Ink Trapping and Colorimetric Variation

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Abstract

This research compared four equations for calculating ink trapping with respect to their correlations with color differences measured by the CIE94 equation. The research questions that this study sought to answer were:

- Do changes in trap values correlate with perceptual changes of overprint colors?
- Which trap calculation method is the most sensitive to colorimetric changes?

The goals were to determine if ink trapping is a useful process control parameter, and, if so, which trapping equation should be used. A press test was conducted at the Graphic Arts Technical Foundation (GATF) where the ink and water settings were systematically varied to induce changes in ink trapping. The results were mixed. There were differences in the correlations for the different two-color overprints and for the different experimental conditions. Also, the trap correlations for the press running at equilibrium were different than the correlations when large color changes were induced. The Ritz formula correlated the best at equilibrium and the Preucil formula correlated best for the larger color changes. Overall, there were strong enough correlations with the color difference values to warrant the measurement of ink trapping for process control, and the Preucil equation performed the best in the critical regions where meaningful color differences were present.

Introduction

Multicolor printing usually involves the overprinting of transparent inks in immediate succession without allowing individual ink layers to dry. It is known that the transfer of ink to printed ink films will not equal the transfer of that same ink to unprinted paper. *Ink trapping* refers to measures of the efficiency of ink-to-ink transfer compared to ink-to-paper transfer. Ink trapping is measured from the two-color overprinted solids (blue, green, and red) and their constituent colors (cyan, magenta, and yellow). Several equations have been proposed over the past 40 years for measuring this phenomenon.

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There is also a substantial difference in ink transfer characteristics onto dry ink films rather than wet ones. The terms *dry trapping* and *wet trapping* describe these two scenarios. Wet trapping is both the more common scenario and the more troublesome one.

Ink trapping is unrelated to image trapping, which is the deliberate slight overlapping of image elements to compensate for inevitable misregister that will occur on the press.

There is no consensus among industry specifications groups on the levels of ink trapping to expect from a given process, or, indeed, on the value of measuring ink trapping at all. The SWOP specifications, for example, do not mention ink trapping, even in the General Reference Section. The GRACoL guidelines similarly avoid the subject, not only in their Process Guidelines Chart, but also in their Presswork and Technical Supplements sections. The ISO standard 12647-2, *Graphic Technology—Process control for the manufacture of half-tone colour separations, proof and production prints—Offset lithographic processes*, does not include any mention or recommendations for ink trapping. The SNAP specifications are an exception in that they do include ink trap values as a reference, although not as a specification.

Although trapping is not usually included in industrywide specifications, many printers measure it as part of their press control strategy. This is evident from the fact that virtually every color control bar sold today contains the necessary patches in the right proximity for making ink trapping measurements. It is further evidenced by the inclusion of ink trapping software in all densitometers and print attribute systems on the market today.

The authors, in their involvement with the GATF Sheetfed Offset Printing Specifications (ShOPS) initiative to define meaningful print specifications for sheetfed lithography, have posed two research questions relative to ink trapping.

- Do changes in trap values correlate with colorimetric changes of overprint colors?
- Which trap calculation method is the most sensitive to colorimetric changes?

The answers to these questions will suggest whether ink trapping is a useful process control parameter to measure during a pressrun. If so, it will be considered as a parameter to be specified in ShOPS. The relationship of ink trapping changes to colorimetric changes is used for this study because colorimetric changes can be linked to perceptual differences.

This study did not address the question of which trapping equation yields the most accurate measure of the percentage of ink transferred to the first-down ink (compared with transfer to unprinted substrate). The trapping values are considered as arbitrary scales, not as accurate percentages, so the values are listed without percentage signs.

Review of Literature

Preucil identified ink trapping as a limitation of printing systems in 1953 along with the phenomenon of hue error. In most cases, Preucil saw that the ink-to-ink transfer was less than the ink-to-paper transfer, but he warned that "the equally serious condition of overtrapping, however, seems to have been almost completely ignored"(1953, p. 107). No method for calculating ink trapping was given in Preucil's 1953 paper.

Ink trapping is one of the causes given by Yule and Clapper (1956) for the failure of the law of additivity of ink densities. The additivity law states that the density of an overprint color should equal the sum of the densities of the constituent colors. Besides imperfect ink transfer (ink trapping), additivity also fails because of differences of gloss, first-surface reflections, multiple internal reflections, opacity of ink film, and spectral characteristics of measuring instruments. The fact that ink trapping values do not equate to accurate percentages of the ink being transferred is due to the other factors that influence additivity failure.

Preucil (1958) provided the first densitometric formula (Figure 1) for ink trapping in 1958. He described the calculated attribute as "apparent trapping (AT)," recognizing that it did not measure the actual amount of ink being transferred.

$$AT = \frac{D_{op} - D_1}{D_2} \times 100$$

Where: D_{op} = density of the overprint
D_1 = density of the first down color
D_2 = density of the second down color

Figure 1. Preucil trapping formula.

In Preucil's equation, and all the other trapping equations mentioned in this paper, the density readings are made with the filter appropriate for the second-down ink, and all the density readings are minus paper (i.e., the density of the paper has been subtracted from them).

The problem that inspired Preucil's work was the difficulty of matching proofs made on a single color press with production runs done on two- and four-color presses. Some plants at the time found it necessary to make different films for proofing and production. Ink trapping and dot gain were identified as the two most prominent causes for the mismatch between the proof and printed sheet.

According to Preucil, the most important factor influencing ink trapping was the tack of the inks. Other contributing factors included the type of ink (especially which pigments were used), the kind of paper, and the water feed rate. The ink tack that Preucil identified as the primary influence on ink trapping cannot be measured because it refers to the tack in the printing nip at the moment of transfer. The S. D. Warren Company (1980) presented a more extensive list of factors that influence ink trapping. The additional factors included press speed, ink temperature, drying time, paper hardness, and paper absorptivity.

Chen and Eldred (1971) compared the densitometric measurement of ink trapping (Preucil) with gravimetric (weight) measurement of ink transfer using the letterpress process. Letterpress was used to avoid the complicating factor of water in the study. Five different types of paper were used. In most instances the two methods yielded results that differed by less than 10 percent. The researchers concluded that the percentage of ink transfer was measured more accurately by weight than by densitometry because the optical properties of the substrates influenced the densitometric trap measurements. The conclusion was that "densitometric comparisons of trapping should be restricted to prints involving the same substrates" (Chen and Eldred, 1971, p. 257).

In 1980, Warren Childers published a second densitometric formula for calculating ink trapping (Figure 2). Childers found that the Preucil formula, which used ratios of logarithms, seriously underestimated the severity of the ink trapping problem. He claimed that his equation would give accurate percentages of ink transfer.

$$\%T = 10^{(D_{op} - D_1 - D_2)} \times 100$$

Figure 2. Childers trapping formula.

