Improving Print Standards by Specifying Isometric Tone Reproduction for the Overall Process

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Abstract: With the advent of computer-to-plate (CTP) and complementing digital proofing, color variability among printers has increased significantly. This variability is due in large part to the addition of a new variable to the plate-making process. This new variable is the ability to apply tone reproduction (TR) or "dot gain" curves in the plate imaging process. Printers employ these tone curves in a great variety of ways. Industry guidelines such as SWOP and GRACOL provide very little guidance as to the tone reproduction of the final printed product. CTP systems could be used to calibrate a printing process to match a tone reproduction specification. TR curves are normally computed individually for each process color, using density measurements. With normal differences in ink trapping, this individual color method can lead to gray balance errors. Our method of computing TR curves uses an "isometric tone scale" of equal values of overprinting cyan, magenta, and yellow. The paper describes how to compute TR curves using colorimetric measurements of this isometric tone scale. We learned that "isometric tone curves" provide a useful method for calibrating different printing systems to match a benchmark proof. The study demonstrates that tone reproduction and gray balance are effective methods of controlling a visual match from press sheet to proof. We suggest that existing printing standards could be improved substantially by the addition of a tone reproduction and gray balance specification.

Introduction

Color printing consistency between different printers and presses is an important goal for the printing industry. Certainly, SWOP, GRACOL, and other accepted industry standards were created in response to lack of uniformity among printers. Advertisers and other big consumers of

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print media commonly find it necessary to simultaneously use multiple print suppliers. As with magazine advertising, different printers must print the same color document at the same time. To insure that client expectations (matching the approved "contract" color proof) are met, specifications for these printers are essential. Developing and improving these industry standards remains an important industry commitment.

For printers with more than one press, consistency between presses is a major goal of process control. For purposes of efficiency and quality, it is a valuable achievement to have all of a company's presses printing to match one common standardized proof.

In addition to SWOP, and GRACOL, the industry's past materials and practices have led to additional de facto standards that aided in the color standardization of work between printers. Ironically, some of our industry's newest and most pervasive innovations have eroded the very standards that we know continue to be important.

Then And Now

In the past, most litho plates were contact exposed from films. It was standard operating procedure to linearize these films. Most operations did this. The same file output to film at different locations would result in equivalent tone values on the films. Linearized films became a de facto industry standard. Then and now, equivalent tone values printed by different printers will yield different results. This is a variable that we continue to deal with, as an industry. Now, we have computer to plate (CTP). This adds a new variable to the plate-making process. CTP presents the opportunity to employ tone reproduction (TR) output curves on the platesetter for any "desired result". Through these curves, CTP systems and their accompanying digital proofers offer a significant measure of control of printing TR. The RIPs driving these systems allow setting TR curves to any desired value. The problem is; **there are no current industry standard target aim point values**. There is currently a great difference of opinion as to what constitutes a "desired result". We find numerous different philosophies on how to apply tone curves to calibrate a CTP system.

For example, some printers simply linearize plates. Linearized plates print with a much lower tone value increase (TVI) than what is recommended in GRACOL or SWOP. Many printers calibrate their new CTP systems by seeking to match the printing and proofs of their old film workflow. Some use this setup to get started with CTP and eventually change it in favor of an "improved" shop standard.

Converting to CTP forces a printer to make a decision about what is a "desired result". With the absence of any TR standard, they can meet the broad requirements of GRACOL and SWOP and still have enough latitude to be quite different than their peers/competitors. Some printers like to say this difference makes them "better" than their competitors. Some simply decide to completely ignore SWOP and GRACOL. As Stanton points out in his GATF Print Attribute study, "the traditional commercial offset industry has historically acted according to a competitive, rather than a cooperative, paradigm." (Stanton and Hutton 2000) Moving away from the de facto standard of linearized film while applying TR curves in plate imaging has led to much industry variation and a move away from standards. Standards remain important. As GRACOL states, "individual shop standards are essential. The closer these are to industry norms, the easier it is to communicate with others in the industry." (GRACOL, 2002)

In the past, linearized films were proofed with "analog" proofing material. Yellow, magenta, cyan, and black were laminated to overlay each other on a common "commercial" or "publication" grade white substrate. The printer had little control over the tone reproduction of the process. Average offset printing tone reproduction (dot gain) was engineered into the most popular material by the manufacturer 3M. Matchprint™ adhered to the color, dot gain, and solid ink density specifications of SWOP. In this era, the printer's task was to match this prepress "contract proof" on the press. This was routine and the standard industry practice at the time.

