SPECTRAL MEASUREMENTS OF OVERPRINTS ON PRESS SHEETS AND PROOFS

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Abstract: Measuring the color of ink on paper with a spectroradiometer has the advantages that the calibration can be done independent of illuminant and so as to minimize metamerism. The disadvantage of the approach lies in the amount of data needed for calibrations. We have explored means of reducing the bulk of data, specifically, the number of calibration patches required by a spectral scanning device to characterize a proofing system or ink-press-paper combination. For example, we asked whether the reflectance spectrum of solid cyan over magenta could be obtained as the product of the separate reflectance spectra of solid cyan and solid magenta. Not surprisingly, the answer is "No," yet we pursued the inquiry in an effort to identify factors contributing to a failure of additivity of log reflectances, for which we might compensate in synthesizing the reflectance spectra of complex overprints. We have compared a press and a proofing system for which trap may be presumed to be ideal (3M's Matchprint I). Apart from trap, discrepancies between calculated and measured spectra can be attributed to a minimum reflectance which appears to depend on both wavelength and ink and is probably the effect of differences in opacity (scatter), interlayer reflections, and gloss. Experiment suggests that internal reflection and light scattering are the more important effects.

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I. Introduction

Our purpose in this paper is to examine the reasons for using spectral scanning instruments in color calibration to press and proofing system. In the course of our examination, we will present detailed data on some aspects of color reproduction by these media.

We will begin with methodology, describing the instruments used for various aspects of the work and the substrates used in the preparation of color samples. Sections III, IV, and V will then focus on results, with section III serving to define terms, to compare and contrast methods of color sample measurement, and to introduce the remaining sections. Section IV will consider fluorescence as it affects the ability to measure colorant spectra independently of the illuminator with spectral scanning devices. Section V will consider the manipulation of spectral data in an effort to predict color of combined colorants from spectral data on individual samples. Our presentation will be guided by Yule (Yule, 1967), beginning with general consideration of factors affecting additivity of reflection densities. We will then present comparisons of measured and calculated spectra on proofs (section V-B) and press sheets (section V-C). In the course of this treatment, we will apply Yule's model for the combination of reflection densities to our own data and make a colorimetric evaluation of it. Lastly, we will draw conclusions (section VI).

II. Methods

Color samples of the 16 solid overprints were prepared on Masterproof stock by the DuPont Cromalin process, on King James stock by 3M's Matchprint I process, on Commercial Base by 3M's Matchprint II process, and on 80 pound Vintage Gloss stock with a Heidelberg GTO V52 sheet fed press. The inks used were manufactured by K + E (Keuffel and Esser) to provide a spectral match to SWOP standards. The press run was carried out by the Systems Technology Section of the Graphics Imaging Systems Division of the Eastman Kodak

Company. By "16 solids" we refer to the combinations of four inks laid down with 100% dot without regard to the sequence in which inks or colorant layers were laid down. This is not to say that sequence is not important, merely that only one sequence was used in each dataset of 16 overprints.

Figure 1 shows two geometries for measuring the reflectance of color samples as a function of wavelength. In reverse geometry, polychromatic radiation is shone on the sample and reflected light is sampled in narrow spectral bands by a monochromator and detector. In forward geometry, narrow band radiation is incident on the sample and all wavelengths of reflected light are collected by the detector at once. Instruments such as the Diano-Hardy Matchscan II (Milton-Roy, Inc.) allow samples to be measured using either geometry, a strategy which is especially useful in evaluating fluorescence (see Grum, 1980, chapter 6). In this work we used the Matchscan II to evaluate fluorescence of proofing substrates as part of the study of source independence of measurements; our results will be presented in Section IV. However, we used a EG&G Gamma Scientific spectroradiometer in the reverse geometry for all the other measurements reported in this paper. In the latter case, samples were illuminated by a filtered tungsten source (Hoffman Engineering model LM-33-30A) intended to approximate a color temperature of 5000K and measured at 5 nm steps between 380 and 780 nm. The half bandwidth of measurement was 5 nm. Spectral data files were processed on a VAX 11/780 as described in the following section.

