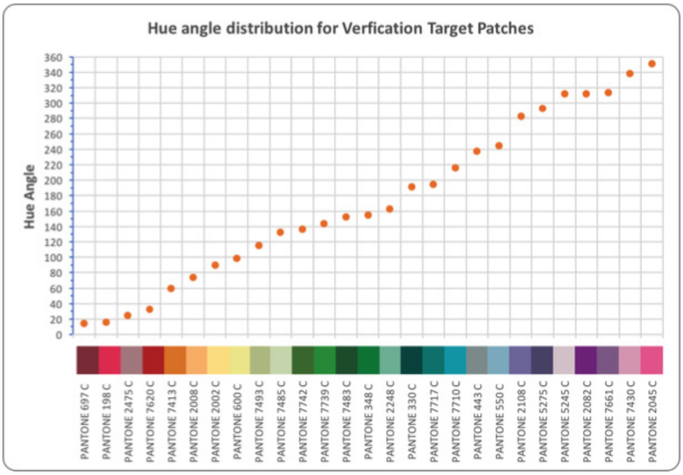

Figure 9: *Hue angle distribution for the 27 selected verification Pantone target*

In addition, the verification target included CMYOGV solids, Black tint (0%, 25%, 50%, 75% 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%, 75%,100% (Orange)
PANTONE Green C - 25%, 50%, 75%,100% (Green)
PANTONE 2091 C - 25%, 50%, 75%,100% (Violet)

The final verification target with all the selected patches plus the tint ramps of the three Pantone color P151C, Green C and P2091C is shown in Figure 10.

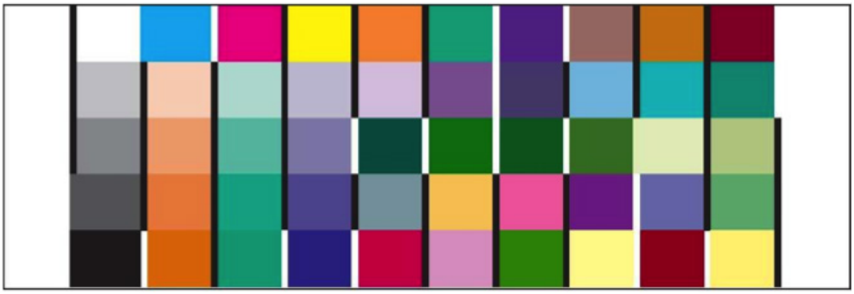

Figure 10: *Custom test chart for the verification press runs*

Verification runs

In order for the verification test run to take place the small custom test chart, that was created with help of Birgit Plautz at GMG, needed to be placed onto the plate template that was used during the course of 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 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 on November 21, 2020. The layout of the test charts can be seen in the Figure below.

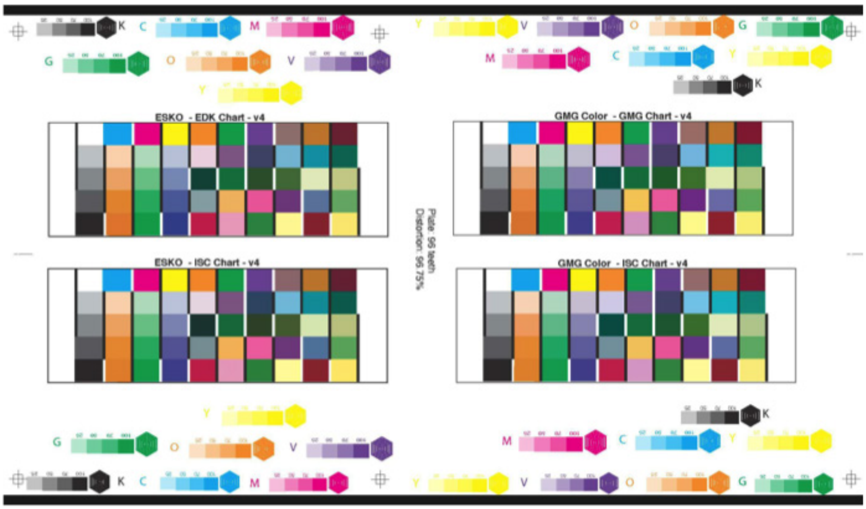

Figure 11: *Layout of the plate used in the verification run*

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 9.

Results

Figure 12 shows the average CIEDE2000 between the expected L*a*b* value of 27 in-gamut spot colors based on the Pantone Plus Solid Coated v3 M1 library and the printed and measured L*a*b* for that spot color. Figure 12 shows two columns, results for the Esko solution when using the proprietary Esko Equinox 4x4 EDK characterization chart (Esko - EDK) and the results when Esko created a color characterization with the non-proprietary, Idealliance Small 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 Delta E (better results) when using the 4x4 EDK chart (3872 patches) compared to the Idealliance Small Chart (400 patches).