The publication of Childers' trapping formula in *Graphic Arts Monthly* invoked a rebuttal from Zenon Elyjiw (1981) of Rochester Institute of Technology (RIT), who defended the Preucil formula. This brought a response from Childers (1982) and another from Elyjiw (1982). Childers reasserted that the Preucil formula did not yield accurate estimates of the percentage of ink transferred because the formula relied on the quotient of logarithms. Elyjiw argued that the technique of dividing logarithms was acceptable because the measure of interest was ink film thickness, not opacity (the antilog of density). He also supplied a graph showing that the Preucil formula produced linear results within the range of practical printing densities, while the Childers formula did not.

Jorgensen (1982) reviewed a broad range of options for measuring ink trap in lithography. His study included optical, gravimetric, and other measurements. In the optical category, Jorgensen was early in considering colorimetry and spectrophotometry in addition to densitometry. Beginning with densitometric measurements, Jorgensen cites several reasons why densitometric trap calculations (or even single-color density measurements) do not reliably measure ink film thickness. Still, he concludes that, "as a process control during a pressrun to detect ink trap changes, the densitometer and trap formulas often do quite well except where opaque overprint ink layers are involved" (Jorgensen, 1982, p.51).

Using a spectrophotometer to monochromatically measure trapping eliminated errors associated with wide-band filters and infrared leakage, but the optical properties of the print still contributed to additivity failure in trap measurements. Also, integrating sphere light sources in some instruments could introduce new error sources. Jorgensen felt that spectrophotometers and densitometers were equally well suited to making ink trap measurements. With respect to colorimetry, Jorgensen reported that there was not a mathematical formula yet devised to equate colorimetric values with ink trapping conditions. Also, all of the optical limitations that affect densitometry also affect colorimetry.

Jorgensen reported that reliable gravimetric methods had not yet been developed for lithography. Other methods of measuring ink film thickness, including magnetic, dielectric, supersonic, and radioactive, were considered unsuitable or impractical for lithography.

Subjective evaluation was the most prevalent means of process control for ink trapping. Jorgensen concluded that this was the best method to use to monitor production because the human vision system is very sensitive at detecting small color differences when comparing a sample with the OK sheet. Furthermore, subjective evaluation can detect discontinuities in the ink films, such as snowflaking or blotchiness, which are clues to the cause of poor ink trapping.

Brunner (DuPont 1984) developed another alternative ink trapping equation in 1983. The Brunner equation (Figure 3) converts all densities to their equivalent light absorption values. The reflectance of the overprint color is then divided by the sum of the reflectances of the first-down and second-down inks (all reflectances relating to the filter appropriate for the second-down ink). The Brunner trapping formula yields higher values than the other trapping formulas. Brunner recommends values higher than 95% for good printing.

$$\%T = \frac{1-10^{-D_{op}}}{1-10^{-(D_1+D_2)}} \times 100$$

Figure 3. Brunner trapping formula.

Field (1985) conducted a study comparing the Preucil, Childers, and Brunner trapping formulas in terms of the percentage of ink transferred. His test used a clear plastic substrate, a hand application method, and transmission density measurements. Field used the same inks for the first and second applications in his experiment (i.e., cyan on cyan, yellow on yellow, etc.). This laboratory method was designed to avoid many of the concerns of additivity failure. Within the confines of his experiment, Field concluded that the Preucil formula was the only one that had a linear response to changing ink transfer percentages. "The Childers and Brunner equations predict the direction of trapping change, but because of their non-linear characteristics, do not do a very good job in predicting the magnitude of the change. The Childers equation seriously overestimates overtrapping and undertrapping. The Brunner seriously underestimates overtrapping and undertrapping" (pp. 393-394).

Also in 1985, Hamilton examined the Preucil, Childers, and Brunner trapping equations in terms of their underlying assumptions:

- The Preucil trapping formula is based on the definition that trap is equal to the relative amount of ink that is transferred to the paper.
- Childers' formula is based on trapping being equal to the relative amount of light being reflected by the ink.
- Brunner's formula is based on trapping being equal to the relative amount of light absorbed by the ink.

Hamilton tested the three equations at the boundary conditions of 100 and 0 percent ink transfer under the assumptions that there was no additivity failure and the paper was a perfect reflector. Hamilton found that all three equations properly yielded 100% trapping values, but only the Preucil equation properly yielded a value of 0% trapping for the no-transfer condition. Hamilton concluded that consensus was needed with respect to the underlying phenomenon that ink trapping should measure in order to know which equation to use.

The following year, Hamilton (1986) addressed the problem of measuring ink trapping on newsprint. The Preucil formula relies on the assumptions that ink densities are additive and that ink film thickness and ink density are directly proportional. As previously discussed, the law of additivity of densities does not hold for a variety of reasons. Hamilton noted that there is a maximum achievable density for every combination of inks. This phenomenon has a particularly strong effect with newspaper printing, where the maximum densities are relatively low. Hamilton developed a modified version of the Preucil formula (Figure 4) using a correction factor that accounts for the maximum obtainable density of the process. He attributed the correction factor to the earlier work of John Yule.

$$\text{Trap} = \frac{\log\left[1 + \dfrac{D_{210} - D_{10}}{D_M - D_{210}}\right]}{\log\left[1 + \dfrac{D_{20} - D_0}{D_M - D_{20}}\right]} \times 100$$

Figure 4. Hamilton newspaper trapping formula.

Hamilton claimed that his formula was less susceptible to errors associated with the additivities and subadditivities of densities than was Preucil's formula. In the intervening years, Hamilton's formula has not come into widespread use due, in part, to the difficulty of establishing reliable maximum obtainable density values. Three such values would be needed for each printing condition: the maximum magenta density obtainable in blues and the maximum yellow densities obtainable in greens and reds.

The Hamilton trapping formula was not included in this study due to the lack of viable values for the maximum density correction factors. Furthermore, this study looked at ink trapping by sheetfed lithography on coated paper, and the Hamilton formula was generated for the special concerns of measuring ink trapping on newsprint.

Ritz (1996) devised a new method of measuring trapping. He felt a weakness with the Preucil method was that it was useful only within the production run. It was not possible to meaningfully compare trapping values between printed sheets and proofs, or even between different ink and paper combinations, because of the failure of ink density additivity.

