# Color Reproduction Optimization: A Study of Current Technology & Practice for the Flexographic Printing Process

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Abstract: Accurate color reproduction is a critical concern in the printing industry. Over the years, technological improvements continued to make color reproduction predictable and reduced difficulties experienced in the industry. G7$^{TM}$ is a proposed calibration method for commercial offset lithographic printing that was developed to support the GRACoL7$^{TM}$ specification; it also suggests improved color matching across media and printing processes. The goal of G7$^{TM}$ is to match appearance in which gray balance is one of the most vital metrics of visual appearance (Hutcheson) across various media. Therefore, when G7$^{TM}$ calibration is used for any print reproduction proces, the appearance of the color reproductions from different devices should "appear" the same.

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The printing process used for this study was flexographic corrugated direct printing, using the G7™ calibration methodology on a Bobst 160, sheetfeed corrugated printing press. Fifteen samples were randomly selected for data analysis. The results showed when G7™ calibration methodology was applied to the corrugated printing process using standard inks and optimized material combinations the color reproduction metrics analyzed were close to the standard G7™ condition. Neutral gray was achieved when G7™ calibration methodology was used in the corrugated printing color reproduction process.

## 1. Introduction

Consistent, repeatable, and predictable color is the final result that every printer and converter is looking for when they refer to color reproduction quality. Color reproduction has long been a critical concern in the printing industry. Over the years, technological improvements have continued to make color reproduction easier; and further, have reduced its difficulties to the industry. There are specifications that have been written to provide printers reference sources to enable process control. GRACoL is such a reference document for quality color printing in the offset lithographic process. G7™ is a proposed calibration method developed to support the GRACoL7™ specification; it also suggests improved color matching across media and printing processes.

The goal of G7™ is to match gray balance, which is one of the most vital metrics of visual appearance (Hutcheson), across various media. Therefore, when G7™ calibration is used for printing process color reproductions, the appearance of the reproductions from different devices should "look" the same. Over the years, the printing industry has used different specifications as references for the different printing segments such as offset lithography, flexography and gravure to control the processes and resulting color reproduction. If G7™ can be applied to different printing segments beyond commercial offset lithography, and achieve the goal of matching visual appearance, this calibration methodology could help printers by improving and simplifying process control. The resulting outcome could provide a print manufacturing methodology for color appearance results that are as similar as possible.

### 1.1 Problem Statement

G7™, a method for calibrating presses to optimize printing conditions, was released in March 2006. G7™ calibration methodology utilizes colorimetric measurements to solve the problem of matching the appearance of the proofs with printed products. It calibrates devices to a specified condition that is capable of optimizing color reproduction. The G7™ methodology was originally developed for the commercial lithographic printing segment. However, the aim of G7™ is to match appearances of proofs and prints. The calibration method of G7™ should apply to other printing processes and devices according to its concept. Therefore, this concept should be applicable with other printing segments and procedures in theory. Flexography is a cost effective and simple printing process used for packaging printing. Flexography is capable of producing products on a variety of different substrates. The use of flexographic printing continues to grow (Knepp, 2006). It is a different printing process compared to the commercial offset lithography. Water-based inks, flexible plates, and pressure sensitive films or corrugated substrates used in flexography are all very different from the materials typically used in commercial offset lithography. In addition, the Flexographic Technical Association (FTA) committee for G7™ has been working to utilize G7™ calibration methodology to create a reference data set for the flexographic industry. Segments such as newsprint, flexible packaging, labels and envelopes have successfully utilized G7$^{TM}$ calibration methodology. Do these same principles apply to the corrugated segment? The color reproduction of corrugated printing is improving with technical advancements. There is a demand to recognize the need to optimize color reproduction in corrugated printing. Therefore, the problem of this study is how the G7$^{TM}$ calibration method can be utilized in corrugated printing to optimize color reproduction.

### 1.2 Purpose of the Study

This study addressed the use of the G7$^{TM}$ calibration method in the direct print corrugated printing process. In order to test the methodology of G7$^{TM}$ calibration in flexographic corrugated printing to optimize color reproduction, the objectives of this study were:

1. To explore the ability of using G7$^{TM}$ calibration methodology in direct print corrugated board.
2. To establish a reference data set for the direct print corrugated process.

## 2. Review of the Related Literature

### 2.1 Introduction

A critical issue for the majority of print buyers, especially those in consumer product companies has been the quality of color reproduction between print market segments and printing processes. Optimal color reproduction results depend on controlling the many process variables from creation to prepress to pressroom to finishing and converting. Optimal color reproduction is the primary focus of this study. Therefore, this study was conducted to analyze the current technology and practices for optimizing color reproduction. To support the study, significant technology which is G7$^{TM}$ calibration methodology for optimize color reproduction is discussed, and corrugated printing in the flexographic industry is also presented.