III. Tristimulus versus Spectral Colorimetry

The measurement of color on proofs and press sheets is the first step towards press/proof calibration. The basic specification of the color of a sample, from which other colorimetric quantities are derived, is in terms of tristimulus values (TSVs) defined as follows:

$$TSV = \int cmf(\lambda) * S(\lambda) * r(\lambda)\, d\lambda \qquad (1)$$

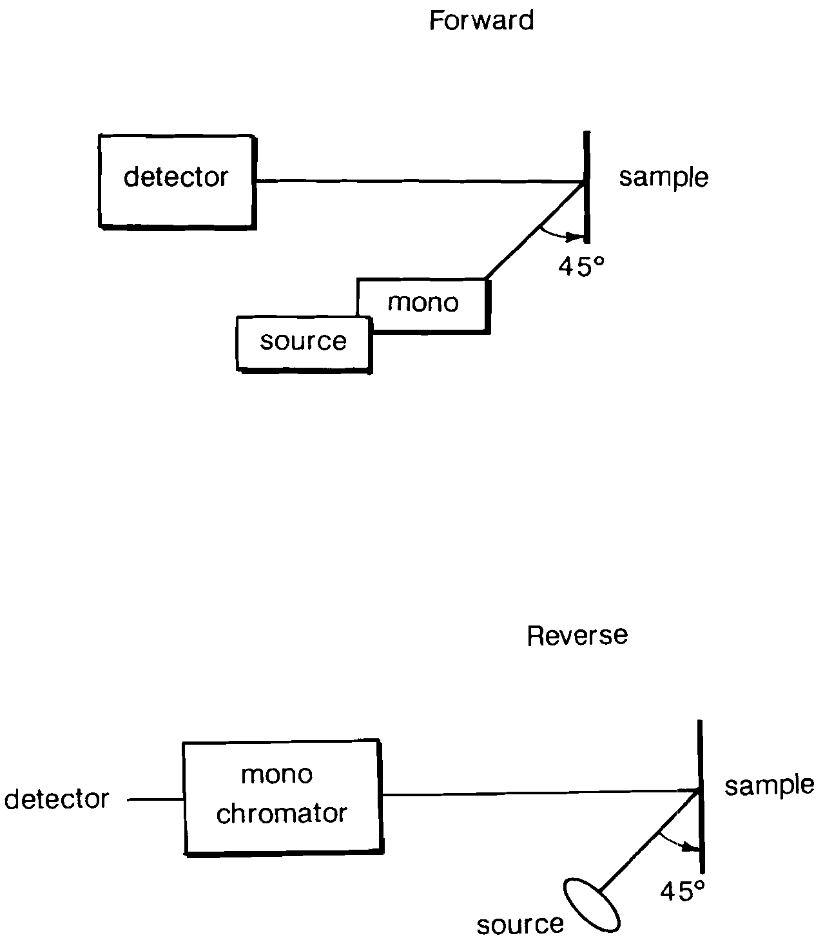

Figure 1. Arrangements for sample measurement in reverse and forward geometries.

where $S(\lambda)$ is the spectral radiance distribution of the source (illuminant and stock), $r(\lambda)$ the spectral reflectance of the sample, and $cmf(\lambda)$ the $\bar{x}$, $\bar{y}$ and $\bar{z}$ color matching functions of the CIE.

A tristimulus colorimeter is an instrument that measures TSVs directly by filtering the reflectance of the sample through three or four filters that closely fit the color matching functions. This has the advantage of speeding data collection since the bulk of the data needed to characterize the sample is much less than that needed with a spectral scanning instrument and little or no computation is necessary to arrive at the result.

In contrast, a spectral scanning instrument can be used to measure each of the functions within the integral in equation 1, affording the following advantages over tristimulus colorimetry:

(a) The cmfs can be exact, eliminating the errors in color measurement which occur due to filter imperfections in tristimulus colorimeters. An important caveat, however, is that the numerical integration must be carried out with adequate precision -- we have encountered canned software packages which have generated bad colorimetric data due to truncation effects in the calculations.

(b) Spectral scanning instruments have the advantage of source independence. Since the integration of the effects of the source are included after the measurement, any source may be inserted in equation 1. This is not the case with tristimulus colorimeters, since the integration takes place in the instrument and the source's spectral characteristics are inherent in the measurement. Source independence is a considerable advantage, since some lamps used for color appraisal, are undesirable for color measurement. However, an important caveat regarding source substitution has to do with samples which fluoresce. In this case, detailed knowledge of excitation and emission bands of the substrate are prerequisite to efforts at source substitution. Section IV will be concerned with the evaluation of fluorescence.