Ritz cited "extensive experiments" where the amount of ink deposited had no strong correlation with the visual or densitometric color shifts caused by trapping. Ritz attributed this to the differences in the surface characteristics between the first down ink and the overprinted color. The first down ink had a smooth uniform surface characteristic, while the second ink had tiny holes resembling a halftone pattern. Ritz considered it important to learn whether bad ink trapping numbers were actually caused by insufficient ink transfer or by surface tension and film shaping problems. The smoothness and evenness of the overprinted ink film was seen as more important than the transfer rate in producing the overprint colors.

Factors that influenced the wettability of the first-down ink also influenced the smoothness of the second ink. These included too much emulsified dampening solution and the influences of dampening solution additives. The effect was greater on runs with low ink consumption.

Ritz devised a new equation for ink trapping (Figure 5) that was based on the Murray-Davies equation. This equation regards the density of the overprint as a screened tint to account for the discontinuous ink film.

$$\%T = \frac{1-10^{-(D_{op}-D_1)}}{1-10^{-D_2}} \times 100$$

Figure 5. Ritz trapping formula.

Ritz claimed that the color differences between proof and color print are easily visualized with his trapping formula. He also claimed that his trapping formula had an inherent advantage for visualizing color drifts in dot-based color mixing systems, such as traditional printing.

A recent Japanese study of ink trapping by Fukasawa et al. (1998) was summarized in the PIRA abstracts. The Fukasawa study examined ink absorption and ink trapping on coated paper. An evaluation of blue trapping showed that a 0.7-second interval was needed between the two ink applications to achieve a stable trapping ratio (64.2%). This was equivalent to a press speed of about 197 feet per minute, roughly half of the speed of a 26-inch sheetfed press running at 15,000 impressions per hour. Fukasawa and his colleagues also found that the size of the calcium carbonate particles in the paper coating formulation affected the ink trapping. Smaller diameter particles (0.85 microns) required a shorter interval before stable ink trapping was achieved; however, larger particles (2.2 microns) resulted in higher ink trapping values (77.9% instead of 69.5%).

Color Difference Formulas

This study compares the changes in trap values with the perceptual changes of the overprint colors. Any effort to quantify human perception is confounded by a variety of psychological and environmental factors. Lighting characteristics, sample sizes, sample separation, surface texture, and surround conditions, for example, must all be controlled in order to make meaningful color comparisons. This study was not concerned with critical color matches, but rather with color changes that were easily noticeable. Selected pairs of samples were evaluated under standard viewing conditions to confirm that measured color difference indices were indicating noticeable changes in the perceived appearance of the blue, green, and red overprints.

To quantify the perceptual changes, colorimetric readings were taken and used to compute color difference values. There are several different color difference formulas that attempt to accurately describe perceptual color differences. The ΔE index was an early formula used for this purpose; however, the accuracy of the ΔE index is compromised because it weighs changes in lightness, hue, and saturation equally, while the human visual system does not. Building on earlier work (Clark, 1984), the Color Measurement Committee of the Commission Internationale de l'Éclairage (CIE) developed the CMC(*l:c*) color difference formula to provide more accurate perceptual color information. This color difference formula was used in the GATF Print Attribute Study (Stanton and Hutton, 2000).

Various color difference formulas, including CMC(*l:c*), BFD(*l:c*), CIE94, LCD, and CIEDE2000, were recently compared by the Imaging Technologies working group of the CIE in formulating recommended methods to derive color differences for images (Luo, et al., 2000). CIE94 was chosen for this study based on appropriateness for the task and ease of computation. Figure 6 shows the color differences calculated by ΔE, CMC(*l:c*), and CIE94 for some of the samples used in this study.

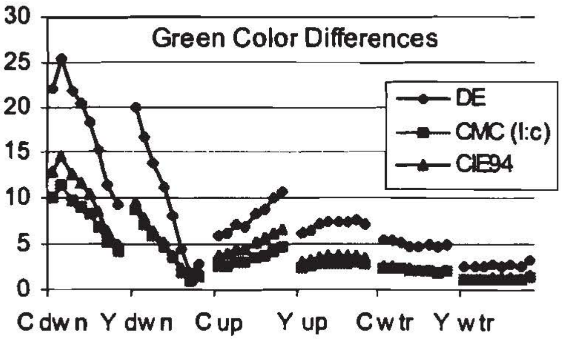

Figure 6. Color differences calculated by ΔE, CMC(*l:c*) and CIE94.

The data in Figure 6 reveal that there is good agreement between the color differences calculated by the CMC(*l:c*) and CIE94 equations, while the ΔE calculations show more pronounced color differences overall.

Experimental Procedure

For this study, a press test was conducted at GATF on a 26-inch sheetfed press with coated paper. The materials selected for the press test (listed in Table 1) were commonly used products that represent a viable commercial sheetfed printing system.

Printing press	Komori Lithrone 628
Paper	Sappi Lustro Gloss, 80lb
Ink	K&E Novastar F1 Drive IK
Fountain solution	Prisco 3451U Concentrate & Alkaless 3000
Blankets	Day Patriot 3000
Plates (conventional)	Fuji FND
Plates (CTP)	Kodak Electra 830w
Press measuring	X-Rite Auto Tracking Spectrophotometer

Table 1. Press test materials and equipment.

Platemaking for this test was done two ways:

- Through a film-based (conventional) workflow.
- Through a computer-to-plate (CTP) workflow.

For the conventional plates, 0.07-in. Fuji film was imaged on a Fuji Luxel F-9000 imagesetter. An X-Rite 361-T transmission densitometer was used to measure the films to ensure that target tint values were within +/- 0.5%. Fuji

FND plates were made from these films. Proper plate exposure was controlled with a UGRA plate control target. Dot areas on the plates were measured with a Beta Ultra Dottie, and a 50% film tint was found to yield a 54% plate dot.

For the CTP workflow, Kodak Electra 830w thermal plates were imaged on a CREO/ Scitex Trendsetter. The platesetter was adjusted to provide linear plates. Proper plate exposure was confirmed with the GATF Digital Plate Control Target. Midtone dot areas on the plates were measured with the Beta Ultra Dottie, and found to be within +/- 0.5% of 50%.

The test form used in this study (Figure 7) was designed for two purposes: to make trapping measurements and to provide characterization data for the ShOPS printing conditions (not part of this study).