## 2.2 GRACoL Specification and G7$^{TM}$

General Requirements for Applications in Commercial Offset Lithography (GRACoL) is a document that can be used as a reference source in the printing industry for quality color printing specifically in commercial printing markets. It develops the best practices of new technology influence and its impact on the workflow of commercial offset lithography. It is a registered trademark of IDEAlliance (Quiz: Do you know the difference between GRACoL, GRACoL7 and G7?). By following the GRACoL guidelines and recommendations, printers will benefit in the following ways:

1. Reduce costs, decrease turn-around times, and avoid re-makes.
2. Develop internal guidelines for process control.
3. Obtain print predictability.
4. Demonstrate printing quality through print guidelines and target goals.
5. Explain what is reasonable to ask of print suppliers.

(What is GRACoL?)

G7$^{TM}$ requires the use of up-to-date technology, such as spectrophotometry, colorimetry and CTP (computer-to-plate), to provide improved press control and tighter toleranceing compared to the old version of GRACoL. G7$^{TM}$ methodology utilizes the ISO 12647 Standard sets as the basis for quality printing. It requires printing with inks that are defined by ISO 2846-1. The dry solids would be measured as close as possible to the ISO 12647 CIELab values for seven colors, which are four process colors and their two-color overprints. The major difference between the old version of GRACoL and G7$^{TM}$ is that

G7™ focuses on colorimetric data for gray balance and a standardized "Neutral Print Density Curve" (NPDC), rather than traditional tone value increase (TVI) aims for each ink. This new methodology allows users to achieve a closer visual match from device to device; meanwhile it maintains the same overall appearance. This approach does not have a perfect match in all colors, but it does reduce the need for creating different press characterization for each press, which is a valuable benefit in today's ICC workflow (Welcome to GRACoL7.0).

### 2.3 G7™ Calibration Methodology

The procedures of applying G7™ calibration methodology involves:

1. The output of un-calibrated digital plates
2. Calibration runs,
3. Matching gray balance
4. Creating neutral print density curve
5. Calibration of the RIP system
6. The output of calibrated digital plates
7. A qualification run
8. A characterization run (optional)

A simple explanation of G7™ calibration procedures is provided in the following contents. The critical target used for G7™ methodology, which is a P2P (print to proof) target. A set of un-calibrated plates are output with two P2P targets rotated 180º from each other. The press is optimized to it's best physical and chemical condition to run the calibration job. Once the press is running, the densities of each ink are set to the nominal solid ink densities and L*a*b* values that G7™ specifies. If there is a difference between the ink density and the L*a*b* values, the L*a*b* values take priority. Once the press run is completed, the TVI (tone value increase) values are measured. According to G7™, the TVI should be about ±2% for cyan, magenta, and yellow. The black is about 3% to 6% higher. After achieving these steps, the gray balance needs to be adjusted to match the G7™ specifications. Once the measurements have been reached, across the press sheet evenness then is checked. Afterwards, the press is run at production speed and at least 1,000 sheets are run to stabilize the press. The measurements are taken again to ensure there is little deviation from the goal measurements. From this point, the calibration run is complete and the P2P target is measured. The measured data is plotted on a G7™ graph. Once the information is obtained, the curve can be applied in CTP software or the RIP system. A new set of calibrated plates are output with an IT8.7/4 target as well as images. The new set of calibrated plates are used for the second press run, which is a qualification run that aims for the same densities and colorimetric values as achieved at the end of the calibration run. The k-only and cmy-only gray scales of the P2P target are remeasured and are plotted as neutral density vs dot percentage. Confirmation is used that the new graph curve matches the desired graph curve. Checks must also be made that other parameters, such as gray balance and ink density are still within tolerance. An ICC profile will then be created. The final press run is a characterization run, which an ICC profile is applied to the images. According to *Calibrating, Printing and Proofing to the G7™ Method*, the characterization run is an optional. If NPDC and gray balance calibration are successful in the qualification run stage and standard inks and paper were used, then the optimal color reproduction condition for the press should be achieved.

## 2.4 Introduction to Corrugated Printing in Flexographic Printing Industry

Corrugated board is a durable, flexible, and lightweight material used for shipping containers, packaging and point of purchase displays. Flexographic printing is the most common form of printing on corrugated stock because it is economical and cost effective process, and can be used for short or long runs (Complete corrugated print package, 2002). Because corrugated printing is mainly on boxes or containers, the strength of the container is important. Therefore, the protective container is often used as a display. This brought pressure to today's corrugated printers to understand how to control their printing variables such as substrates, plates, and inks. The substrate used for corrugated printing is made up of a top and bottom layer and wavy layers between them called flutes. The closer the flutes are, the more uniform the caliper of the printing surface will be. Plates that are used to print high quality products usually have high hardness, which will cause less distortion when printing. Flexographic inks by definition are liquid and quick drying. However, inks that are used on a corrugated printing press are different from typical narrow-web and wide-web flexographic presses. These inks require slower drying for corrugated printing due to the large diameters of the anilox rolls and the size of the plates. (Utschig, 2004).

The corrugated market is being influenced by new technologies. The fact is that corrugated printing is also flexible, strong, space efficient, and one of the most environmentally cooperative materials. This makes corrugated printing a complete packaging solution (Wright, 1999).