(c) Use of a spectral scanning instrument makes it possible to ask the following question,

$$r_{12}(\lambda) = r_1(\lambda) * r_2(\lambda) \ ? \qquad (2)$$

Since reflection density is the negative log of reflectance, this is tantamount to asking if reflection densities add. The ability to isolate and manipulate reflectance spectra (lamp and paper stock excluded) is most useful in the detailed evaluation of models of density combination such as Yule's (Yule, 1967), which will be the subject of section V-B. Throughout the balance of this paper, we will refer to the "product" of two reflectance spectra; by this we mean the spectrum constituted by multiplying the relative reflectances of the individual samples at each wavelength. The ordinates of spectral plots will be labeled "relative reflectance," because the quantity plotted at each wavelength is reflectance relative to that of paper stock illuminated by the measuring source.

IV. Source Independence?

It was noted in the previous section that the ability to extract the source (as reflected from stock) from the measured spectrum of a colorant film is essential to manipulations such as "multiplication" of spectra and that fluorescence in the colorant would limit any effort to extract a source. Figure 2a and b show, respectively, the spectra of Masterproof stock and Cromalin yellow toner measured with forward and reverse geometries. The spectra, in part a of the figure, suggest that the stock has a low reflectance below 400 nm and that its whiteners absorb light of this wavelength and re-emit up-spectrum, possibly at about 450 nm. It is probably this emission which accounts for the relatively high reflectance to monochromatic illumination of 400 nm. The effect of the fluorescence in the yellow toner (part b) appears to be a narrowing of bandwidth; density at 450 nm is enhanced while

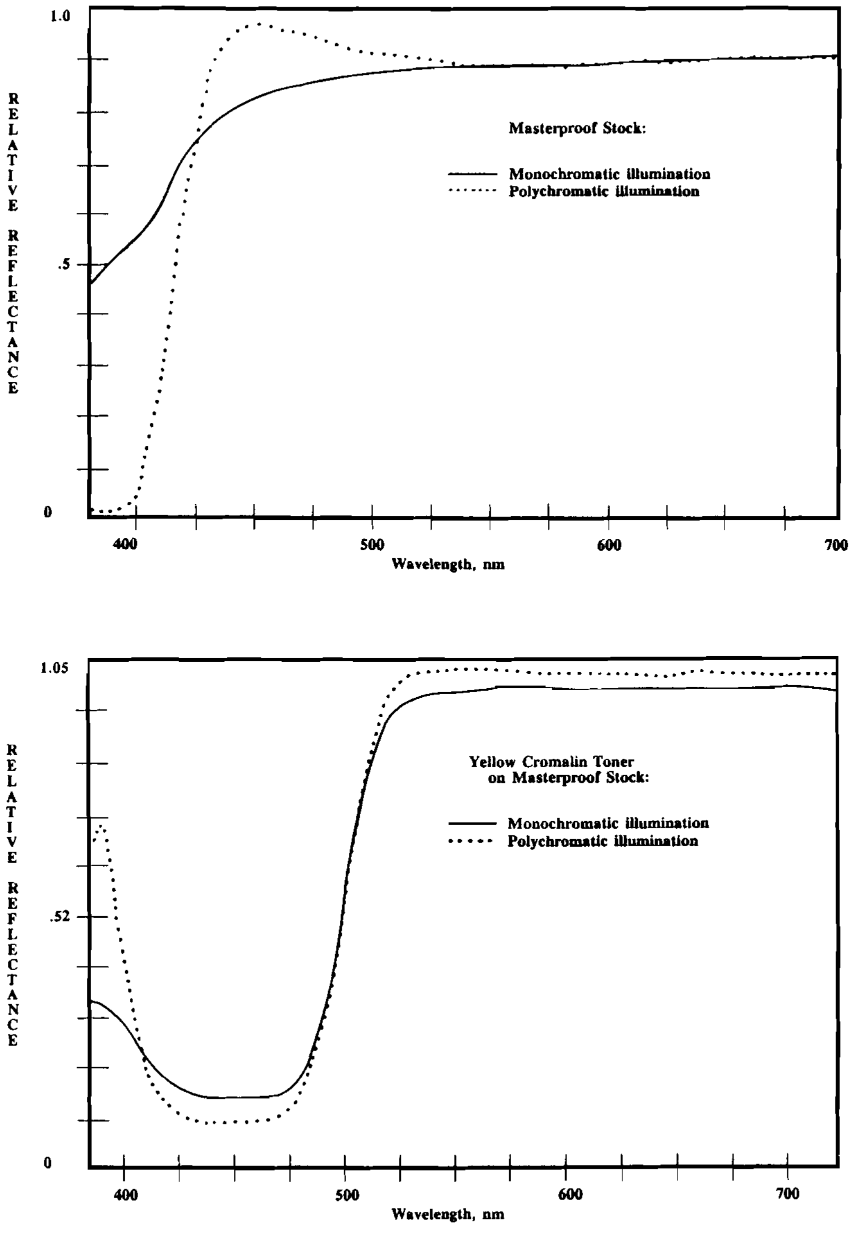

Figure 2. Demonstration of fluorescence in a proofing stock and yellow toner.

density outside the pass band on either side is reduced. Indeed, relative reflectance exceeds 1.0 throughout much of the long-wave region of the spectrum.