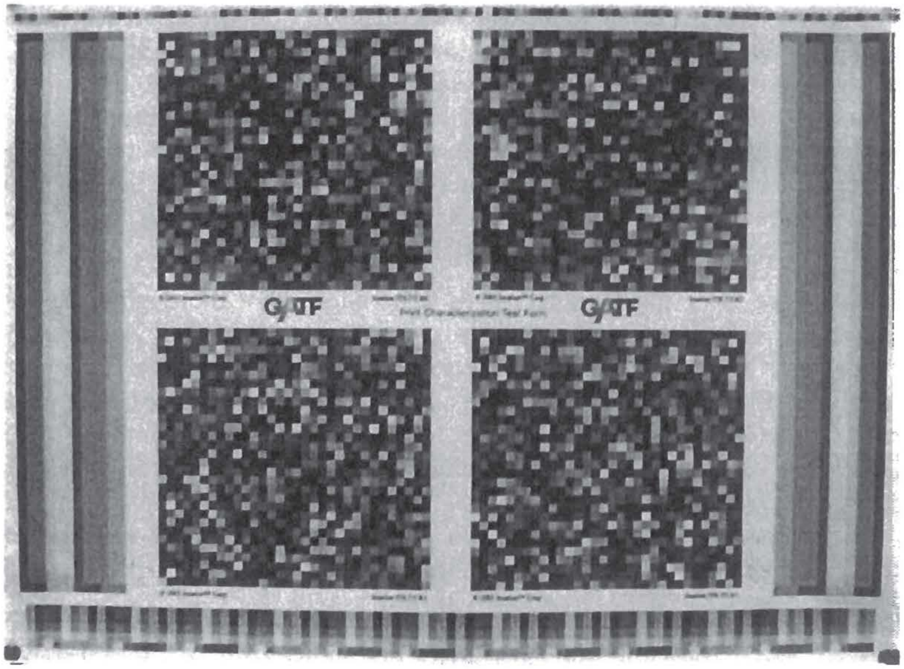

Figure 7. Test form.

The test form contained GATF Ladder Targets to determine if the press was being affected by directional imaging anomalies, like slurring or doubling. The four randomized IT8 targets, which were included on the test form for measuring characterization data, provided a sufficient amount of ink takeoff for the test form to represent a "normal" print job. A color control bar at the trailing edge of the test form was used to balance the ink settings during the pressrun. A custom five-tier color bar along the gripper edge of the form was used make the ink trapping measurements for this study. The patch sequences on this color bar were arranged to provide the three necessary patches for each ink trapping measurement side by side so that they would fall within the same ink key zones.

Both conventional and CTP printing plates were used during this study, but no differences in ink trapping due to printing plates were found. Except where noted, the data presented in this paper is from the CTP plates.

At the outset of the test, the press was adjusted to achieve densities of cyan 1.35, magenta 1.40, yellow 1.00, and black 1.60 (all within tolerances of +/- 0.05). After the press had stabilized, several hundred sheets were run at these conditions. The ink trapping values from this portion of the press test were treated as the normal levels for this printing system.

The experimental printing conditions of the press were then modified systematically to induce changes in ink trapping. The modifications included increasing and decreasing inking levels, and increasing water levels, for cyan, magenta, and yellow in turn. Of these nine experimental conditions, only six affected any given overprint (e.g., changing magenta did not influence green overprints). Only one modification was carried out at a time. The delivery pile was flagged to identify the samples associated with each modification. Between each modification the press conditions were returned to the normal levels established at the outset of the press test. Scrap paper was printed between each press adjustment to allow time for the system to stabilize. The changes in dampening were done last due to concerns that increased dampening might have a persistent effect on the rheological properties of the inks.

After the press test, the samples were allowed to dry thoroughly before measurements were made. Measurements were made with an X-Rite 941 Spectrophotometer interfaced with a personal computer so that the data was captured in an Excel spreadsheet. Both densitometric and colorimetric data were captured from the measurements. One hundred consecutive samples were measured from the normal printing condition to examine the variability of ink trapping compared to the variability of color appearance attributes. Eight samples were randomly picked from each printing condition, but were kept in order so that increasing effects of the printing modifications could be studied.

Photomicrographs were made from patches of a normal sample to evaluate whether the second-down ink film was more discontinuous than the first-down ink, as suggested by Ritz. An Olympus BH2 microscope, fitted with an Agfa StudioCam digital camera, was interfaced with an Apple G4 computer to capture the images.

Assumptions and Limitations

As with most studies of lithographic printing systems, several assumptions and limitations apply to the findings of this study. It was assumed, for instance, that the press system was representative of other sheetfed lithographic press systems. The term "press system" here refers to the printing materials as well as the printing machine. Thus, it was assumed that the paper, inks, plates, blankets, fountain solution, and additives interacted in a typical way compared to other materials of their kinds.

It was assumed that the attribute of ink trapping would be consistent for the same printing system over time. It was also assumed that ink trapping on a 26-inch six-color press would be representative of other press sizes and configurations. It was assumed that the color measuring instruments, which were calibrated and checked against the manufactures' reference plaques, gave true readings of the attributes being measured.

Even if all the assumptions that underlie this study were true, the findings are still limited in their scope of application. For example:

- Heatset and non-heatset lithographic presses (which utilize different inking systems) should not be expected to exhibit ink trapping conditions similar to those of sheetfed presses.
- Ink trapping on one- and two-color presses, which is necessarily dry trapping for at least one of the overprint colors, will differ from the trapping values found in this study.
- Ink trapping on different classes of substrates, like uncoated paper, will be different from the values found in this study.

Even within the category of sheetfed printing on gloss coated paper, ink trapping values would be expected to differ because of the properties of different papers and inks. Previous studies indicate that changing press speed alone causes changes in ink trapping for a given printing system.

In spite of the assumptions and limitations that bear on this study, the relationship between ink trapping and the perceptual changes in the two-color overprints should hold across a variety of printing systems. Furthermore, the sheetfed printing system used was chosen deliberately to be representative of other systems serving this particular market segment.

Photomicrographs

Overprint patches of blue, green, and red, together with the constituent cyan, magenta, and yellow patches, were photographed at 200X magnification. Figure 8 shows photomicrographs of the blue overprint with its adjacent cyan and magenta patches. The red and green series are not shown because blue was typical of the others and because this paper is reproduced in black and white.

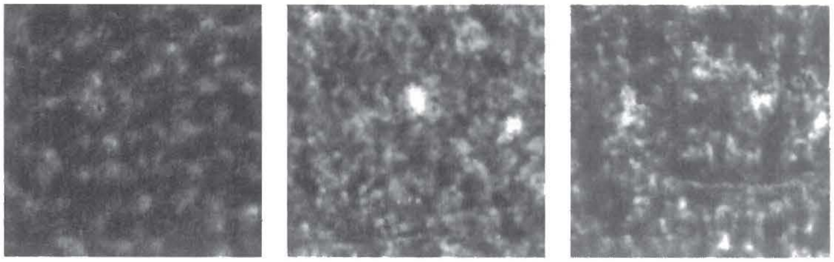

Figure 8. Photomicrographs of blue overprint, cyan, and magenta patches.