## 3. G7™ Experiment

### 3.1 Design of Research

An experimental research method was utilized to study and test the current technologies and concepts on color reproduction to fulfill the purposes of this study. The current technology used is the G7™ calibration methodology. The study also aimed to establish a reference data set for corrugated printing.

### 3.2 G7™ Experiment Procedure on Direct Print Corrugated Board

Research procedures are shown in Figure 1 in the following order: The digital CMYK file was designed to output a set of linear plates. ISO ink set was used for calibration run. Hue angle was used as a criterion to determine the press goal condition. Data was collected to create a calibration curve and then applied to the RIP for output of a second set of calibrated plates. The validation run was then used to confirm the calibration. The detailed procedures for each step will be explained in the following sections.

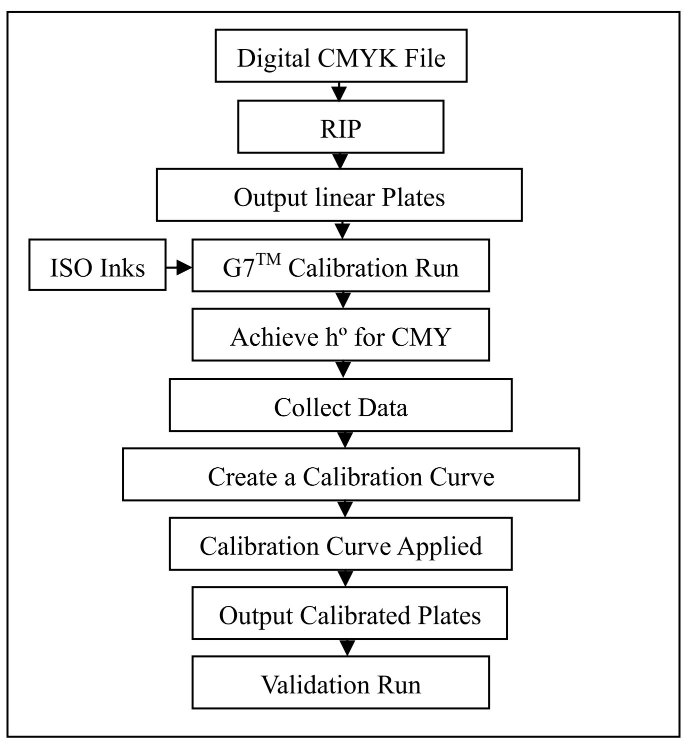


Figure 1 Research Procedure Flow Chart

3.2.1 Create Test Forms

Two test forms were created for two press runs, which were the calibration run and validation run as show in the Appendix. The components on the test forms included two P2P targets rotated 180° from each other, two G7$^{TM}$ critical images, four process color tint scales, impression targets in four colors, registration marks, type print ability targets in four colors, and IT8.7/4 characterization targets. Gray balance charts were added to the second test form.

3.2.2 Prepare ISO Inks

The key for G7$^{TM}$ is the standard ISO ink. The G7$^{TM}$ inks for flexo were ISO 2846-5 as shown in Table 1 below.

Table 1

| ISO 2846-5 flexo inks | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Colorimetric values for 0/45 and 45/0 geometry, illuminant $D_{50}$, 2° observer | | | | | | | | | |
| | Colorimetric values | | | | | Tolerances | | | |
| | $L^*$ | a* | B* | C* | h° | $\Delta E_{ab*}$ | Δa* | Δb* | ΔL* |
| Y | 91.0 | -5.0 | 95.0 | 95.1 | 93.0 | 5.0 | - | - | - |
| M | 52.0 | 71.0 | 1.0 | 71.0 | 359.2 | 6.0 | - | - | - |
| C | 58.0 | -38.0 | -45.0 | 58.9 | 229.8 | 6.0 | - | - | - |
| K | ≤18.0 | 0.5 | 0.0 | 0.5 | 0 | | ±1.5 | ±2.0 | 0, -18.0 |
| There is no symmetrical tolerance for L but an upper limit for black. | | | | | | | | | |

In addition, Dr. Mark Mazur from DuPont Cyrel, the technical advisor of this study, advised the fuse CIELCh instead of CIELab because color of inks is critical. Therefore, C* and h° were calculated from Lab in spreadsheet. In addition, by looking at Δh° and ΔC*, there will be better indicators than just looking at ΔE. As well, Δh° and ΔC* were used to determine the tolerances. Then, the goal was to try to get as close as possible to a Δh° of 0. However, ΔC* tolerances might be affected by the type of substrate is used. As the result, it might significant differ from the ΔC* tolerances. Dr. Mazur has suggested that hue is more important than chroma because it may be difficult to get as close as possible to a ΔC* of 0 on a particular substrate, such as newsprint.

Several samples from different ink vendors were measured to collect CIELCh and compared to ISO 2846-5 ink specifications. Δh° and ΔC* were calculated to determine the choice of ink vendor. Because it was difficult to get a Δh° and ΔC* of 0, the tolerances were increased to be within ±2° for Δh° and ±2 for ΔC*. When there was a doubt, Δh° took priority. The results showed that inks from Color Resolution International (CRI) were closed to the ISO 2846-5 specification (Table 2 below).