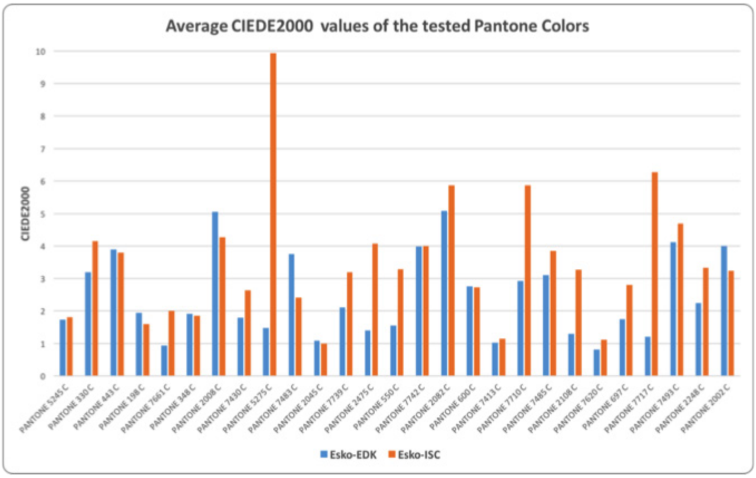

Figure 12: *The Delta E between the Pantone Plus Solid Coated L*a*b* library values and the printed and measured values for Esko when using the 4x4 EDK chart (blue) and the Idealliance Small Chart (Orange).*

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, Idealliance Small Chart (GMG - ISC).

In general, we see that many colors can be reproduced to < 2 CIEDE2000 (a typical tolerance in package printing), and we see that OpenColor generally produces much lower Delta E (better results) when using the OpenColor chart (700 patches) compared to the Idealliance Small Chart (400 patches).

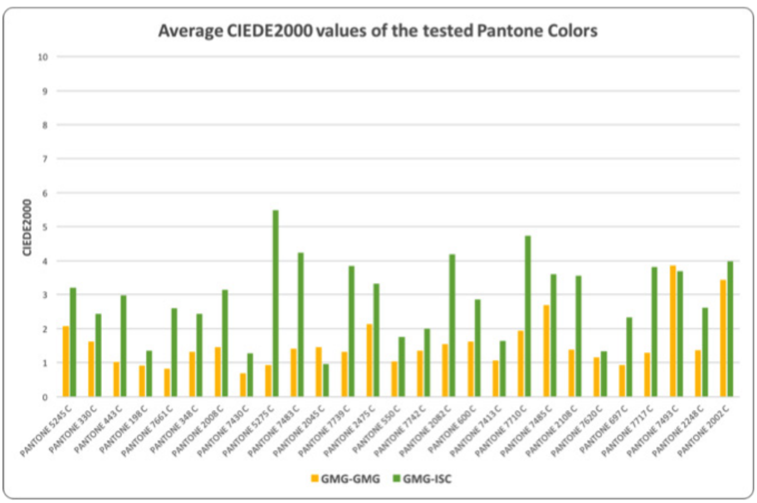

Figure 13: *The Delta E between the Pantone Plus Solid Coated L*a*b* library values and the printed and measured values for GMG Color when using the OpenColor chart (Yellow) and the Idealliance Small Chart (Green).*

The average CIEDE2000 values over the 27 in-gamut spot colors are shown below, for Esko Equinox and GMG OpenColor, Figure 14. We see that Esko has a lower average Delta E when using its own proprietary characterization chart compared to the generic Idealliance Small Chart.

	Esko- EDK	ESKO- ISC
MIN	0.82	0.99
STD	1.29	1.92
AVG	2.45	3.49
95th Perc.	4.77	6.15
MAX	5.08	9.93

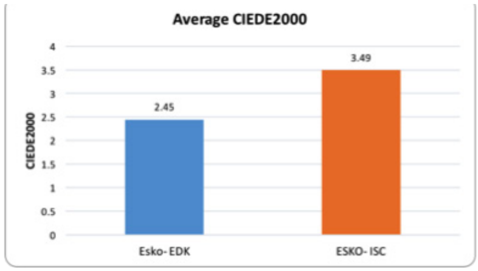

Figure 14: *The statistics for the 27 spot colors for the Esko Equinox solutions with the 4x4 EDK chart is compared to the same solution when using the Idealliance Small Chart (ISC). A lower Delta E is better*

	GMG- GMG	GMG- ISC
MIN	0.69	0.96
STD	0.75	1.15
AVG	1.55	2.94
95th Perc.	3.22	4.58
MAX	3.87	5.49

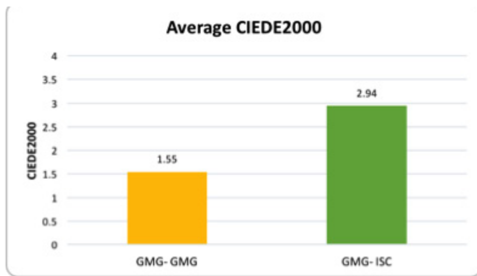

Figure 15: *The statistics for the 27 spot colors for the GMG OpenColor solutions with OpenColor characterization chart is compared to the same solution when using the Idealliance Small Chart (ISC). A lower Delta E is better.*

The separation build for the spot colors were analyzed between the vendor solutions. In particular different spot color builds were analyzed in terms of CMYK-OGV inking values, Figure 16. Pantone 2108 C was reproduced with Delta E = 1 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.