The blue overprint resulted from magenta being printed on top of cyan. The measured trap value for the blue patch was 82.8 (Preucil) or 84.6 (Ritz).

The high-resolution color images of the photomicrographs were studied. It could not be confirmed that the magenta ink layer on top of the cyan was less continuous than the cyan ink layer on paper (as suggested by Ritz). The same observation was made for the other overprint colors and their constituent ink films. The results were not quantifiable, but the researchers estimated that the single ink films were as discontinuous as the second-down inks on top of them.

Previous Results

The data from the GATF Print Attribute Study (Stanton and Hutton, 2000) was analyzed to determine the range of trapping values found in a large sample of sheetfed lithographic printing systems on gloss coated papers. There were 33 printing companies in the sample and 68 printing conditions. A different printing condition usually represented a different type of coated paper; thus, if a company submitted two sets of samples on two types of coated paper, it was described as one printing company with two printing conditions. The printers who used two-color presses were eliminated, as were all printing conditions that were not on #1 or #2 gloss coated paper.

Trapping values were calculated with the Preucil, Childers, Brunner, and Ritz equations for the whole group. Trapping was then recalculated for a subgroup that consisted of only the printers who fell within +/-0.10 density units of target values of 1.40 magenta, 1.35 cyan, and 1.00 yellow. Summary statistics were then calculated for the subgroups. Table 2 shows the blue ink trapping statistics.

All Samples = 33 printers, 68 ink/paper combinations (gloss coated stock)									
Blue	Den-C	Den-M	L*	a*	b*	Preu.	Brun.	Chil.	Ritz
average	1.31	1.37	25.1	21.7	-44.6	72.7	96.9	45.0	87.5
std dev	0.12	0.10	2.5	4.3	2.8	5.9	1.0	8.8	3.2
min	1.02	1.13	19.7	3.7	-51.8	53.6	92.3	31.5	71.4
max	1.61	1.60	31.6	30.1	-37.2	86.3	98.4	71.8	92.0
range	0.58	0.47	11.9	26.5	14.6	32.6	6.1	40.3	20.6
Samples where 1.25≤Cden≤1.45 & 1.30≤Mden≤1.50 = 21 printers, 35 combinations									
Blue	Den-C	Den-M	L*	a*	b*	Preu.	Brun.	Chil.	Ritz
average	1.35	1.40	24.6	21.5	-44.8	71.4	96.9	42.2	87.9
std dev	0.06	0.05	1.6	3.3	2.1	4.4	0.8	5.5	2.1
min	1.25	1.30	21.8	14.4	-48.0	61.9	95.0	31.8	83.2
max	1.44	1.50	27.6	28.2	-40.0	79.1	98.1	53.6	91.6
range	0.20	0.20	5.9	13.8	8.0	17.1	3.2	21.7	8.5

Table 2. Blue trapping summary from GATF Print Attribute Study.

Examination of Table 2 reveals that there was a wide range of cyan and magenta densities and blue trapping conditions in the samples submitted to the GATF Print Attribute Study. The four trapping equations showed substantially different average values and ranges. The Brunner equation shows a limited range and low variability compared to the other trapping measurements. Compared to the other methods of calculating trap, the Brunner equation lacks sensitivity to changes in printing conditions. Visual examination confirmed that there were striking differences in the hues of the blue patches on many of the samples submitted.

When the samples were restricted to include only those that were within 0.10 density units of the target values, both the range and the variability within the group (as measured by standard deviation) were reduced. It is interesting that the standard deviations of the ink densities was roughly cut in half, while the standard deviations of the trapping values showed much smaller reductions.

The green and red trap tables showed similar interrelationships as those seen in Table 2. The average blue, green, and red trap values from the restricted sample (densities within 0.10 of target) are shown in Table 3.

Trapping		Preucil	Brunner	Childers	Ritz
Blue	Average	71.4	96.9	42.2	87.9
	Stan. Dev.	4.4	0.8	5.5	2.1
Green	Average	86. 9	96.7	76. 4	81.1
	Stan. Dev.	4.1	1.2	6.4	3.1
Red	Average	75.3	98.2	60.5	75.8
	Stan. Dev.	6.6	0.6	8.6	4.5

Table 3. Average trapping from restricted sample of GATF Print Attribute Study.

The values in Table 3 are averages from 21 printing companies representing 35 conditions. The samples were all printed on gloss coated papers with four- or six-color sheetfed presses. The samples were all printed within a density range of 1.30–1.50 magenta, 1.25–1.45 cyan, and 0.90–1.10 yellow. It is reasonable to assume that these values are representative of the industry segment that produces high-quality full-color printing for products such as annual reports or advertising brochures.

Results of Press Test

After the press was balanced to target ink densities, it was allowed to run for several minutes to settle. One hundred consecutive samples were collected near the end of this time to get a measure of the natural variability that the process exhibited when no adjustments were being made. Table 4 shows summary statistics for cyan, magenta, and yellow densities for the 100 samples. The *GATF Research & Technology Report* (Stanton, 2001) includes additional analysis of the 50% tint densities.

	Mean	Std Dev	Range	Skew	Skew/SE	Kurt	Kurt/SE
Cyan	1.309	0.014	0.060	0.398	1.648	-0.362	-0.757
Magenta	1.405	0.014	0.067	0.278	1.152	-0.272	-0.568
Yellow	0.989	0.004	0.017	0.266	1.103	-0.351	-0.733

Table 4. Density statistics for 100 consecutive samples.

The standard deviations and ranges in Table 4 indicate that the press was stable and capable of efficiently producing products within tolerances of +/-0.05, which are commonly used in the industry. The mean values show that the cyan density was not centered at the 1.35 target value, but rather at 1.31, however, it was stable around the 1.31 mean. Ink dryback may partially explain the drop in cyan density from the measurements made at press side and those recorded in Table 4. The ratios of skewness and kurtosis to their standard errors (0.241 for skewness and 0.478 for kurtosis) show that the solid density distributions can be considered as normal (i.e., they fall between +2.0 and -2.0).

The blue, green, and red ink trapping values and the L*, a*, and b* values for the 100 consecutive samples are shown in Table 5. The ink traps in Table 5 have been computed by the Preucil, Brunner, Childers, and Ritz equations.