Table 2

| | CRI | | ISO 2846-5 | | Tolerances | |
|---|---|---|---|---|---|---|
| | h° | C* | h° | C* | Δh° | ΔC* |
| Y | 94.9 | 99.3 | 93.0 | 95.1 | 1.87° | 4.20 |
| M | 355.5 | 67.0 | 359.2 | 71.0 | -3.66° | -4.03 |
| C | 232.7 | 60.2 | 229.8 | 58.9 | 2.91° | 1.31 |
| K | 49.5 | 0.8 | NA | 0.5 | NA | 0.32 |
| Allow tolerances to be within ±2° | | | | | | |

However, magenta and cyan inks still varied from the acceptable tolerance. Ink vendor, Color Resolution International was asked to re-formulate the inks according to our desired tolerances and ensured a single pigment for all inks. The G7$^{TM}$ committee from FTA (Flexographic Technical Association) had advised the researcher that single pigment was important and required for ISO standard ink set.

### 3.2.3 Substrates

The corrugated segment manager of the G7$^{TM}$ committee, Cordes Porcher, suggested the researcher use an E-flute coated stock. Therefore, Kemiart lite E-flute coated stock was used as the substrate. Paper white was measured by a GretagMacBeth Spectrolino Spectrophotometer. The CIELab results for paper white were L* 93.91, a* 0.89, b* 1.1. As defined in the G7$^{TM}$ document, a standard paper for commercial printing was ISO paper type 1 with a nominal white point of 95 L* (±3), 0 a* (±2), -2 b* (±2) measured with white backing. Since the printing process used for this study was flexography the ISO 12647-6 standard was used. ISO 12647-6 does not define a standard substrate for corrugated printing, but it defines paper white as print substrate color restrictions. Table 3 showed the differences among ISO 12647-2, ISO 12647-6, and the substrate that was used for the study.

Table 3

| Kemiart lite Paper White | | | ISO 12647-6 Print Substrate Color Restrictions | | | ISO 12647-2 Paper White | | |
|---|---|---|---|---|---|---|---|---|
| L* | a* | b* | L* | a* | b* | L* | a* | b* |
| 93.91 | 0.89 | 1.1 | ≥90 | -3 to +3 | -5 to +5 | 95 | 0 | -2 |
| | | | | | | ±3 | ±2 | ±2 |

The nominal white point measured from the substrate was within both ISO 12647-6 and 12647-2 standards. In addition, G7$^{TM}$ has provided 3 ways to correct gray balance if non-standard paper was used. They are no gray correction, full gray correction, and partial gray correction. No gray correction was used for this study, which was simply allowed gray balance to shift to paper white. The reason for using no gray correction was that the paper white of the substrate was already within both ISO 12647-6 and 12647-2 standards. Therefore, no gray correction was the better choice.

Before setting up the feeder, with corrugated substrate, each sheet of corrugated board was vacuumed on all sides and edges. A critical issue with corrugated boards is dust. When the board is manufacturer, it generates substantial amounts of dust. Dust effects feed and increases the variation among the printed reproductions. The purpose of vacuuming was to remove dust from the substrate and reduce the variations during printing.

3.2.4 Outputting Linear Plates

A set of linear digital plates were output for the calibration run. The RIP system used was an Esko. The plates were then shipped to Mark Tr´ece Inc. for mounting. The output settings and mounting materials used are listed in Table 4.

Table 4

| | | | |
|---|---|---|---|
| Plate Thickness | 0.107 | Carrier | 0.060 Rogers SM |
| Plate Relief | 0.025 | Tape | Rogers 3120 foam tape |
| Line screen | 85 lpi | Screen angle | K45° C15° M75° Y90° |
| Dot shape | Circular | | |

The press used for the test was a Bobst 160 located at Clemson Unversity's Printing and Converting Laboratory (PrintCon). There have been a number of tests on this press to determine the optimum plate package. Based on the previous press tests the conclusion was to use the above plate package.

3.2.5 Calibration Run

The job was run on PrintCon's 4-color inline directed print corrugated press, the Bobst 160, with a printing sequence of KCMY. The inking systems used on the press differed between the first station and the other three stations. The first station used a two roll with reverse angle doctor blade system with 700 lpi and 2.8 bcm anilox roll. The other three stations used a chamber system with 500 lpi and 3.0 bcm anilox roll.

The completed press characterization report was listed in the Appendix. The pH and viscosity of inks were measured and were listed in Table 5 above.

Table 5

| | K | C | M | Y |
|---|---|---|---|---|
| pH | 9.39 | 9.5 | 9.32 | 9.64 |
| Viscosity | 25 sec. | 33 sec. | 25 sec. | 27 sec. |

The strategy of the calibration run was to target hue angle for cyan, magenta, and yellow and achieve nominal gray balance at 50C 40M 40Y. As discussed in section 3.2.2, both chroma and hue angle are important. However, it was more manageable to target one variable instead of targeting two variables (both C* and h°). In addition, in order to ensure the stability of the press condition, 1 sheet was taken from every 50 sheets to check hº. The results were in Table 6 below. The overall hue angle of cyan, magenta, and yellow were very consistent. We did not have a significant variation among sheet to sheet on hue angle readings.