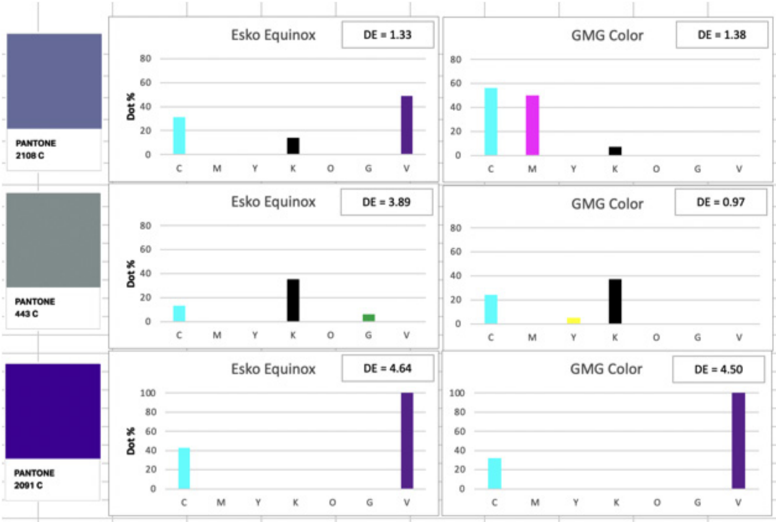

Figure 16: *The separation build for three different spot colors was analyzed between the vendor solutions. Pantone 2108 C had a similar (good) Delta E for both solutions, Pantone 443 C was bad for Esko but good for GMG Color and Pantone 2091 C was bad for both vendors.*

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 can contribute and create a large CIEDE2000.

Pantone 2091 C used a similar separation in both vendors, and was out of gamut and was subsequently reproduced with a high Delta E by both solutions. Pantone 2091 C was not part of the official 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 EG colorant in the separation, and indeed OpenColor was forced to use an EG colorant - Violet.

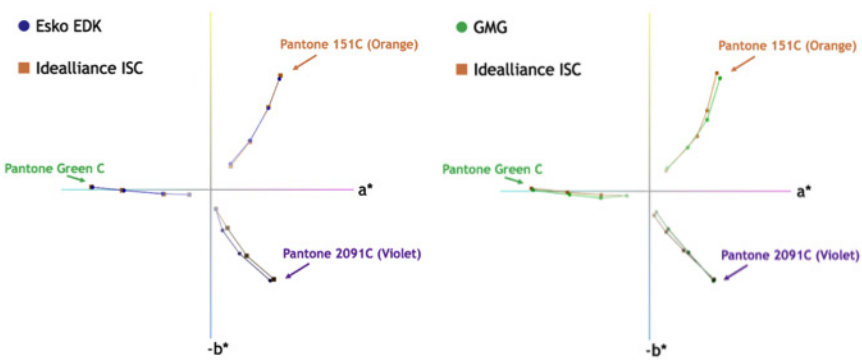

Figure 17: *Esko (left) and GMG (Right), Orange, Green and Violet spot color tone ramps were plotted for printed tints of 25%, 50%, 75%, 100%.*

In addition to solid spot colors, packaging may often contain vignettes or gradients, i.e. spot color tints. It is therefore of interest to evaluate the transition of a spot color from 0-100% tint. Spot colors close to the expanded color inks were chosen to encourage the vendor to utilize O-G-V colorants. It is conceivable that a solution may favour a CMYK build at less saturated colors and switching to ECG colorants when a color is out of process inks' gamut.

The real estate on the press form allowed only a few discrete steps in a tonal ramp as follows.

- PANTONE 151 C (Orange) 25%, 50%, 75%, 100%
- PANTONE Green C (Green) 25%, 50%, 75%, 100%
- PANTONE 2091 C (Violet) 25%, 50%, 75%, 100%

The hue angle that a tone ramp should follow is not defined, there are no target L*a*b* values per se, therefore this data is provided for information only.

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

- Esko Equinox 4x4 EDK chart - 3872 patches
- GMG OpenColor characterization chart - 700 patches
- Idealliance Small Chart - 400 patches.

It is relevant to examine the color gamut that each of the 3 different characterization charts determine 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 colorspace 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. At the 2019 Annual Technical Conference of TAGA Hoffstadt (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 = 16384 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 – 5,000. At the time the number of patches used by GMG OpenColor was 4200 (35x30 patches on 4 pages). At the same conference a presentation by Braun & Alejandro (Braun, T., Alejandro, J., 2019) showed that not much more accuracy is gained by test charts with a large number of 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 of less than 1.0 is 150.

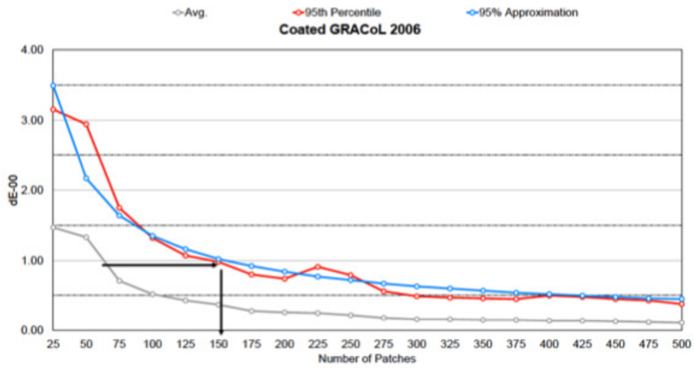

Figure 18: *Number of test patches needed to achieve a 95th percentile of the test patches ot have a CIEDE2000 of 1.0 according to Braun & Alejandro (Braun, T., Alejandro, J., 2019)*

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 3000.