The presence of whiteners in stock appears to be commonplace and can be dealt with, since the spectral manipulations we propose require extraction of source and stock together. However, the extent of fluorescence in the yellow toner make it unsuitable for the kinds of studies we will describe in the following section and explain the absence of spectra based on Cromalin samples. However, we should note that we saw evidence of weaker fluorescence in other proofing systems.

V. Synthesis of Reflection Spectra

Neugebauer's model of halftone color reproduction involves additive mixing of the colors of 16 possible solid overprints (where four inks are involved), their proportions in the mixture depending on their likelihood of occurrence in the domain of the single dot. The colors of the overprints are specified by TSVs. A variant (Masia, 1984; Schwartz, Holub, and Gilbert, 1985) of Neugebauer's model for relating color to dot structure is employed in the DESIGNMASTER^R 8000, whose operation is grounded in a perceptually uniform color space. As noted in section III, there is no way to obtain the colors of multi-ink overprints from the TSVs of single ink solids, but with spectral data there may be. It is the purpose of this section to explore this possibility.

Yule (Yule, 1967, especially chapters 7 and 8) has provided a detailed discussion of factors limiting additivity of reflection densities in multi-layered systems of color reproduction. These include first surface reflection, multiple internal reflections due to boundaries of colorant layers or to opacity of pigments, as well as trapping and back transfer of ink. The interactions of factors causing additivity failure can be very complicated and we will describe some efforts to separate or control for them while presenting data from Matchprint I and II proofing systems and a sheet fed press.

A. General consideration of factors in additivity failure.

As a prelude to detailed discussion of the data, we offer a brief explanation of each of the factors and of our control. The term "control" may seem pretentious, but the lack of rigor in our controls may be compensated by a look at output of real press and proofing systems when operated in a conventional way.

1. First surface reflections.

An amount of incident light is reflected from the surface of the print which is independent of the density of ink film(s). This results in higher measured reflectances for overprints than would be expected, as shown by the following inequality:

$$r_1 * r_2 = \frac{I_{f1} + I_s}{I_w} \quad \frac{I_{f2} + I_s}{I_w} \leq \frac{I_{f1}}{I_w} * \frac{I_{f2}}{I_w} + \frac{I_s}{I_w} = r_{12} \qquad (3)$$

where R1 and R2 are percent reflectances for the individual colorant layers, R12, the reflectance of the overprint, Iw, the radiance of the paper substrate, Is, the radiance of the first surface reflection off a colorant layer, and the Ifs are radiances measured through the colorants. All terms are functions of wavelength except for Is. The foregoing can be simplified and rearranged to give

$$\frac{I_{f1}\, I_{f2}}{I_w^2} + \left(\frac{I_s}{I_w} * \frac{I_{f1} + I_{f2} + I_s}{I_w} \right) \leq \frac{If_1\, If_2}{I_w^2} + \frac{I_s}{I_w} \qquad (4)$$

Since all ratios are fractional, we've made our point. It is clear that, in the absence of any other factors limiting reflection density, first surface reflection can be ultimately limiting.

2. Multiple internal reflections.

These result from reflections off the inner surface of the film(s) back toward the paper or from scatter of the light by particles of dye (opacity). In our abstract, we referred to both of these as opacity, but they are distinct effects. Regarding the first, Williams and Clapper (Williams and Clapper, 1953) deduced a quadratic relation between reflectance and transmittance of a film of colorant. Figure 3 is a plot of reflection density as a function of transmission density for a paper base of 80% reflectance and a colorant film of refractive index 1.53, as computed by Williams and Clapper's equation. The solid line represents a power law with exponent 2, which would apply if no internal reflections (such as are illustrated by the inset) occurred. The figure shows that the reflection density of the film is greater than the transmission density, but doubling of transmission density always results in less than a doubling of reflection density. Hence, there's additivity failure for overprint densities. This law predicts no bound on reflection density, although it should be clear that there may ultimately be other limitations. Opacity resulting in light scatter will generally increase the density of a film; when a partly opaque film overlays another film, however, it limits access of light to the underlying films, causing additivity failure. We will try to weigh the effects of opacity by comparing alternate sequences of colorant film laydown. We will examine Williams-Clapper effects by looking at additivity of films which do or do not overlap in terms of spectral absorption.