Table 6

| | Y | Y (Δhº) | M | M (Δhº) | C | C (Δhº) |
|---|---|---|---|---|---|---|
| 1~50 | 94.49 | 1.49 | 355.12 | -4.09 | 234.31 | 4.51 |
| 51~100 | 94.21 | 1.21 | 354.95 | -4.25 | 233.22 | 3.67 |
| 101~150 | 94.23 | 1.23 | 354.97 | -4.23 | 233.47 | 3.67 |
| 151~200 | 94.22 | 1.22 | 354.94 | -4.26 | 233.08 | 3.28 |
| 201~240 | 94.19 | 1.19 | 354.94 | -4.26 | 233.40 | 3.60 |

Note: Δhº was the difference between the actual hº reading and hº from ISO 2846-5

The tolerances of magenta and cyan were a little higher than the acceptable tolerance, which was ±2°. The researcher and the assisting press operator added more impressions to cyan and magenta and ran several sheets more to determine if target h° could be achieved. Results showed no changes on the h°. In the case of offset lithography, ink keys are used to adjust ink volume to achieve nominal gray balance at 50C40M40Y with 0.0 a* (±1.0), -1.0 b* (±2.0). However, instead of ink keys, corrugated presses change anilox rollers to adjust ink volume. This was not convenient at PrintCon since such a change in anilox was such a time consuming process that was restricted by press time limitations and a demand for the current configuration on the press. Due to limited adjustments capability on the corrugated press, the researcher made the decision to run the press with the condition that the average h° of cyan was 3.2°~4.5°, magenta was -4.1°~-4.26°, yellow was 1.19°~1.48°, and nominal gray balance at 50C40M40Y has a*=1.48 and b*=0.34.

### 3.2.6 Sampling

According to the G7™ document, after achieving goal condition, at least 1000 sheets have to run at the typical production speed. This is not practical to corrugated printing segment due to the expense of the corrugated boards. The suggestions from the G7™ panel of FTA suggested that at least 250 sheets run at the production speed. Once the press condition was acceptable, 250 sheets were run at the typical production speed, which was 3200 sheets per hour. The samples were numbered in sequence with a total of 240 samples obtained from the calibration run. The researcher then took every 5$^{th}$ sheet until a total of 15 sheets were collected.

### 3.2.7 Measuring

The G7™ proof-to-print process target was measured to create a calibration curve. There are two ways to measure a P2P target. One is manually measuring column 4 (K only) and column 5 (CMY only) and plot data on to a G7™ graph. The other measuring method is automatically measuring the entire P2P target and plot data into IDEALink Curve Software. This study used Eye-OneIO with a 2° observer angle and D50 illuminant to automatically measure the entire P2P targets. There were two P2P targets on the test form, providing two data entries per sample. This resulted in a total of 30 data entries.

### 3.2.8 Created Calibration Curve

Data was then plotted into IDEALink Curve Software to build the calibration curve. A total of 30 data sets were added into IDEALink Curve Software to analyze the neutral curve, color, gray balance, and tone value increase curve and, in addition, to compare to the standard.

## 4. Results and Findings

This section reports the results of the calibration run and other findings obtained through the experiment.

### 4.1 Neutral Print Density Curve

Figure 2 shows the neutral curve of the result of the calibration run as compared to the standard. The green curve was the ideal, which was the standard and the red curve was the curve of corrugated board. It was interesting how close the neutral curve of direct print corrugated board was to the standard. Two different processes and different substrates reproduced this close result of neutral density. Only minor adjustments will be needed to create a calibration curve later for qualification run. However, there were more differences on the K only neutral print density curve between direct print corrugated board and the standard. This could be due to the differences of inking system and anilox used. The first station, black, used a two roll with reverse angle doctor blade. A chamber system was used for the other three stations.

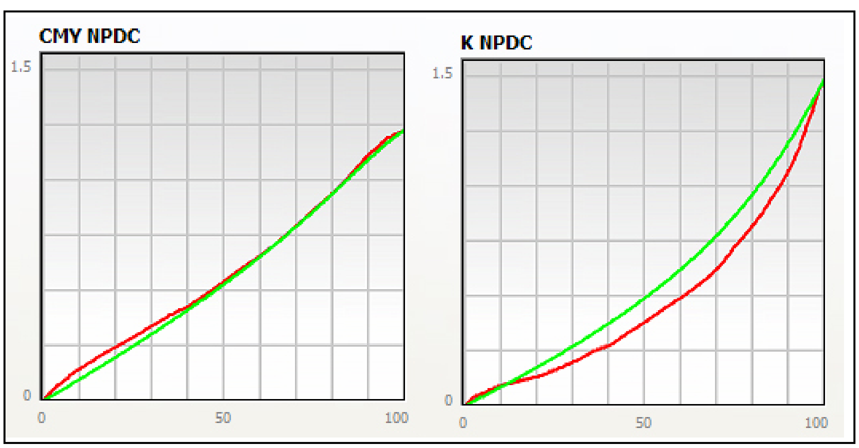


Figure 2

4.2 Color Analysis

The function of color analysis in IDEALink Curve Software allows for evaluating ink hue/chroma, analyzing gray balance, and analyzing TVI. The following sections discuss the results and findings from these three tasks.