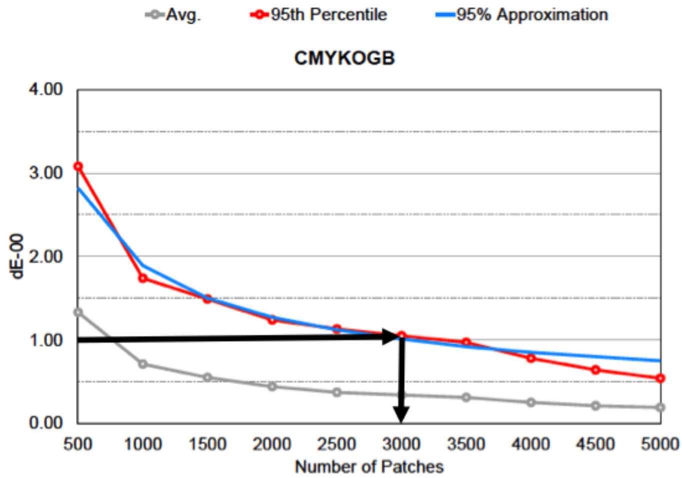

Figure 19: *Number of test patches needed to achieve a 95th percentile of the test patches ot have a CIEDE2000 of 1.0 according to Braun & Alejandro (Braun, T., Alejandro, J., 2019)*

The paper by Braun and Alejandro provides a formula that can be used to calculate the number of test patches that are needed to achieve a certain Delta E, for a specified printing system. The formula is as follows:

$$e = \frac{k}{n^g}$$

The letter e represents the Delta E value that one wants to achieve. Braun and Alejandro also provided 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 Delta E of 1 results in the number of patches needed to achieve a Delta E of 1 as 3227. A closer look at Figure 19 shows that the curve of the 95th percentile intersects with a y-axis value of 1 around this number of patches.

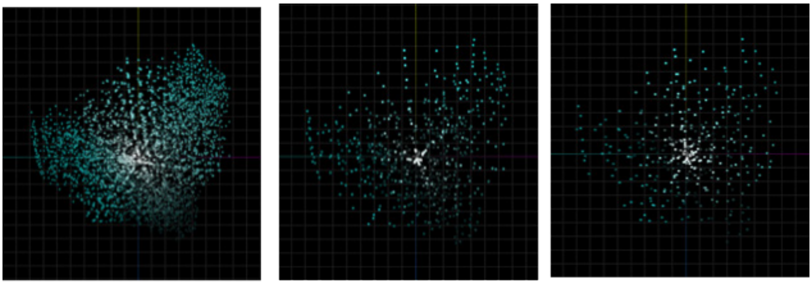

Figure 20: *(from left to right : Esko EDK, GMG, Idealliance ISC). From the L*a*b* 2-dimensional color gamut we see that the Esko EDK solution (left) has many more patches and therefore a much denser color cloud, while the Idealliance Small Chart (right) appears to be missing data from some areas of the colorspace*

In analysis of the L*a*b* 2-dimensional projection of the characterization measurements, Figure 20, we see that the Esko EDK solution has many more patches and therefore a much denser color cloud. The large number of patches appears to needlessly oversample the colorspace as it does not lead to lower Delta E in the analysis. Furthermore, the larger number of patches requires 4 press runs on a narrow-web flexographic press as used in this project and also by a typical packaging customer. The large number of patches could be useful in a very "noisy", unstable printing process, 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 on press variation below.

At the other extreme, the Idealliance Small Chart has so few patches (or patches with poorly chosen inking values) that some areas of the colorspace 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 Idealliance Small Chart characterization data.

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 opened up 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 were done in December 2020. The following charts were measured with a Techkon SpectroDens listed in the Materials used section:

- Esko EDK target with the following sub-targets:
  - CMYK
  - YMOK (Orange)
  - YCGK (Green)
  - MCVK (Violet)
- GMG characterization target
- Idealliance Small Chart (ISC)
- Esko verification run
- GMG verification run

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

- Solid ink 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

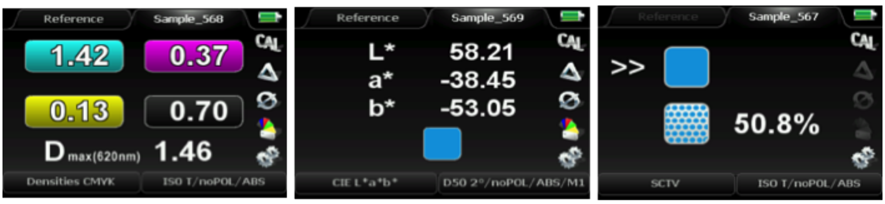

Figure 21: *Screens of the Techkon SpectroDens spectrophotometer, showing the SID, L*a*b* and SCTV measurement functions.*

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 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. The higher the value for print contrast the better the print quality in the tint percentages above 70%.

Solid ink densities

The average solid ink 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 the images below.