		Tp	Tb	Tc	Tr	L*	a*	b*
Blue	**avg**	72.155	97.015	42.592	88.515	24.591	22.479	-45.923
	std dev	0.670	0.115	1.045	0.304	0.300	0.410	0.250
	variance	0.449	0.013	1.092	0.093	0.090	0.168	0.063
	range	3.514	0.530	5.416	1.351	1.330	1.860	1.370
Green	**avg**	84.106	95.998	71.296	81.056	51.571	-64.354	24.905
	std dev	0.375	0.114	0.595	0.192	0.169	0.210	0.316
	variance	0.140	0.013	0.354	0.037	0.028	0.044	0.100
	range	1.811	0.541	2.787	1.067	0.720	1.000	1.530
Red	**avg**	72.917	98.042	56.189	75.960	47.272	66.310	42.705
	std dev	0.628	0.063	0.761	0.365	0.103	0.167	0.433
	variance	0.395	0.004	0.579	0.133	0.011	0.028	0.188
	range	3.695	0.339	4.220	2.133	0.690	0.950	2.460

Table 5. Ink trapping statistics for 100 consecutive samples.

There are distinct differences between the trap values calculated by the various equations. In the blue trap, for instance, the transfer of magenta to cyan for the same 100 sheets is calculated as 72, 97, 43, and 89 by the Preucil, Brunner, Childers, and Ritz equations, respectively. Overall, the Brunner trap values are consistently the highest, and the Childers values are the lowest. Furthermore, the Brunner trap values show the lowest variability and ranges for all colors, while the Childers trap values are the highest.

The values in Table 5 also show that the pressrun done for this study was representative of the average conditions found during the GATF Print Attribute Study (see Table 2).

To examine the sensitivity of the trap equations to colorimetric changes in the overprints, delta trap values were computed as the difference between the mean values for each attribute and the individual measurements. The results of the calculations for the four trap equations, the CIE94 color difference formula, and CIEDE for the 100 consecutive samples are shown in Table 6.

		ΔTp	ΔTb	ΔTc	ΔTr	CIE94	ΔE
Blue	**avg**	0.526	0.092	0.816	0.243	0.335	0.491
	std dev	0.411	0.069	0.647	0.182	0.209	0.276
	variance	0.169	0.005	0.419	0.033	0.044	0.076
	range	2.106	0.272	3.205	0.785	0.960	1.264
Green	**avg**	0.305	0.091	0.481	0.152	0.204	0.427
	std dev	0.215	0.067	0.347	0.116	0.109	0.233
	variance	0.046	0.005	0.121	0.014	0.012	0.054
	range	1.006	0.313	1.462	0.540	0.534	0.970
Red	**avg**	0.475	0.046	0.585	0.269	0.180	0.367
	std dev	0.408	0.044	0.482	0.245	0.110	0.190
	variance	0.167	0.002	0.233	0.060	0.012	0.036
	range	2.443	0.215	2.687	1.456	0.554	1.537

Table 6. Delta traps and color differences for 100 consecutive samples.

The values in Table 6 indicate that the blue overprint at equilibrium would fluctuate within a range of about +/- 0.6 CIE94 delta E units, or approximately +/- 0.8 CIEDE units. The green and red overprints were slightly more stable. The four trapping equations yield very different delta trap ranges. The blue trap would be expected to fluctuate about +/- 1.2 Preucil units, +/- 0.2 Brunner units, +/- 1.9 Childers units, or +/- 0.5 Ritz units. This indicates that the Brunner equation is relatively insensitive to small fluctuations in overprint colors, while the Preucil and Childers equations show more color variation than CIE94 calculations would indicate.

When a test of equality of variances was applied to the delta trap values compared with the CIE94 values, only the Ritz variance for green was statistically equal to the CIE94 variance at a 0.01 confidence level. The Brunner variances were significantly lower than CIE94, while the Preucil and Childers variances were higher. It is assumed that both the densitometric and the colorimetric readings were influenced by random noise factors which were exacerbated by the fact that only single readings were taken for each measurement.

The correlations between the delta trap values and the CIE94 color differences for the press running at equilibrium are shown in Table 7. This table also includes the correlations between the different trap values.

		Preucil	**Brunner**	**Childers**	**Ritz**
Blue	**CIE94**	0.183	0.778	0.007	0.963
	Preucil		0.601	0.882	0.100
	Brunner			0.311	0.750
	Childers				-0.088
Green	**CIE94**	0.214	0.325	0.164	0.428
	Preucil		0.891	0.964	0.342
	Brunner			0.769	0.587
	Childers				0.171
Red	**CIE94**	0.480	0.745	0.360	0.722
	Preucil		0.765	0.965	0.791
	Brunner			0.655	0.854
	Childers				0.639

Table 7. Correlations for 100 consecutive samples.

The values in Table 7 show that the Ritz equation had the best correlation with CIE94 for all three overprint colors (although the correlation with the green overprint was substantially weaker than the others). The Brunner equation also showed strong correlation for the blue and red overprints, but not for green. The Preucil and Childers showed only weak relationships for any of the overprint colors. Thus, at press equilibrium, the Ritz equation was the best indicator of CIE94 color differences. However, for a trapping formula to be a useful process control measure, it must correlate well with measured color differences in a range of easily noticeable color differences where the quality of the printing is being adversely affected.

Two sample regression graphs are shown in Figure 9 for the delta trap data of the 100 consecutive samples. The Preucil regression graph shows large errors around the best fit line, although there is a weak positive relationship over the 100 samples. The Ritz delta trap data is a much better fit to the regression line showing a stronger correlation to CIE94 color differences at press equilibrium conditions. The other trap equations resulted in regressions similar to the Preucil graph. Overall, at press equilibrium the variations of the trap measurements do not correspond well with the small variations in the color difference calculations.

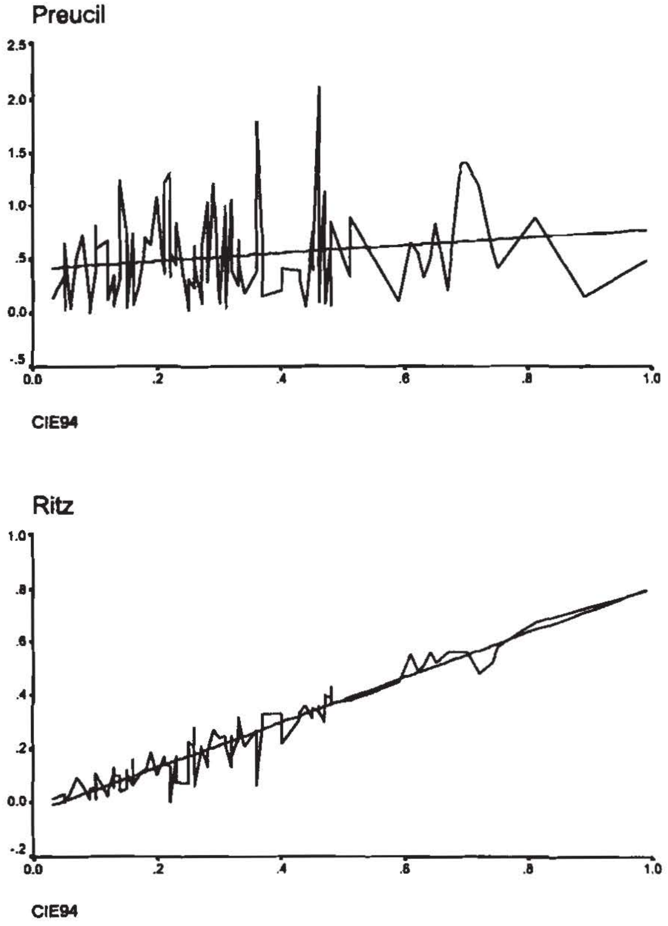

Figure 9. Preucil and Ritz regression with CIE94 for 100 samples.