4.2.1 Evaluate Ink Hue/Chroma

Evaluation of ink hue/chroma allows comparing the ink hue and chroma to specifications for publication printing (SWOP/ISO TR001) or standard commercial printing inks (ISO 12647-2). Each comparison is detailed in the following Figures.

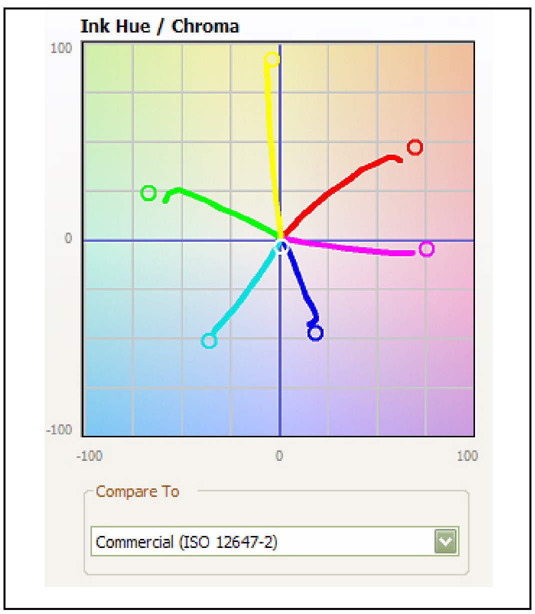


Figure 3

Figure 3 shows the analysis of color compared to ISO 12647-6. The circles indicate ISO 12647-2. Ideally, the end points should terminate within each circle. It was interesting that cyan and yellow were close to the ISO 12647-2 standard. There were color shifts on two color overprints; red, green, and blue. Red shifted to magenta, green shifted to cyan, and blue shifted to cyan. The paper white did not end within the circle (white circle).

Figure 4 showed the results of comparing colors of direct print corrugated board and GRACoL 2006 Coated 1. The results were similar to ISO 12647-2 because they were both standard for commercial printing.

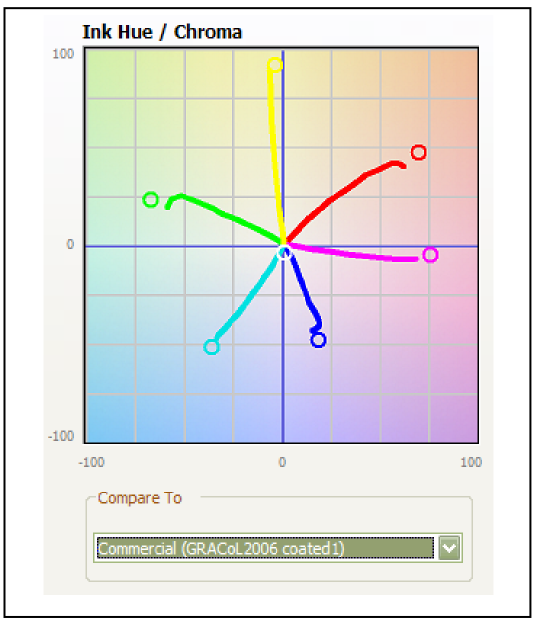


Figure 4

The results of comparing color of direct print corrugated board and SWOP (TR001) was shown in Figure 5. Magenta, red, and blue end within the circles, which means they reached the target for SWOP (TR001). Blue had a color shift at the end, but its end point still terminated within the circle. The interesting finding of this figure was the end point of yellow was not at the end within the circle, but it went through the circle. Cyan and green were not within the circles, but touched the circle. Cyan and green were very close to SWOP (TR001). Blue and green had color shifts toward cyan. In addition, the paper white was at the (0, 0) origin and within the circle.

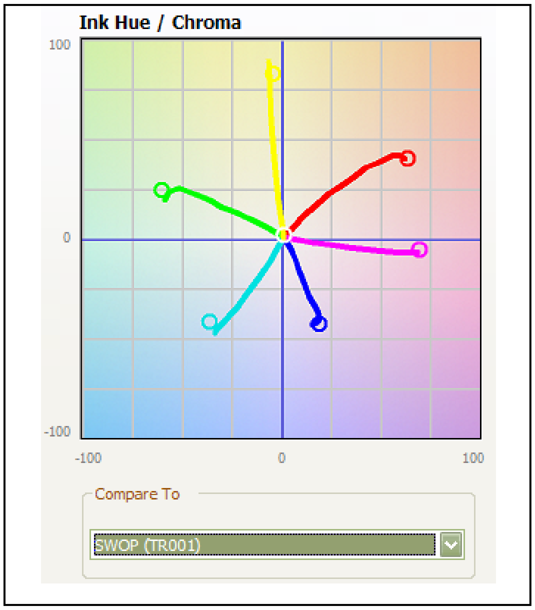


Figure 5

When compared to SWOP (2006 Coated 3), the end points of yellow and cyan were within standard and magenta was close to standard (Figure 6). Two color overprint; red, green, and blue, all had color shifts towered magenta and cyan. The white point ended within the SWOP (2006 Coated 3) standard. The results of colors were very different when compared to commercial standards and publication standards. The results of direct print corrugated board were much closer to publications standards. When compared to both publication standards, SWOP (TR001) and SWOP (2006 Coated 3), the results of the colors of direct print corrugated board were much closer to SWOP (TR001) than SWOP (2006 Coated 3).