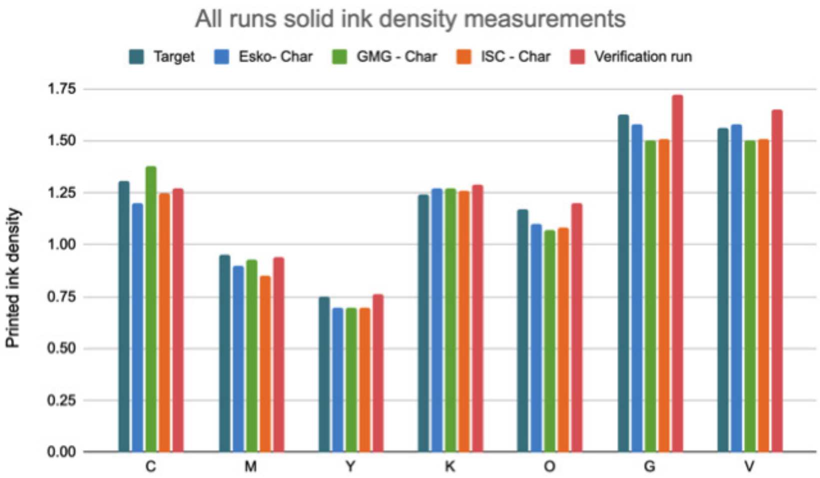

Figure 22: *Average solid ink densities for the seven process colors for all press runs*

In Figure 22 you can see the average solid ink densities for all seven process colors. The only ink densities that stand out are the densities for Orange, Green and Violet in the verification run that are a little bit higher than the average ink densities printed in the previous runs.

The next two Figures show the average printed ink densities for Esko and GMG only in relation to the verification run.

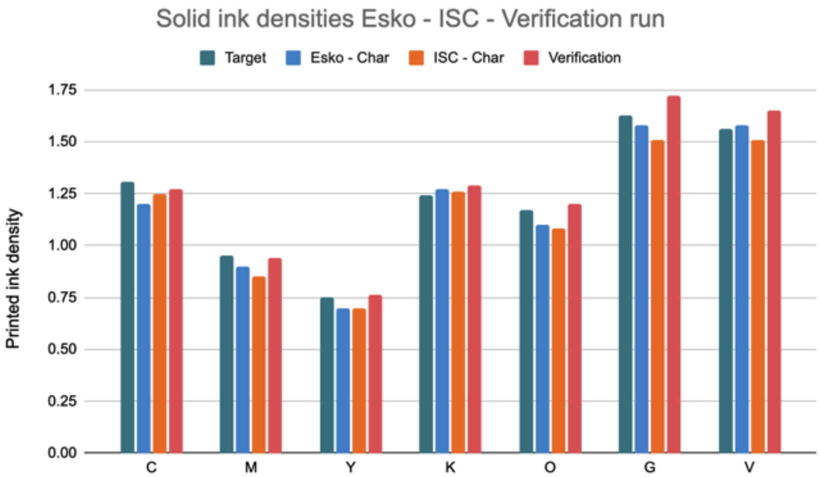

Figure 23: *Average solid ink densities for the seven process colors of the Esko EDK*

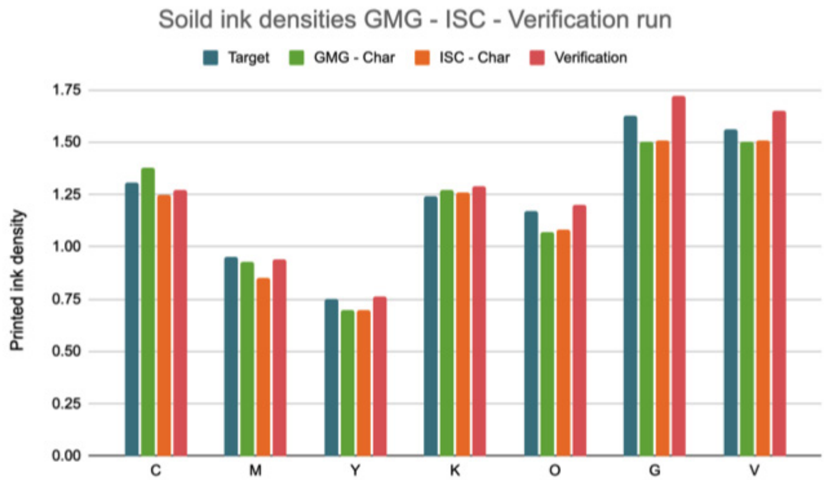

Figure 24: *Average solid ink densities for the seven process colors of the GMG characterization run in relation to the Idealliance ISC run and the verification press run*

From Figure 22 to 24 one can come to the conclusion that there were some print ink density variations. These variations were only somewhat significant for the Orange, Green and Violet inks in the verification press run. Since these graphs don't show great difference it is important to examine also the tone value curves of all the press runs conducted in this study.

SCTV curves

A point of interest are the tone value curves since tint values of CMYKOGV are used to build the Pantone colors. Differences between the characterization runs and the verification runs 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 the Figure below and detailed curves from all the runs can be found in the appendix.