At the height of its popularity, this prepress proof enjoyed 65% of the U.S. market share. This popularity made it a de facto industry standard proof. In this period, standard industry practice was to print from plates exposed from linearized films and attempt to match the common 3M proof made from the same films. The prevailing de facto process-color printing tone reproduction standard was the cumulative result of these materials and processes being used at the time. There was precious little control of TR in the film-making, proofing, and plate-making processes. They were what they were and they worked pretty well.

The necessary switch to digital proofing has had its own effect on our loss of industry printing standards. New variables have also been added to the proofing process. Tone curves are now applied in the digital proofing process. Again, there are no guidelines for the application of these curves. More inconsistency in proofing arises from the fact that digital proofing is frequently done on inkjet equipment not originally designed for this purpose.

In the pre-CTP era, the de facto standard pre-press proof drove the process. The printer's task was to match the contract proof. If you were a printer that couldn't closely match the common analog pre-press proof, you weren't competitive. The pre-press color proof was the solid industry “gold standard”. Now, proofing systems are commonly matched to the printing system (plate-making and presswork). This is a complete reversal of past practice. The printing and therefore proof may or may not match the SWOP or GRACOL standard. This and other changes in industry materials and practices are leading to a state of “color anarchy” in the commercial printing business.

We propose adding recommended specification of tone reproduction and gray balance to industry standards such as SWOP and GRACOL. This will provide printers with guidelines in the calibration of this new plate imaging control. It will make these specifications more complete.

The International Standards Organization ISO is proposing just such an addition to their offset print standards. (ISO, 2003) They present a series of TR curves for various paper stocks and plate types. A printer using CTP would have little problem adjusting plate tone curves to match these printing specifications. Printed work from two printers running to these specifications and using GRACOL/SWOP standard process inks (ISO 2846-1[1]) would be very comparable. Under this scenario, the color variation among printers that we are experiencing today would be greatly reduced. With some TR guidelines, printers wouldn’t be forced to make their own independent decisions about what is a desired printing tone reproduction. We would be using our newly acquired ability to adjust TR in plate-making as a means to meet standards instead of as a method toward unpredictability.

Objectives

This study has a twofold purpose. First, it will attempt to determine what information needs to be added to current printing standards specifications to identify tone reproduction and gray balance. Next, it will endeavor to devise a method for calibrating a proof or press-sheet by means of TR and gray balance to match a reference standard. Our calibration methods will be confined to adjusting TR curves. These are easily applied on any CTP system. The method will optimize a visual match between the adjusted output and a reference. Exact colorimetric matches may not be possible with only one-dimensional tone curves. This is a straightforward calibration method that would be a necessity before any further color characterization of the printing system.

Methodology

In an effort to improve upon current methods of measuring and calculating tone reproduction curves, we created a new 168 patch test target. The target consists of the commonly used individual cyan, magenta, and yellow tone scales in 5% increments from 0% to 100%. To this we added an “isometric tone scale.” An “isometric tone scale” is a scale in 5% increments from 0% to 100% of equal values of overprinting cyan, magenta, and yellow (CMY). We constructed three other scales to accompany the isometric scale. These scales are similar, overprinting C, M, and Y. Each of these scales has either a slight red, green, or blue color cast, in comparison to the isometric scale. Reducing the cyan, magenta, or yellow 20%, in each scale respectively forms this cast. In the scale with the red cast, the magenta and yellow steps range from 0% to 100% in 5% increments. The overprinting cyan steps range from 0% to 80%, across the 21 steps. 20% of the cyan is removed from each step. The other two scales (green cast and blue cast) are constructed in a similar fashion. (Appendix A).

Our printing test form, (Appendix A) with isometric scales, was provided to a commercial sheet-fed printer who uses CTP. The printer produced their usual digital contract proof of the 19”x 25” test form. The form was printed as a “live” job. The printer was instructed to print in their normal fashion, using their standard densities and procedures. The printer’s goal was to match their “house” contract proof for color approval. The press operator was instructed to consider our target along with the other images in make-ready color adjustments. Instructions were to match the color of all the images, including the target, to the proof. In color adjustment, our target was not given any higher priority than any other image on the sheet. Solid ink densities SID and tone value increases for the test press sheet are listed in Table 1.