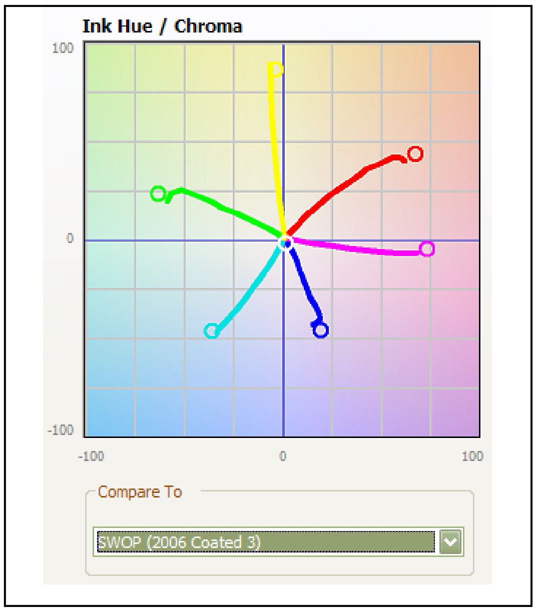


Figure 6

Figure 7 shows the result of the comparison of direct print corrugated board to SWOP (2006 Coated 5). Overall, cyan, magenta, yellow, red, green, and blue were close to SWOP (2006 Coated 5). This comparison result was more similar to SWOP (TR001) overall. The white point was at the circle, which was the SWOP (2006 Coated 5) standard. Two color overprints; green and blue, had a significant color shift toward cyan, while red had a slight color shift toward magenta. The chroma comparison was similar to SWOP (TR001) and SWOP (2006 Coated 3), but was significantly different from commercial standards. Commercial (ISO 12647-2) and commercial (2006 Coated 1) were more saturated than publication SWOP standards.

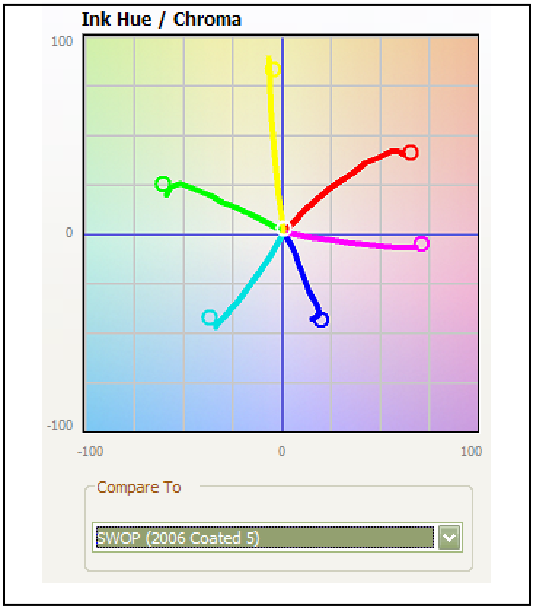


Figure 7

4.2.2 Gray Balance Analysis

Figure 8 was the result of the CMY gray balance curve. The red curve indicated a* and the blue curve indicated b*. In theory, the blue and red curves should be parallel and close to 0. The b* value was slightly high at the highlights and shadows and a* was slightly low at the shadows. The colorimetric value of a* and b* were close to 0 at midtones, but slightly shifted to yellow (+b*) and red (+a*). The curve also showed that the CMY gray balance was more neutral at quarter-tone to midtones (30% to 50%). The CMY gray balance had color shifts to yellow (+b*) and green (-a*) at the shadows. The neutral at highlights shifted to yellow (+b*) and red (+a*), which was the result of no gray correction whcih allowed the gray shift to paper white (0.89 a*, 1.1 b*).