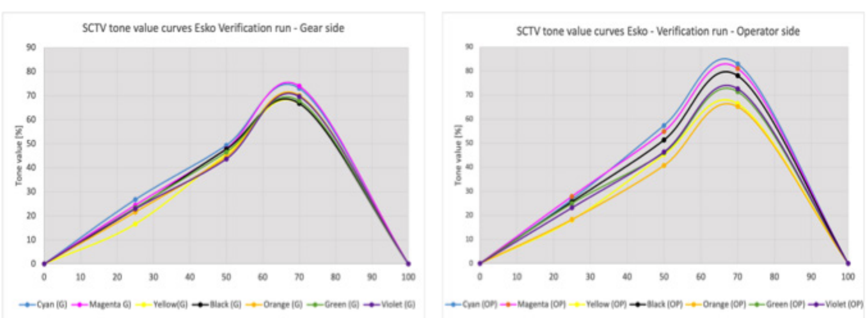

Figure 25: *SCTV tone value curves from the Esko verification run for the gear and operator side*

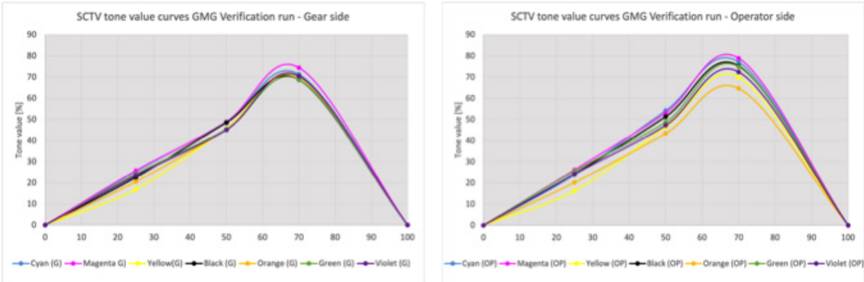

Figure 26: *SCTV tone value curves from the GMG verification run for the gear and operator side*

From Figure 25 and 26 it can be seen that there is a difference in the SCTV curves between the gear and the operator side. Most likely this 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.

Color differences between the characterization and verification 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 determined with the online calculator available at www.brucelindbloom.com . The results are shown in the figures below.

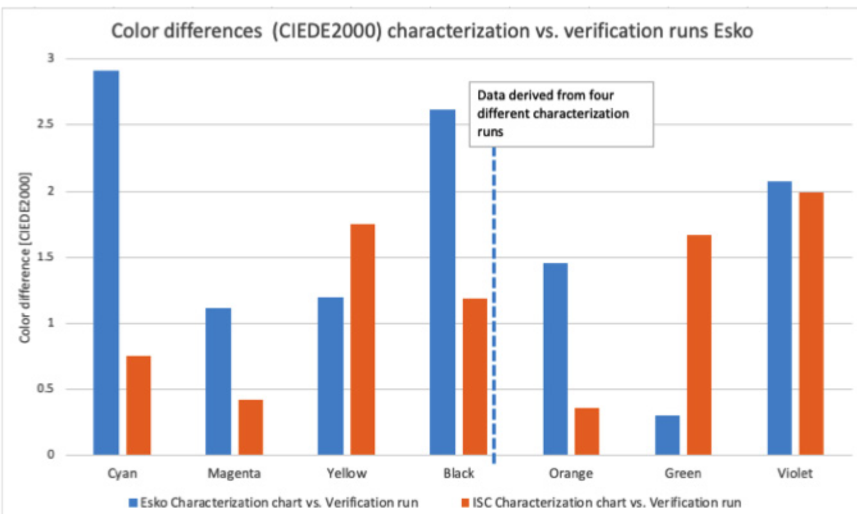

Figure 27: *CIEDE2000 values between the Esko characterization and verification run and the ISC run and the Esko verification run*

The biggest color differences were determined for Cyan and Black between the Esko EDK characterization run and the verification run. Surprisingly the color differences between the ISC characterization run and the Esko verification run are in general smaller. The largest color differences were determined for Cyan, Black and Violet 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 the 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. 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.

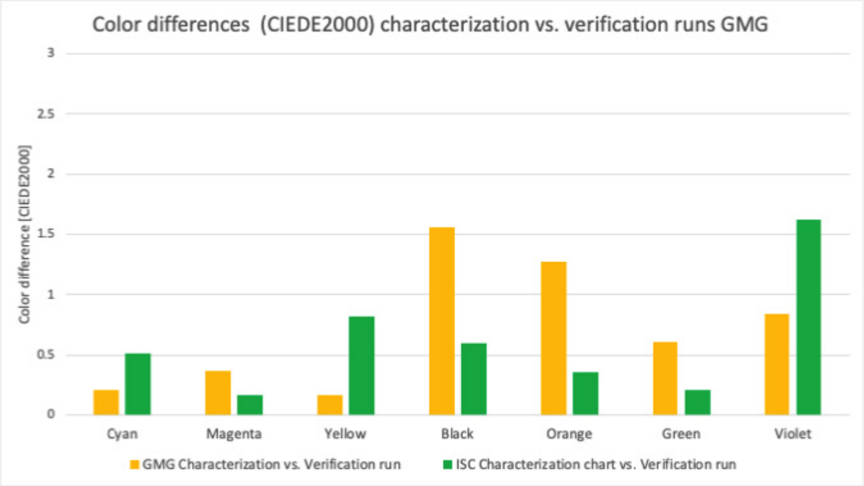

Figure 28: *CIEDE2000 values between the GMG characterization and verification run and the ISC run and the GMG verification run*

Figure 28 paints a slightly different picture. The largest color differences between the characterization and the verification run were determined for Black, Orange and Violet with 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. For the color differences between the ISC characterization run and the largest differences were determined for Violet, Yellow and Black. 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.