SID				TVI %			
C	M	Y	K	C	M	Y	K
1.48	1.45	1.05	1.83	18.5	21.5	19.5	18

Table 1

The press-sheet to proof match was determined by visual assessment of the press operator. The printer supplied us with 10 “color approved” press sheets. The sheets were pulled randomly from the production run, after the press stabilized. The printer also supplied us with their “approved” color contract proof of the press form. The proof was high-end halftone dot proof from a major manufacturer. The company to match their printing characteristics calibrated the proofing system.

Calculating Tone Reproduction (TR) Curves

We first made a visual assessment of the test press sheets. We compared the sheets to the “approved” contract proof, under industry standard 5000ºK lighting. We chose sheets that had the closest appearance match to the printer’s contract proof. A Gretag Spectrolino™ spectrophotometer was used to read all of the target patches. The instrument was configured to measure each color patch twice and record the average. Spectral data was taken from all target patches.

One of our goals was to advance the methods used to create TR curves that are used to match one process to another. The current practice uses density measurement of individual C, M, Y, and K tone scales to calculate a match of the TR of a process to an aim TR. Densitometers are commonly used for this purpose.

We used five different "Matching Methods" to calculate TR curves that would provide the optimum match from our digital proof to the reference press-sheet. We used spectral data from all of the target patches for all subsequent calculations. Calculated status T density was used in method "#1". Colorimetric reflectance was used for our TR calculations in "#2" – "#5". We compared five methods of calculating TR. These TR curves were generated to determine the best method for optimizing a match between a reference press-sheet and a optimized proof. The four "Matching Methods" compared were:

1.) Use the current practice of Status T density method from individual (non-overprinting) CMYK scales.
2.) Use colorimetric reflectance from individual CMYK scales.
3.) Use colorimetric reflectance from the isometric (overprinting) scales.
4.) Linearly blend the colorimetric reflectance data from Method #3 to Method #2.
5.) Blend the colorimetric reflectance data from Method #3 to Method #2, blending more quickly from highlight to shadow.

For Method "#1", standard Status T density readings were taken from the individual CMYK scales of the press-sheet and the proof. Density was converted to percent dot (Murray – Davies) (ANSI CGATS.4-1993) Standard interpolation methods were used to generate TR curves used to match the proof to the press-sheet reference. (Appendix B)

For Method "#2", colorimetric reflectance values were calculated using spectral data from the individual (non-overprinted) CMYK scales. Method #2 was identical to Method #1. Colorimetric reflectance was used in place of density. These values were converted to percent dot and standard interpolation methods were then used to generate TR curves used to match the proof to the press-sheet reference. (Appendix B)

In Method "#3" colorimetric reflectance values from the isometric (overprinting) scale were used to calculate a TR match from the reference press-sheet to the proof. Data from the overprinting scales with the red, green, and blue casts was utilized to optimize these curves to produce a proof with an isometric scale that was an exact colorimetric match to the reference press-sheet. (Appendix B)

Method "#4" combined the data and techniques from methods "#2" and "#3" to generate TR curves that are optimized for the proof to attempt to match the color and gray balance of the press-sheet reference. The tone curves of methods #2 and #3 were blended linearly. The highlight end of the scale began with the full values of method #3 (data from the "isometric scale") and ended in the shadows with the full values of Method #2. (Appendix B)

Finally, method #5 was the same as the previous method #4 except the rate of transition from highlight to shadow was increased. This allowed more overall effect from the #2 curves data.

Testing Tone Reproduction Curves

The resulting CMYK tone curves were employed to produce color proofs to test their efficacy. Applying them to produce digital prepress proofs on a Kodak Approval™ XP4 tested the TR curves. The proofer was driven by a Creo Brisque™ DFE version 4.1. The calculated optimized TR curves were loaded into the DFE software. These curves were applied by the RIP to adjust the TR of the final output. The curves were optimized in an attempt to visually match a reference press-sheet.

We carefully compared the optimized proofs to the reference press-sheets. A GTI™ color-viewing booth with 5000ºK lighting in a standard viewing condition was used for visual assessment.

Individual CMYK scales on the proof were used as a quality check. Percent dot readings were taken from these patches and compared to file tone values to insure the curves were accurately applied. Tone values measured on the proofs were all within .5% of the requested value. ΔE94 comparisons were made between the proofs and the press-sheets as another point of reference and to assist the reader who does not have the possibility for a visual comparison.

