Implementing Process Color Printing by Colorimetry

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Abstract
Standards-based printing is shifting from densitometry-based specifications to colorimetry-based specifications. Similar to switching rules in the middle of the game, this has caused confusions in pressrooms worldwide. This paper reviews how standards-based printing began, describes underlying reasons for shifting process control aims from densitometry to colorimetry, and addresses issues in implementing colorimetry in the pressroom. Analysis of ink drawdown samples and a sheet-fed lithographic press run were conducted to develop procedures that would allow pressmen to adopt colorimetry in the pressroom. In doing so, this paper also elaborates on how conformance to printing standards can be verified by colorimetry.

Keywords: process color, colorimetry, densitometry, printing standards

1. Introduction
Print media has been an effective mass communication media for centuries. Contents were printed and print quality was in the hands of the printer. As printing technology developed, process color printing became possible to render pictorial color images in the form of editorial contents and advertisements. Due to market conditions and technology advancements, print buyers and content creators started to demand color accuracy and consistency in printing. Standards-based printing began evolving from craft to science. Specifications Web Offset Publication (SWOP) was the first printing standard developed in 1970s. Densitometric parameters, e.g., solid ink density and tonal value increase (TVI) were used to specify aim points and tolerances for process color printing. Portable densitometers were also developed in the 1970s to help pressmen implement color control in the pressroom. The process of adopting densitometers to aid pressmen in ink key settings and maintaining color consistency was a slow process. It took 15 years to transform the publication printing industry from eyeball-based color adjustment to instrument-based control because print-by-number involves not only capital investment, but also training and cultural change in the pressroom.

Printing technology mainly addresses the output side of the graphic arts industry. Print buyers need a total solution that encompasses content creation, prepress, printing, and distribution. Digital color management became a solution that addresses the integration of prepress and press to make color portable and predictable in the early 1990s. International Color Consortium (ICC) is the standardization body that specifies the file format for look-up tables that describe the relationship between the device color space and the device-independent color space. The metrology for device-independent color space is colorimetry.

The effectiveness of color management depends on color repeatability of the printing device. Device color repeatability begins from the color of the ink in the can. ISO 2846 specifies colors of process inks by colorimetry. It became evident that printing process control aims, such as ISO 12647, are shifted from densitometry to colorimetry. Therefore, the integration of prepress and press by means of color management is the main driver for implementing colorimetry in the pressroom.

Objectives
Densitometry has proven to be effective for process control in the pressroom. But density numbers do not correlate to colorimetric numbers directly. Thus, the issue at hand is how to apply colorimetry in the pressroom. There are four issues: (1) how to verify ink, (2) how to achieve press make-ready, (3) how to exercise process control, and (4) how to verify printing conformance by colorimetry.
2. Experimental

A pressman has to place the right amount of process color (CMYK) inks in register with one another on the substrate during the press make-ready. He also has to maintain the control of the press run so that all products printed conform to colorimetric requirements. This paper addresses that: (1) the correct inks are used, (2) the correct amount of ink is printed, (3) color control is maintained throughout the press run, and (4) color quality assurance is documented colorimetrically.

1. Verifying Ink

How does a pressman know he uses the correct process color inks to begin with? Process color inks are specified in ISO 2846-1 (ISO, 2006) and ISO 12647-2 (ISO, 2004). In this case, colorimetric values \((L^*/a*/b^*)\) of CMYK solids are specified as K: 16/0/0; C: 54/-36/-49, M: 46/72/-5, and Y: 88/-6/90. Instead of sending inks to a laboratory, we verify the correctness of process inks by ink drawdown with a grind gauge block on a Little Joe proofer with inks supplied by Kohl & Madden. A single impression from the grind gauge block produces a range of ink film thicknesses. Color measurements were made at various ink film thicknesses. Color differences were calculated relative to the ISO specified aim points. ISO 12647-2 also specifies that deviation of CMYK solids should be less than 5 \(\Delta E\).

2. Conforming to Colorimetric Aims

We organized a press run with the following equipment, materials and procedures. From the input side, a customized test form was used for the press run. As shown in Figure 1, the test form can be used for calibration, press capability study and characterization.

The Creo Prinergy 3 CTP system was used to produce a set of linear plates at 170 lpi AM screening. A 6-color Heidelberg Speedmaster 74 sheet-fed offset press was used to print the test form on Sappi Lustro, Grade 1 coated paper, at the speed of 8,000 impressions per hour. The printing sequence for the 6-color press was blank-blank-K-C-M-Y-aqueous coating. Because of the use of aqueous coating, press sheets were delivered dry and color measurement can be done without delay. We measured color control bars, located at the perimeter of the test form, to set ink keys.

![Figure 1. Test form printed in the first press run](image)

In order to print by colorimetry, we used the IntelliTrax, a scanning spectro-densitometer from X-Rite, capable of measuring multiple color control patches width-wise in density and color. Any color measurement system capable of providing densitometric and colorimetric values must collect spectral data from the press sheets and compute density and color by formulation.