Print contrast

According to Breede, Handbook of Graphic Arts Equations (Breede, 1999), "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 this determination the print contrast on the CMYK colors was only used. The results are shown in the Figures below.

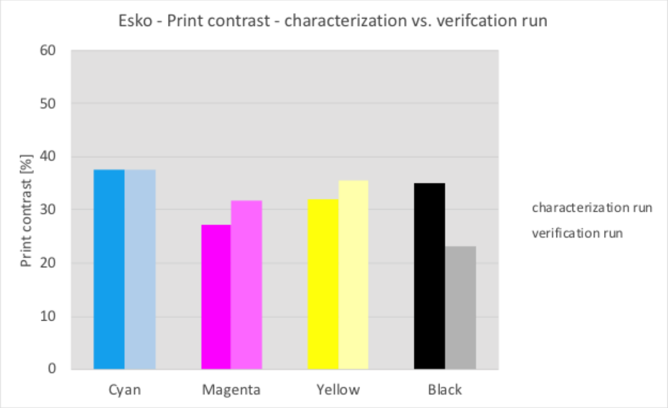

Figure 29: *Print contrast between the Esko characterization and verification run. The characterization run are the solid color bars and the verification run are the tint color bars.*

The four process colors CMYK show similar print contrast, except Black in the verification run. For print contrast a higher number is more desirable.

The same determination was conducted for the GMG press runs. The results are shown in the Figure below.

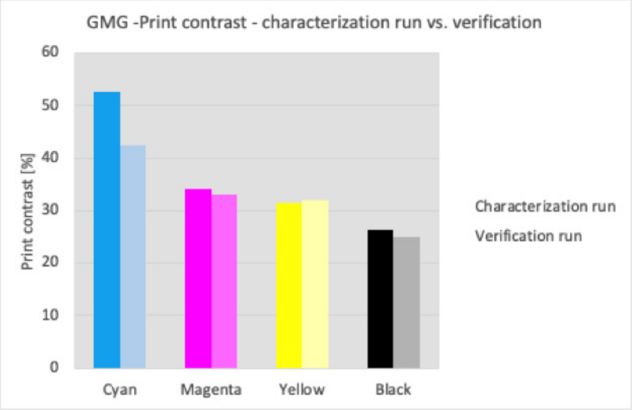

Figure 30: *Print contrast between the GMG characterization and verification run. The characterization run are the solid color bars and the verification run are the tint color bars.*

For the GMG press runs a more uniform print contrast behavior was observed. The only outlier was Cyan in the characterization run, which showed quite a high print contrast.

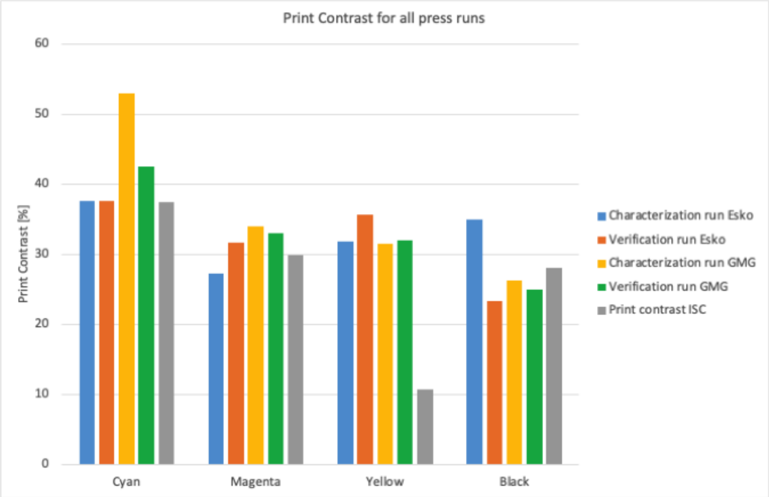

Figure 31: *Print contrast values for all print runs*

From Figure 31 it can be seen that the print contrasts for all press runs were relatively the same with two outliers. One is Cyan in the GMG characterization run and the other is Yellow for the ISC run.

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.

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 of having 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 a verification run to validate all the previous steps which result in quite accurate color builds of the tested Pantone colors. A bit of a disappointing result was that roughly only 65% of Pantone Plus Solid Coated colors were within the color gamut and the parameters of substrate, inks, and anilox rollers. 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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Appendix