Assumptions and Limitations

Since the reference press-sheets in this study were printed under normal production conditions, there are several assumptions and limitations that apply to our findings and conclusions. It was assumed that the printing conditions used to print our press-sheet references were typical of the industry. Density, and dot gain measures from the reference press-sheets confirm this. The "printing system" we refer to takes into account all of the variables that collectively shape the appearance of the finished product.

A Kodak Approval™ XP4 digital proofer was used to test how closely our optimized TR curves came to matching the reference press-sheet. We were able to show the level of achievable match by applying our optimized curves on the Approval™. The proofer was calibrated and operated under the strict process control guidelines of the manufacturer. The study did not demonstrate optimizing the match in the opposite direction (applying curves to the printing system to match a standard proof).

Results and Discussion

Although there is no currently accepted quantifiable method for determining a match between a proof and press-sheet, ΔE94 is often used to indicate a match between specific colors. Selected colors sampled from the photo imagery were compared colorimetrically between the proof and reference press-sheet. The results of this comparison for our best match are shown in Table 2. Since the reader cannot make a visual assessment of the match to the press-sheet, we report the average ΔE94 for specific sampled colors. This should give the reader a general impression of the level of match. By noting particular images, you can see how our best "Matching Method" affected the different color areas of the test form. (i.e. pure saturated overprints, pastels, and neutrals or near neutrals - "isometric" CMY overprints). CIE94 was chosen as an appropriate difference measure based on the CIE Imaging Technologies working group recommendations. (Luo,et al., 2000) Stanton also uses this measure for color difference comparisons in his trapping study. (Stanton and Radencic, 2001)

	"Faces" Photo	"Neutrals" Photo
Proof W/ #4 Calculated TR	3.32 Average ΔE94	2.75 Average ΔE94
Printer's Contract Proof	3.60 Average ΔE94	3.09 Average ΔE94

Table 2

We used visual assessment as a major factor in judging the level to which a proof matched a reference press-sheet. Visual assessment continues to be the major technique used in the industry approval process for both client and production personnel.

Matching Method #1

Our results show that the four methods we used to calculate TR curves to a best possible visual match of a proof to a reference press-sheet, each affected different color attributes of the proof. Method "#1" optimized a match to the individual CMYK non-overprinting tone scales. This is the classic method in use today; which relies on Status T densities to calculate the optimum curves. Visually the four individual tone scales match very closely from proof to reference press-sheet. What are not good matches, unfortunately, are the images. The images on the proof appear lighter and de-saturated compared with the press-sheet. This method matched the individual C, M, Y, and K tone scales very well. Visual assessment of the color images, however, illustrates a "commercially unacceptable" level of match.

Matching Method #2

Method "#2" used colorimetric reflectance instead of Status T density for the TR curve calculations. We theorized that colorimetric density provides for more actual color information than Status T density. Again, as in method "#1", the individual CMYK scales were almost an identical visual match to the reference press-sheet. The images appear "fuller" with higher color saturation than with the previous method. Color saturation of the proof continued to be less than the reference. The images and the overprinting isometric scales continued to appear lighter than the reference press-sheet. The level of match between the two continues to be less than "commercially acceptable."

Matching Method #3

Method "#3" applied the colorimetric reflectance values from the overprinting isometric scales in the calculation. The goal of Method #3 was to achieve a colorimetric match of the isometric scale to the reference press-sheet. This method begins taking into account ink, color, and other interactions that result from overprinting (trapping) the "wet" C, M, and Y inks. This isometric (equal C, M, and Y) scale represents colors close to neutral. Our calculations to optimize the proof's match to the reference affect the colors closest to the isometric scale (browns and neutrals).

In fact, the overprinting isometric scale on the proof was visually an exact match to the reference press-sheet. Subsequent measurement showed no higher than 2 ΔE difference between the proof and the reference press-sheet for any patch on the isometric scale. Neutrals on the proof matched the press-sheet very closely. One of our test form images consists mostly of neutrals or near neutrals. (Appendix A) This image matched the reference very faithfully. Other images with more saturated colors fared poorly in matching the reference with this method. These images had oversaturated colors when compared to the reference press-sheet. Our image with the main skin tone reference was noticeably oversaturated compared to the reference.