Solid ink densities of K: 1.69, C: 1.45, M: 1.52, Y: 1.00 were initially set using the X-Rite IntelliTrax scanning spectro-densitometer as the aim points (Figure 2). Press sheet densities were converted to CIELAB values in IntelliTrax and compared to ISO 12647-2 colorimetric aim points. Densities that correspond to the smallest \(\Delta E\) for each of the CMYK keys were selected as the new aim points. In other words, pressmen are able to use familiar density for initial ink setting and ink key adjustments while conforming to colorimetric specifications.
3. Controlling Color

When spectral reflectance data are collected, we can compute Status T ($D_T$) density per CGATS. We can compute spectral ($D_{nm}$) density at the wavelength having the maximum light absorption. As shown in Figure 3, the wavelength with the maximum absorption for cyan ink is at 630 nm; the wavelength of the magenta ink is at 570 nm; and the wavelength of the yellow ink is at 430 nm. We can also compute metric chroma (C*) from the spectral data per CGATS. The question we want to answer is, “Which metric provides the best signal for detecting process change or drift?”

In this study, we answer the above question by (1) selecting an ink film thickness (IFT) from the drawdown sample that matches the colorimetric aim point closest as the new reference, (2) calculating $\Delta D_T$, $\Delta D_{nm}$, and $\Delta C*$ between the new reference and a range of ink film thickness of interest, and (3) studying the linearity and magnitude of change for each of the three metrics.

4. Assuring Process Quality

Printing specifications only provide aim points and tolerances. Press make-ready only provides evidence of initial conformance. Neither the specification nor the make-ready stipulates the spatial uniformity and the temporal consistency of the entire press run. In this study, we measure a pre-determined CMY chromatic gray patch over the width of the OK press sheet and press sheets sampled over time, respectively, to document the uniformity and the stability of the press run.

3. Results and Discussions

Below are results with discussions relative to major findings and experiences gained in ink verification, press make-ready, process control, and press run quality assurance based on colorimetric analyses.

1. Ink Verification
Figure 4 shows color difference as a function of relative ink film thickness. We collected multiple measurements from the drawdown sample plus trend lines in order to smooth out the noise. Notice that \( \Delta E \) values at the ink film thickness at 5.5 relative IFT are less than the allotted tolerance of 5 \( \Delta E \) for all three inks. This provides evidence of ink conformance.

Even though we did not know the exact ink film thickness, we know that the grind gauge block indicating the ink film at 5.5 \( \mu m \) has been split twice. The first ink split is between the ink in the gauge and the blanket; and the second ink split is between the ink on the blanket and the paper. Assuming that the ink split ratio is 45:55, the resulting ink film thickness is 5.5 x 0.45 x 0.45 or about one \( \mu m \).

Figure 4. Color difference as a function of relative ink film thickness

Conformance to ink specification is the first step in implementing printing process control by colorimetry. Measuring ink drawdown samples with a spectrophotometer and the prescribed ink verification method in-house encourages us. We can extend the ink verification method to verifying spot color accuracy prior to the press run.

2. Colorimetric Conformance

Putting the correct amount of process inks quickly and accurately is the goal of press make-ready. ISO 12647-2 stipulates a window of 5\( \Delta E \) for CMYK solid plus RGB overprints as the conformance rule. As shown in Table 1, all solid ink patches, except the (M + C) blue overprint, are in conformance. Achieving correct overprint color is a printability issue, e.g., adjusting ink sequence or ink tack. The tolerance of 5 \( \Delta E \) on primary chromatic inks may be used strategically to encourage conformance of two-color overprint RGB colors.

Table 1. Colorimetric conformance of process color printing

<table>
<thead>
<tr>
<th>ID</th>
<th>Location</th>
<th>K</th>
<th>C</th>
<th>M</th>
<th>Y</th>
<th>( \Delta E_{ab} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>2</td>
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<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>A3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>4.1</td>
</tr>
<tr>
<td>4</td>
<td>A4</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>0</td>
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</tr>
<tr>
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<td>A5</td>
<td>0</td>
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<td>0</td>
<td>100</td>
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</tr>
<tr>
<td>6</td>
<td>A6</td>
<td>0</td>
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</tr>
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<td>B12</td>
<td>100</td>
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<td>0</td>
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</tr>
</tbody>
</table>

In addition, current ISO 12647-2 also stipulates that tonal value increase (TVI) of each of the tonal ramps be conformed. TVI, traditionally defined densitometrically, has been redefined from using tristimulus values in ISO 12647-1 (ISO, 2004). We find the TVI aspect of the printing standard confusing, adding no value, and is difficult to implement.

Instead of using the seven solid ink patches and TVI as conformance criteria, we propose the use of metric chroma (C*) to calibrate tonal ramps of CMY via transfer curves. Figure 5 shows the magenta gradation in terms of C* between the initial press run and the ISO 12647-2. For the black printer, Darkness (100 – L*) can be used to calibrate the black ramp.
To answer the question of colorimetric conformance, we compare a significantly larger number of color patches instead of the seven solid ink patches as specified in the current ISO 12647-2 standard. TVI should be eliminated from being a part of the standards. This is because TVI is a calibration issue, and not a conformance issue.