Detailed SCTV curves from the Esko characterization press runs

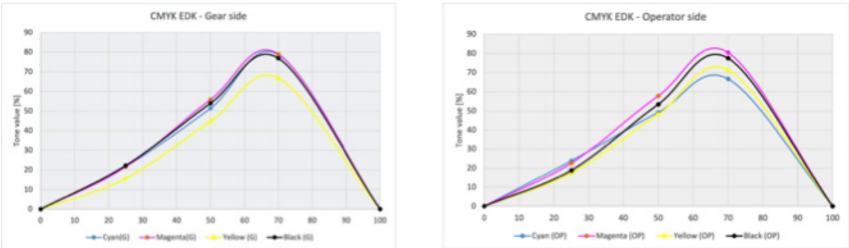

Figure: *CMYK EDK tone value curves*

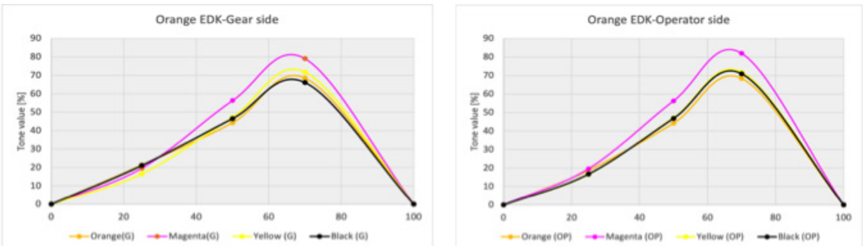

Figure: *OMYK (Orange) EDK target tone value curves*

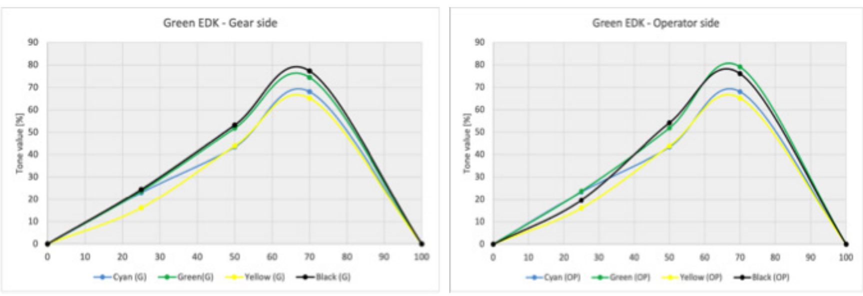

Figure: *CGYK (Green) EDK target tone value curves*

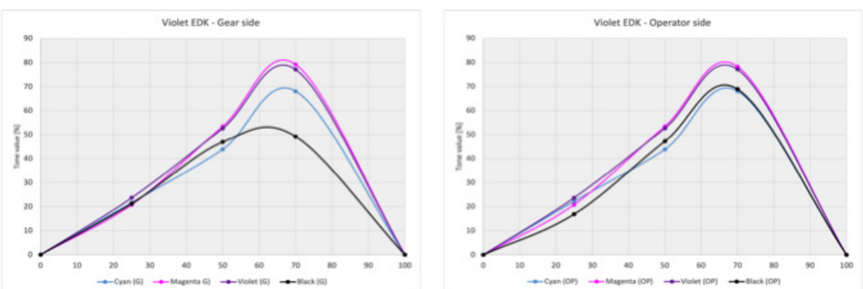

Figure: *CMVK (Violet) EDK target tone value curves*

Detailed SCTV curves from the GMG characterization press run

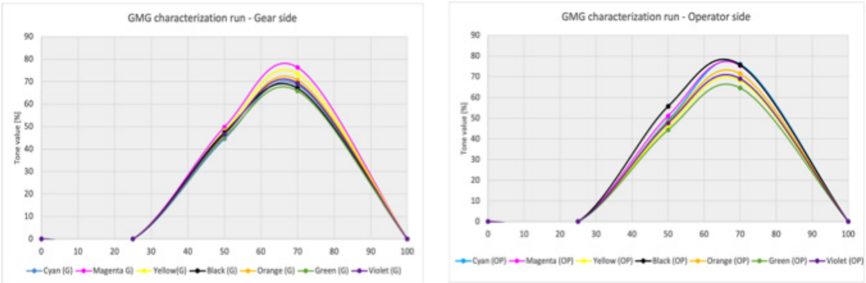

Figure: *Tone value curves for the GMG characterization run*

Detailed curves from the Idealliance Small Chart (ISC) characterization run

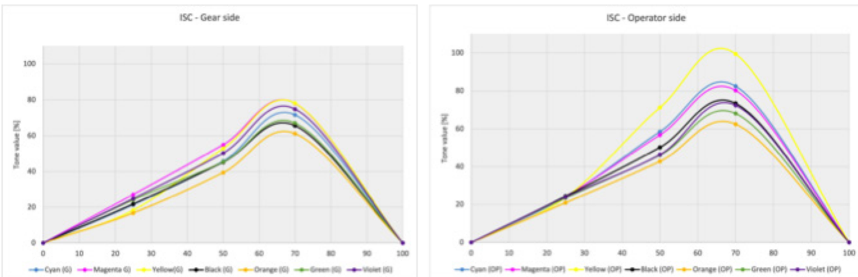

Figure: *Tone value curves for the ISC characterization run*

A detailed list of the selected Pantone patches for Verification target

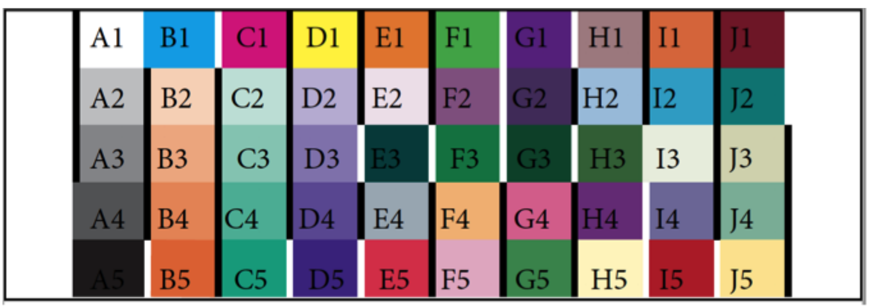

Figure: *Verification target*

#	Color Name	%	
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	

#	Color Name	%	
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	

Table: *List of the colors from the custom verification target*