Method "#4" resulted in the closest match yet from the digital proof to the reference press-sheet. This method employed the colorimetric reflectance data from **both** the overprinting isometric and the individual non-overprinting C, M, Y, and K scales. The tone curves of methods #2 and #3 were blended linearly. The highlight end of the scale began with the full values of method #3 and ended in the shadows with the full values of Method #2. (Appendix B) The calculations integrated the data in such a way that favored the neutral balance (isometric scale based data) from the highlights to midtones and transitioned to favoring colors and matching tone reproduction from the midtones to shadows. Although gray balance began being compromised from the midtones into the shadows, the visual match of important colors (i.e. skin tones) was significantly improved. Also, the black printer effectively masks any cast that may occur in the darker neutral areas.

Method #5 was exactly like #4, except that the rate of transition from highlight to shadow was increased. (Appendix B) There was a modest improvement in the over-saturation of the subject's skin-tones ("Faces" Photo). Gray balance remained excellent and was not influenced by this modification.

Conclusions

Traditional print standards specify basic measurements such as density, dot gain and print contrast. This was appropriate for a time when plates and proofs were made from film.

Today, CTP systems permit control of tone reproduction via tone reproduction curves. It is now possible to calibrate a printing process to a reference process by computing tone reproduction curves from measurements taken of each process.

The current practice for computing tone reproduction curves is to measure step scales of each process color with a densitometer. Tone reproduction curves are computed to match the Murray-Davies percent dot values from one process to the other. This approach will correct large differences in tone reproduction, but usually requires further manual adjustments and numerous iterations to achieve an excellent match. This is especially true when the colorants are not the same, such as when matching a press sheet to a prepress proof.

We speculated that we could improve the match by using colorimetric measurements in the calculation of tone reproduction curves, rather than densitometric measurements. (Method #2) We observed a modest improvement from this change. But the overall color balance was still off in most cases.

It is commonly believed that gray balance is a key factor influencing the match between proof and press. So, we decided to test this idea by matching neutral scales of CMY. It was a big challenge to accomplish this with enough precision to make the results meaningful. We developed a special test object and software, utilizing an "isometric" tone scale. (Appendix C)

By using these isometric tone curves, we achieved an excellent match in terms of gray balance and overall weight. (Method #3) However, certain colors, such as flesh tones, were adversely affected when matching proofs with dissimilar colorants. At first, we attributed this effect to imperfect ink trapping. However, after more careful analysis, we realized the direction of the effect was opposite to what we expected. Now, we believe the effect is due to differences in the gray component of the colorants.

A further test was done blending the isometric and individual tone curves linearly from white to solid. (Method #4) This produced a pleasing result. We then changed the blending function to make a quicker transition. (Method #5) This gave the best overall results in our testing.

Based on our experimental work, we demonstrate it is possible to achieve an excellent visual match between proof and press by applying appropriate tone reproduction curves.

The consistency of printing throughout the industry has declined since the introduction of CTP. Our ability to apply tone curves in platemaking without a generally accepted method for creating such curves has led to "color anarchy". While there are printers who oppose standardization, most of us recognize the benefits, and support standards.

Print standards should provide target data for setting up proofing and platemaking systems. In general, a standard should define the ideal result as exactly as possible, then give a tolerance that is permitted from that ideal result.

Characterizing the print process by measuring a comprehensive printed test chart (e.g. TR004) does not meet this need very well. While it is possible to make ICC-style color profiles from this data, that is not the same as calibrating the printing process. What we need are metrics that specify the printing process exactly, and can serve as a reference for calibration.

We propose that future print standards should specify the tone characteristics of both the pure color axes and the isometric axis. This data is sufficient to obtain an excellent match from press to press and press to proof. More specifically, we suggest using colorimetric XYZ curves for this specification. These curves should be mathematical functions, derived statistically from actual printing. That would remove any discontinuities yet provide compatibility with legacy data.
(See "Colorimetric Specification of Tone Curves"- Appendix C)

Appendix A

Appendix B

General notes on the measurement of data
Measurement of the print samples was done with a GreatgMacbeth Spectrolino/SpectroScan instrument. The Spectrolino was connected to a Power Mac G5 computer running the Mac OS X operating system. Software was GretagMacbeth ProfileMaker Pro's Measure tool, version 4.1.5a. The software was configured to capture spectral data. The measured data for each patch consisted of 36 spectral reflectance values from 380nm to 730nm, in steps of 10 nm. The measurements had 4 digits of precision. Each patch of the test target was measured twice in slightly different locations, and the data averaged. Data was saved in tab-delimited text format.