To test the correlations between the different trap equations and the CIE94 color difference measurements for larger color changes, the press settings were systematically altered to induce changes in ink trapping. Eight samples representing increasing deviation from the base trap values (averages from Table 5) were selected from each of the experimental conditions. There were six experimental conditions for each color of trap. Figure 10 shows graphs of the blue, green, and red trap results for all the various conditions. The conditions are shown along the x-axis. Each small line segment consists of eight data points

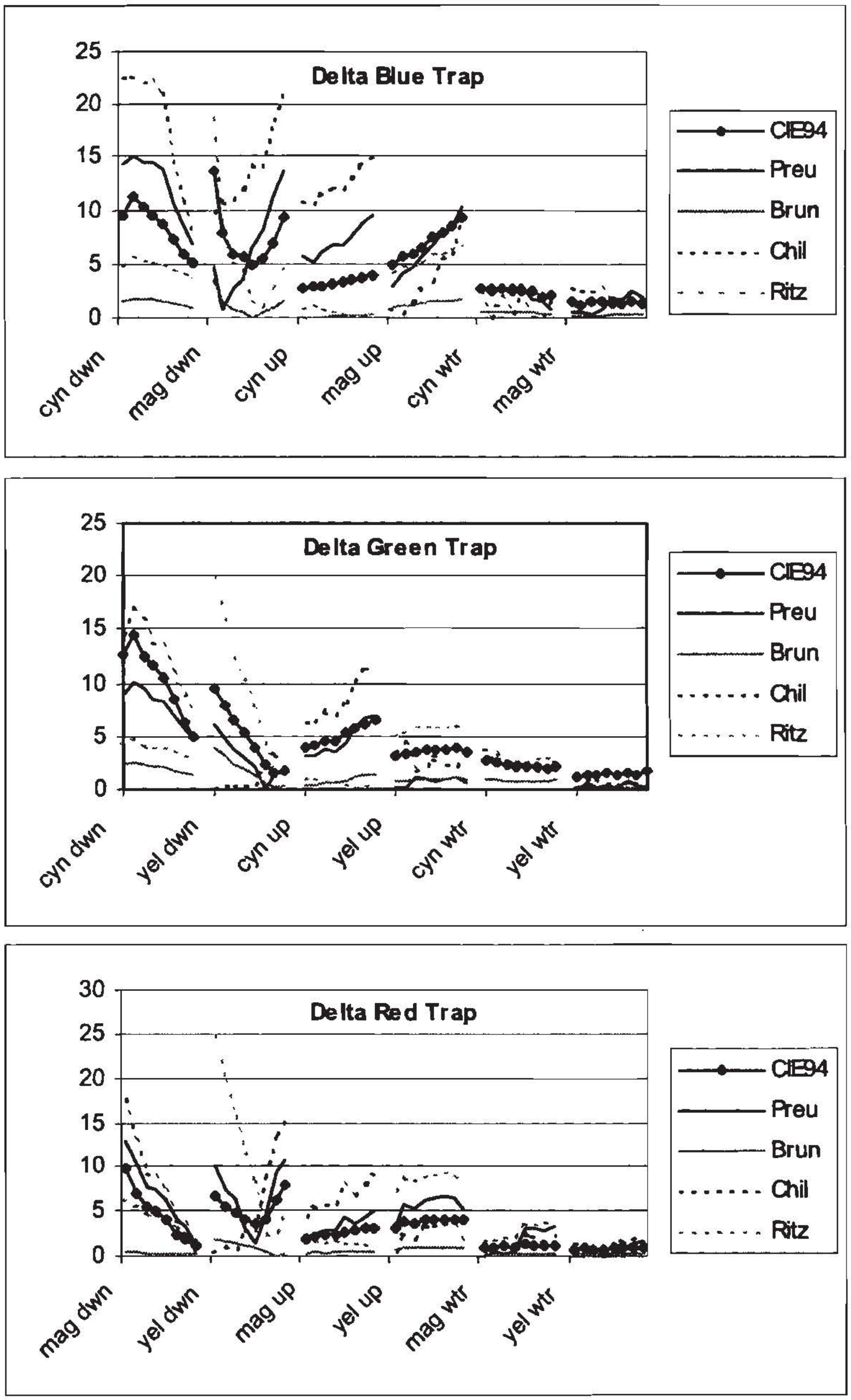

Figure 10. Delta traps and color differences for blue, green, and red.

and does not relate to the other line segments on the x-axis. The colorimetric changes are the line segments with data point markers. They represent the models that the trap formulas are tested against.

Figure 10 shows that the experimental treatments where the water was increased did not result in changes to the color of the overprint as effectively as did changes in the ink densities. This was in spite of the fact that the press operators made substantial increases to the water settings during the press test.

Examination of the graphs in Figure 10 reveals that the various trap equations did not perform equally well with each of the overprint colors, nor with each of the induced press conditions. The graphs in Figure 10 clearly indicate that overall the magnitude of changes were overestimated by the Childers trap equation and underestimated by the Brunner equation.

Some of the sample sequences did not show a continuous increase or decrease in color differences caused by a press adjustment. For example, the color changes of the red overprint caused by reducing the yellow ink were high when the first samples were taken, then they decreased for subsequent samples and then increased again for the last few samples. This could be due to human error in collecting the samples or flagging the delivery pile.