As an example, color differences of the IT8.7/3 basic data (182 patches) between the OK sheet and that from FOGRA39 where ISO 12647-2 aim points are compared. Figure 6 shows the CRF of $\Delta E$ between the two data sets. As a rule of thumb, process conformance threshold (the gray dotted line) is when the median $\Delta E$ is 3, the 90 percent tile $\Delta E$ is 6, and the maximum $\Delta E$ is 12 (Chung, 2001). In Figure 6, the median $\Delta E$ is at 4 that exceeds the conformance threshold. This is where printing conformance just missed out; color image differences are visually noticeable if press sheet were compared with the standard press sheet.

3. Process Control Metrics

Regarding the choice of metric for printing process control, Figure 7 is graph of $\Delta D_T$, $\Delta D_{630}$, and $\Delta C^*$ as a function of $\Delta IFT$ for cyan ink. Here, both status T and spectral density show linear responses to changes in cyan ink film thickness. On the other hand, metric chroma ($C^*$) is only sensitive to changes in low cyan IFT region. Thus, status T density and the spectral density, computed from the reflectance at the wavelength of 630 nm, are the metrics of choice for cyan inking control.
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Figure 7. Three process control metrics in detecting changes in cyan ink film thickness

Figure 8 is graph of $\Delta D_T$, $\Delta D_{430}$, and $\Delta C^*$ as a function of $\Delta IFT$ for magenta ink. Here, all three metrics are linear and behave similarly to changes in magenta ink film thickness. Thus, any one of the three metrics will be useful for magenta inking control.

Figure 8. Three process control metrics in detecting changes in magenta ink film thickness

Figure 9 is graph of $\Delta D_T$, $\Delta D_{430}$, and $\Delta C^*$ as a function of $\Delta IFT$ for yellow ink. Here, all three metrics are linear to changes in yellow ink film thickness. But, the slope of the spectral density of yellow ink is noticeably higher than that of the status T density. In addition, metric chroma has the largest change in yellow ink in comparison to the same range of $\Delta IFT$ in cyan and magenta inks. Thus, status T density is the least useful metric for controlling yellow inking.
Figure 9. Three process control metrics in detecting changes in yellow ink film thickness

By judging from Figure 7-9, there is no single metric that demonstrates the best sensitivity and linearity over the ink film thickness of interest for all three chromatic process inks. If process control is implemented in a closed-loop environment, either spectral density or different metrics may be used without human intervention.

4. Printing Quality Assurance

Instead of assuming that inking is uniform across the sheet, we can investigate the spatial uniformity of the printing system. The spread of the data from its average can then be compared with the tolerance. In this case, we measured a chromatic gray bar plus a black tint across the sheet relative to its average (Figure 10). Notice that there is larger variation at either edge of the sheet. The data could have been removed from the analysis if this is the trim or non-image area of the sheet. While ISO 12647-2 specifies that variation of CMYK solids should be less than 4 ∆E, the spatial uniformity of the printing system, based on 3-color neutrals or black tints, is around 2 ∆E units.

Figure 10. Spatial uniformity as assessed by 3-color gray and black tint

Instead of assuming that process does not drift after its make-ready, we investigate how to document the temporal consistency of the press run. Quality assurance of a press run begins with sampling and measuring multiple press sheets collected over time. We can depict the temporal consistency of a press run by depicting the colorimetric variation of a chromatic gray patch. If the chromatic gray is predetermined, e.g., 75C, 63M, and 60Y, the spread of the data points in a* b* diagram as shown in Figure 11, may be off-centered. In this case, the tighter the spread is, the more consistent the printing process is.
4. Conclusions

Density-based printing standards and using densitometry in the pressroom have facilitated color consistency since 1970s. As the demand for colorimetric accuracy and consistency in process color printing continues, it is inevitable that CIELAB-based printing standards will become the norm. Not only densitometers are replaced by spectral-based color measurement devices, all density-based specifications, including TVI, should be replaced by colorimetric parameters.

We explored the use of colorimetry for ink verification. Since density only specifies ink amount and not color, colorimetry is here to stay. We explored the use of colorimetry for achieving printing aims. Since printing aims are specified colorimetrically, colorimetry is essential for implementing standard-based printing. In addition, the knowledge of the prepress adjustment and the knowledge of the press control are essential to achieve closer printing conformance.

We explored three metrics (status T density, spectral density, and metric chroma) as process control parameters. We did not find a single metric suitable for monitoring all three chromatic process inks significantly better than other metrics. Finally, we looked at how a press run may be certified to assure its spatial uniformity and temporal consistency with the use of colorimetry. The results have been encouraging. More work and user feedback are necessary in order to make the transition from densitometry to colorimetry in the pressroom.

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