The reason for working with spectral data, rather than XYZ or Lab data is that we needed both colorimetric and densitometric measurements for our analysis. Once spectral color measurements are reduced to one of these forms, it is not possible to derive the other. So, we had to start with spectral data.

General notes on computing

Programming was done using the Perl scripting language (www.perl.org). Programs can be written and debugged very quickly in Perl. Because of this, we were able to test our ideas quickly, without losing momentum. Perl has very powerful text processing capabilities, which make it easy to read the measurement data and produce output. There are hundreds of modules available to extend the Perl language. We used the module Math::Spline to do interpolation. We used the module Math::Matrix to solve systems of equations. This simplified our programming work considerably. Altogether, about 2500 lines of code were written for the experiments in this paper.

We used Perl version 5.8.1 running on Mac OS X version 10.3.2. This software is provided as part of the OS X operating system. The modules mentioned above were installed via CPAN (www.cpan.org). Editing was done using BBEdit, version 7.1.2, which provides an excellent environment for developing Perl scripts. We used Microsoft Excel, version 10.1.5, to graph and analyze our data.

Specific notes on computing

To create tone reproduction curves for our matching experiments, we needed to convert the measured spectral data into both densities and colorimetric values. These conversions are defined by standards. We followed ISO 5-3:1995 to compute Status T densities, and ANSI CGATS.5-2003 to compute colorimetric values.

These calculations are straightforward, and differ mainly by the spectral weighting functions. One issue was that our data did not extend out to the wavelengths required for the calculations. To solve this problem, we duplicated the endpoints of our data in each direction to fill in the missing data. The error caused by these missing points is negligible because their spectral weighting functions are extremely small.

Our first matching experiment was based on the current practice for computing tone reproduction curves. Individual tone scales of the process colors are printed on the reference and the press being matched to that reference. Both test objects are measured as spectral data, and then converted to Status T densities. Murray-Davies %-dot values are computed from the densities. These %-dot values are then entered into the CTP system to create a tone reproduction curve.

Our actual computations were simpler than that. Since the reflectance values are computed before converting them to density, we simply scaled those values to map paper-to-paper, and solid-to-solid. The end result is identical to the current practice described above.

We formatted our computed TRC data as a Creo Brisque™ file, and copied it to the Brisque™ via FTP. This saved a lot of typing, and prevented any transcription errors. We identified this TRC as a Type 1 match.

Our second matching experiment was identical to the first, except that colorimetric reflectance was used for the calculations. Instead of the red Status T value, we used the colorimetric X/Xn value. The Y/Yn value replaced the green Status T value, and the Z/Zn value replaced the blue status T value. We used the Y/Yn value in place of the green Status T value for the black printer. We identified this TRC as a Type 2 match.

Our third matching experiment was based on measurements of the isometric tone scale (labeled A on out test object). The patches in this scale all contain equal amounts of cyan, magenta and yellow. Our goal was to make a TRC that resulted in an exact match of this scale from proof to reference. The isometric scale is not exactly neutral. It usually has a brownish cast. But, by matching the isometric scale, the gray balance of the proof will be very close to that of the reference, which was the true objective of this experiment.

In order to compute an isometric TRC, we needed additional information about the near-neutral behavior of the proof. This was provided by three additional scales (labeled B, C and D on our test object). Each of these scales has one color reduced to 80% of the other two. So, scale B is reddish (reduced cyan), scale C is greenish (reduced magenta) and scale D is bluish (reduced yellow). Measurements from these scales allow us to compute the % dot values in the proof to exactly match the reference.

It should be noted that the calculation of the isometric TRC was very sensitive to variations in the measured data. Before writing our own software, we attempted to compute an isometric TRC using conventional ICC profiles. The results of this effort were not sufficiently accurate for our purpose. Also, we had difficulty obtaining good measurements with a capstan-style strip reading spectrophotometer. But, the Spectrolino produced very good, repeatable measurements, and we were eventually able to get an excellent match of the isometric strips. We identified this TRC as a Type 3 match.

Our fourth experiment was an effort to combine a Type 2 and Type 3 TRC in a way that retained the favorable aspects of each. For each process color, we computed a linear blend that began in the highlights as the Type 3 curve and progressed to the Type 2 curve in the shadows. We identified this TRC as a Type 4 match.

Our fifth experiment was identical to the forth, except that the blending was modified to progress more rapidly from highlight to shadow. We put an exponent in the computation of the blending fraction. For this test, the exponent was set to 2, giving a quadratic blend. We identified this TRC as a Type 5 match.