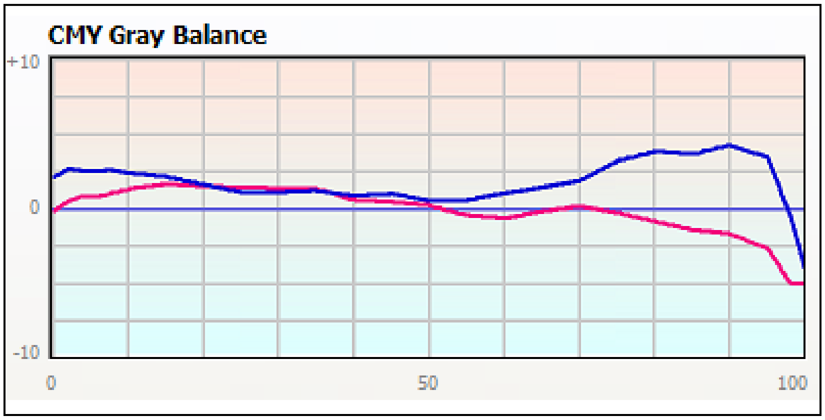


Figure 8

4.2.3 Tone Value Increase Curve Analysis

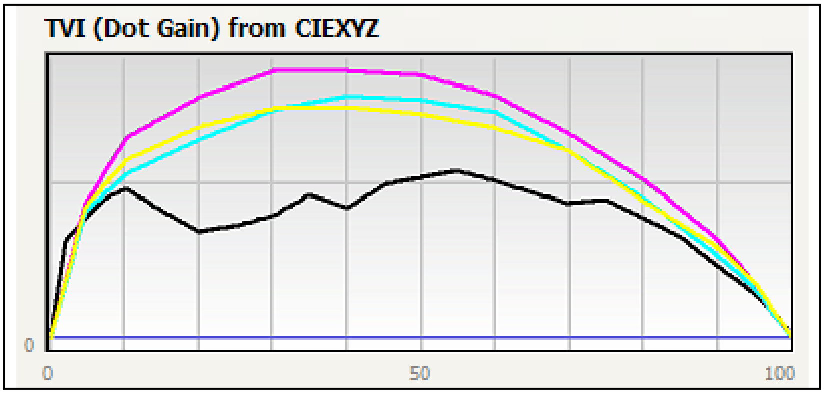


Figure 9

As Figure 9 shown above, cyan, magenta, and yellow had a smooth TVI curve from highlights to shadows. However, the TVI curve of black was not smooth and was significantly different from cyan, magenta, and yellow. Tone value increase dropped from quarter-tones to midtones of black and dropped again at three quarter-tones. These results could be due to the different inking system used for black.

## 5. Conclusions and Recommendations

This section includes the research results and findings from the previous section and provides recommendations for future research.

The CMY neutral print density curve was close to standard. As such, the G7™ calibration methodology that was designed for commercial offset lithographic printing could also be applied with direct print corrugated board. In addition, direct print corrugated board is able to achieve the standard expectations with standard ink sets, digital plates, and G7™ procedures. G7 calibration methodology successfully calibrated direct print corrugated board to optimize color reproduction.

The results of color analysis showed that direct print corrugated board was much closer to publication standards than commercial printing standards. The CMY gray balance curve and TVI curve did not achieve the ideal condition. However, the calibration curve that has been created by this study should be applied to the RIP system. A second set of calibrated plates will then be used for a second run, which is a validation run to verify the calibration. If the calibration procedures are successful, a* and b* curves of CMY gray balance will be parallel and approximate to 0. Also, the TVI curve of black will be smoother.

Future research is recommended to compare the results of print appearances of all of printing segments that have been calibrated to G7™ in flexography to evaluate how close the results are to each other. It is also recommended that non-standard ink sets and conventional plates be used with the G7™ procedures to examine how non-standard materials can be employed to G7™ procedures.

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Quiz: Do you know the difference between GRACoL, GRACoL 7 and GRACOL 7.0?

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Welcome to GRACoL 7.0.

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Test Form for the Calibration Run


Test Form for the Validation Run

Printer: Bobst Flexo 160 City: Pendelton State/ Prov.: SC Country: U.S.A.

Press Room Information:

Run Date: Feb. 26, 2007
Print Process: Flexo corrugated
Machine No. 160
Press Manuf. Bobst
Press Crew: Kern Cox & Li-Wen Chen
Speed: 3200 sheets per hour

Substrate: Coated E-flute Kemiart Lite
Ink Vendor: Color Resolution International
Ink/Base: Water-based
Repeat: 54.4
# of Colors: 4
Metering Sys: 2 roll with reverse angle doctor blade for 1st station, Chamber system for 2nd to 4th stations

Plate: Digital thermal DFM
Plate Height: 0.107
Mounting: 0.060 Rogers SM
Tape: Rogers 3120 foam tape
Screening: Circular dot K45°, C15°, M75°, Y90°
Line Screen: 85
NO DRYERS

| Station/Deck: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Color | Black | Cyan | Magenta | Yellow | | | | |
| Density | | | | | | | | |
| Viscosity | 25 sec. | 33 sec. | 25 sec. | 27 sec. | | | | |
| pH | 9.39 | 9.5 | 9.32 | 9.64 | | | | |
| Temperature | 72°F | 72°F | 72°F | 72°F | | | | |
| Humidity | 22 | 22 | 22 | 22 | | | | |
| Anilox Count | 700 | 500 | 500 | 500 | | | | |
| Anilox Volume | 2.8 bcm | 3.0 bcm | 3.0 bcm | 3.0 bcm | | | | |
| Anilox Angle | 60 | 60 | 60 | 60 | | | | |

Press Characterization Report