Blue	**Preucil**	**Brunner**	**Childers**	**Ritz**
cyn dwn	0.969	0.969	0.959	0.963
mag dwn	0.044	0.984	-0.107	0.905
cyn up	0.950	0.956	0.943	-0.795
mag up	0.994	0.998	0.958	0.996
cyn wtr	0.725	0.911	0.210	0.997
mag wtr	-0.023	0.304	0.482	0.506
Green	**Preucil**	**Brunner**	**Childers**	**Ritz**
cyn dwn	0.989	0.990	0.988	0.967
yel dwn	0.945	0.998	-0.858	0.993
cyn up	0.979	0.976	0.977	-0.901
yel up	0.841	0.910	-0.675	0.996
cyn wtr	0.832	0.570	0.873	-0.486
yel wtr	0.011	0.016	-0.196	0.063
Red	**Preucil**	**Brunner**	**Childers**	**Ritz**
mag dwn	0.993	0.850	0.996	0.979
yel dwn	0.964	-0.161	0.487	0.098
mag up	0.944	0.661	0.947	-0.779
yel up	0.916	0.943	0.855	0.960
mag wtr	0.710	0.486	0.689	0.739
yel wtr	0.447	0.590	0.394	-0.228

Table 8. Correlation coefficients for all test conditions.

Table 8 shows the correlation coefficients for each of the trap equations and each of the test conditions. There is a pronounced difference in the correlations for different test conditions. For example, in the blue overprint, the Preucil equation showed strong a correlation with the CIE94 color differences for reduced cyan ink, but not for reduced magenta ink. This might be due to the fact that the Preucil blue trap calculation is made from the green filter readings, which become smaller when the magenta ink is reduced, thus allowing for a larger margin of error. The Preucil blue trap changes also did not correlate well with CIE94 color differences when the magenta water was increased, however, this can be attributed to the small magnitude of the color change that resulted from the increase in magenta dampening..

To examine the overall effectiveness of the different trap equations, overall correlations were calculated across test conditions for each of the two color overprints. The results are shown in Table 9. The Preucil equation showed strong correlations with all three overprint colors. It was the highest correlation for the green and red overprints and the second highest correlation for the blue overprints. None of the other trapping equations showed high correlations for all three overprint colors. The Brunner correlations were high in blue and green, but moderate in red. The Childers equation showed moderate correlation for blue and relatively strong correlations for the other overprint colors. The Ritz equation had a high correlation for the blue overprints but a low to moderate correlation for the other colors. Between the different trapping equations, the Preucil and Childers equations showed strong correlations for all colors, as did the Brunner and Ritz equations.

		Preucil	**Brunner**	**Childers**	**Ritz**
Blue	**CIE94**	0.723	0.913	0.633	0.801
	Preucil		0.488	0.871	0.207
	Brunner			0.334	0.928
	Childers				0.155
Green	**CIE94**	0.919	0.840	0.799	0.383
	Preucil		0.743	0.874	0.164
	Brunner			0.422	0.775
	Childers				-0.192
Red	**CIE94**	0.951	0.429	0.711	0.574
	Preucil		0.382	0.701	0.551
	Brunner			-0.256	0.942
	Childers				-0.128

Table 9. Correlation coefficients for blue, green, and red overprints.

Figure 11 shows two sample regression lines from this data to graphically illustrate the correlations that were found. It was interesting that the Ritz equation, which had performed best at press equilibrium conditions did not

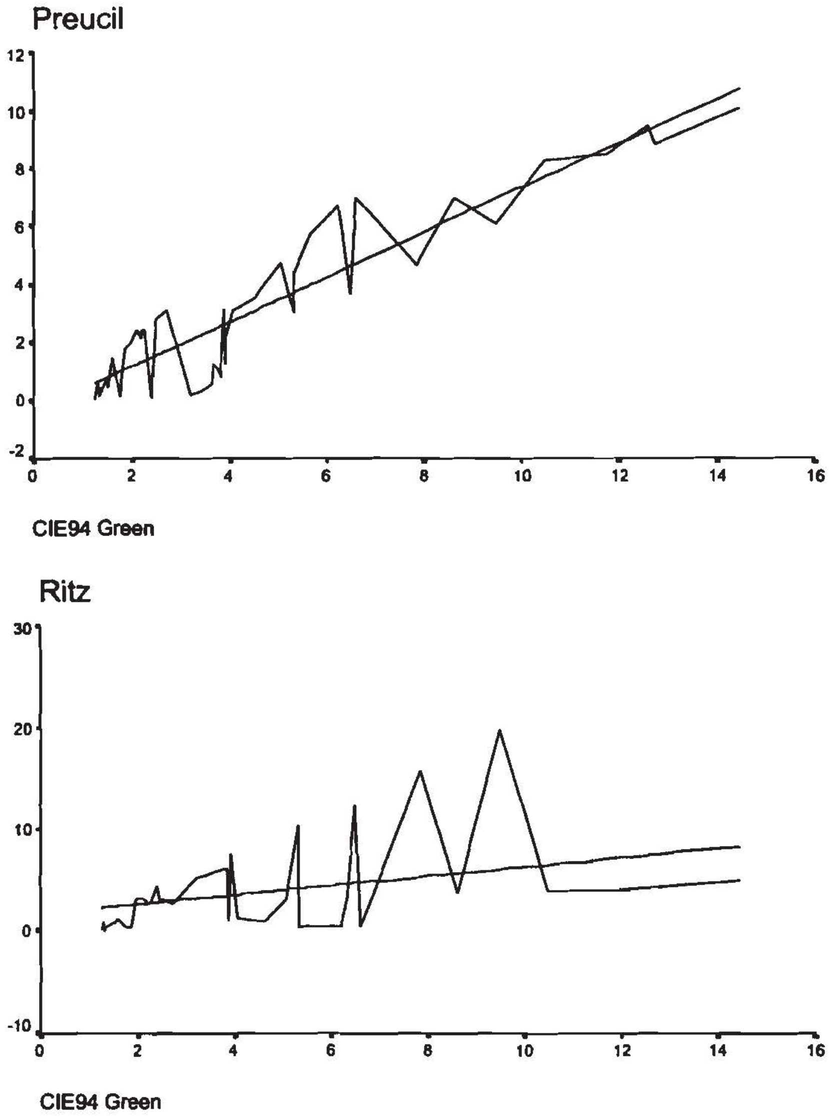

Figure 11. Green regressions for Preucil and Ritz equations.

correlate as well as some of the other equations (notably Preucil) when larger color differences were considered. The correlation for Preucil with green color differences was 0.92, while the same correlation was 0.38 for Ritz.

The Preucil equation was the best of the four equations for matching the CIE94 color differences when the press was not at equilibrium. The Preucil equation would be preferred among the four trapping equations for process control because it is more accurate at the levels where meaningful color differences occur.

The second-best correlations were found with the Brunner equation, but this equation would not be as effective as the Preucil equation for process control because of the narrow range of trap readings that it exhibits.

These findings are encouraging for the use of the Preucil trap equation as a process control parameter, even though its relationship with colorimetrically derived color differences is not uniform for all colors and press conditions. Many lithographers use densitometers for process control in their pressrooms, and, for them, ink trapping can provide a satisfactory means to monitor significant changes that occur in overprint colors.

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