The black TRC for Types 3-5 was the same as Type 2. The isometric scale, and the TRCs derived from it did not involve the black printer.

Appendix C

Colorimetric Specification of Tone Characteristics

The current practice for measuring tone characteristics is to print a test scale of each process color containing tone steps from paper to solid. Density measurements, either Status T (USA) or Status E (Europe), are taken of each step, and then converted to an equivalent % dot using the Murray-Davies equation. These computed % dot values are generally greater than the % dot of the file that produced the plates. In the past, this increase in % dot was known as “dot gain”. That term has fallen out of favor, and we now describe this effect as TVI (tone value increase). Print standards typically specify the TVI for a 50% value of each process color.

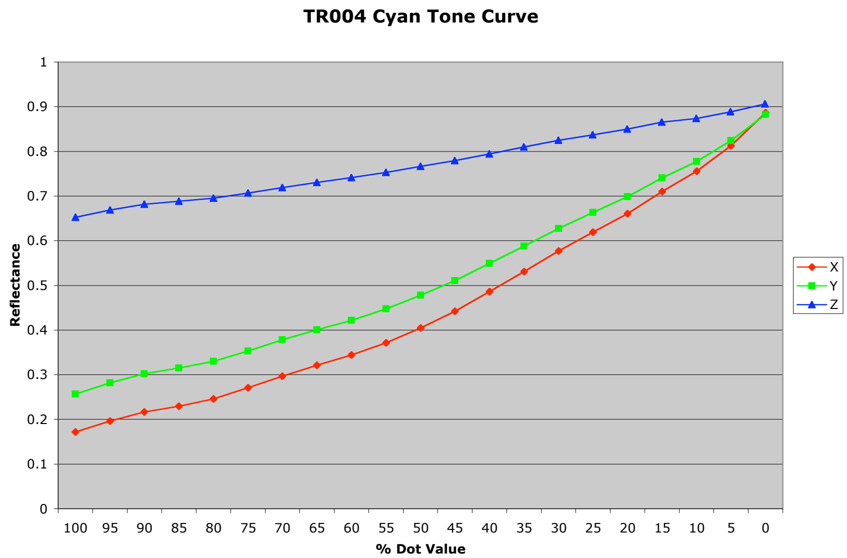
The most recent work in print standards (ISO 12647-2:2003) no longer uses densitometry to specify the solid ink colors. These specifications are now in colorimetric values. With this change, it is reasonable to question the continued use of densitometry to specify the non-solid tone values.

We think the entire tone characteristic should be specified using colorimetry. This direction is strongly supported by the fact that ICC profiles (and the data they’re made from) contain colorimetric measurements of these tone scales. Colorimetric tone characteristics may be taken directly from print characterization data, such as TR004 (CGATS, 2003). This would help to unify print standards with the world of color management.

As an example, a colorimetric tone curve from the TR004 data is shown below.

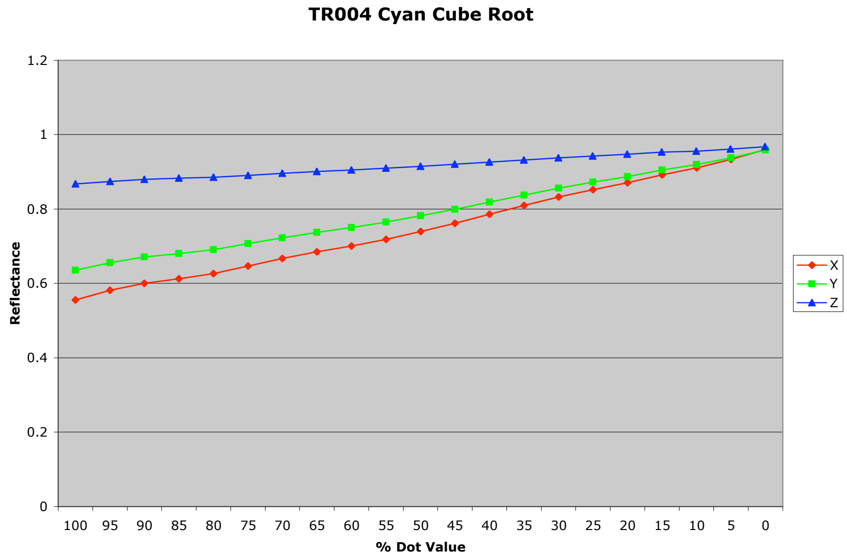
The X/Xn, Y/Yn, Z/Zn values of the cyan tone scale are plotted against % dot. The left-most points represent the colorimetric values of the solid cyan ink. The right-most points represent the colorimetric values of the paper stock.

Notice there are three curves, one each for X, Y and Z. This creates a complication when computing a tone curve. For that purpose, we need a single value that represents the visual effect of the ink patch. There are various ways to handle this. In our experiments, we used the curve with the greatest contrast. In this case (cyan), that would be the X curve. Another approach would be to combine all three curves together, by using their arithmetic or geometric mean.



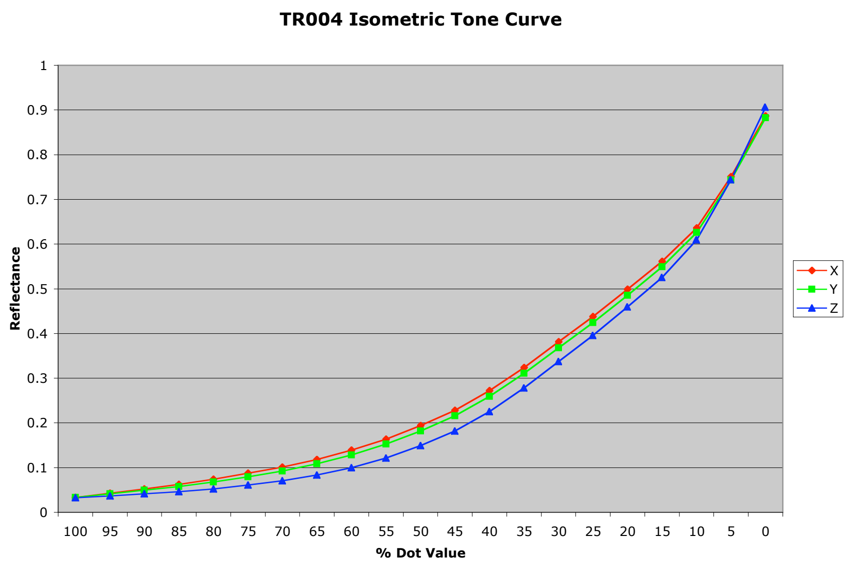
The TR004 data shown above required two years of careful work to complete. It is representative of high quality presswork in a commercial sheetfed environment. Despite all the effort that went into creating this data, the curves are not very smooth. There are factors related to the particular equipment, materials and calibration of this presswork that led to these results. If the same test were run again, in a different print shop, the curves would look different. This is real printing, and it is imperfect.

An important question is whether or not a print standard should be defined using actual data from a particular press run. In our opinion, tone characteristics should be defined by formulas derived statistically from actual print data.
The graph below illustrates how this might work. The data points in this graph are the just the cube root of the data shown above. These curves are nearly straight, and could be represented very nicely by linear equations. Interestingly, the conversion from XYZ to Lab begins by taking the cube root of the XYZ data. So, if a press were calibrated to perfect curves made in this way, there would be a linear relationship between % dot and Lab values.



Explanation of Isometric Tone Characteristics

In this paper, the term "isometric" means equal measures of cyan, magenta and yellow. Isometric tone characteristics contain colorimetric measurements of a tone scale composed of isometric patches. Below is an isometric tone curve from the TR004 test data.



Print standards begin by specifying the paper and inks. Then, tone characteristics specify the amount of ink laid on the paper for a given % dot value. By this way of thinking, it is perfectly logical to calibrate a system based on measurements of the pure process colors. The results from this calibration method can be excellent, provided the raw materials are similar between reference and proof. But, when there are differences in the paper and/or colorants, the match may not be all that good.

The isometric tone curves define the gray balance characteristics of the reference standard. The calibration of the printing system can be fine tuned, based on this information. A geometric interpretation of the isometric curve is that it characterizes the center of the CMY color cube, while the individual color tone curves characterize the edges of the cube. Taken together, these five tone curves characterize the printing process very tightly.

When calibration is done using TRCs, it is not generally possible to get a perfect match of the individual color tone curves and the isometric tone curve at the same time. But it is possible to get an optimal result that is somewhat better than using the individual colors alone.

For CTP systems that support device link profiles, it would be possible to exactly match all five tone curves. We anticipate that this would produce very good results, even when the colorants are different. This is a topic for further investigation.

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