3. Ink trap.

Optical measures of trap generally confound the various causes of additivity failure; for most purposes this isn't a problem. Strictly, however, trap has to do with differences in thicknesses of ink films which depend on whether they go down on paper or atop another ink film. We will try to attempt to examine this in a general way by comparing press output with that

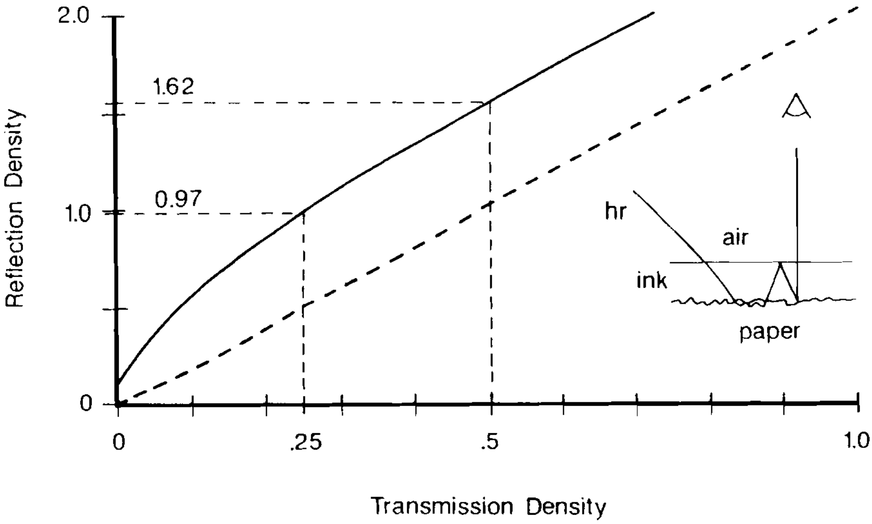

Figure 3. Williams and Clapper model of multiple internal reflections of light within film on paper.

of proofing systems which may be presumed to be immune from trap.

B. Comparisons of measured and calculated spectra on proofs.

In what follows, we will examine reflection spectra in the light of foregoing considerations.

1. Gloss and minimum reflectance of proofing systems.

Figure 4, a through c, shows reflectance spectra for cyan, magenta, and yellow laminates of Matchprint I (solid curves) and Matchprint II (dashed curves). Although the latter has more vivid color and a longer dynamic range, the spectra of Figure 4 might lead one to expect the contrary. In the main, however, the samples are remarkably similar.

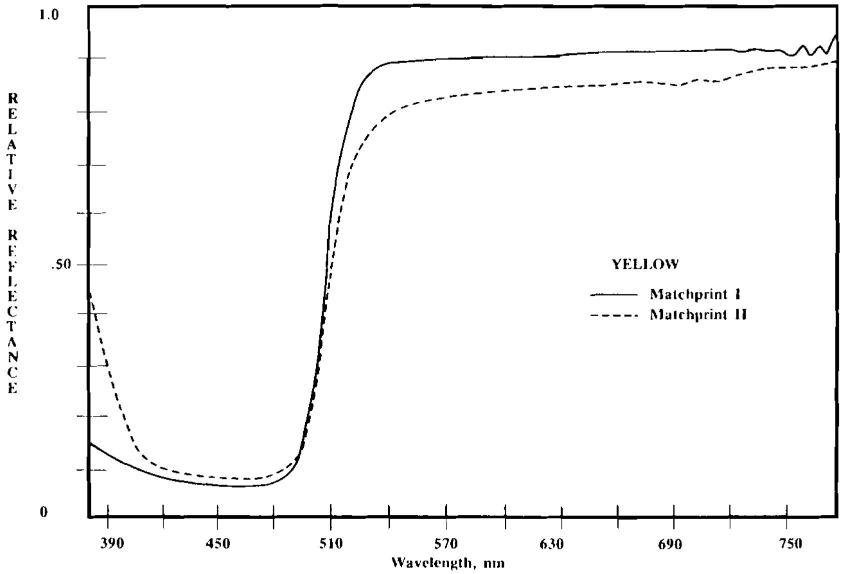

Figure 4a. Comparison of yellow laminate for Matchprints I and II.

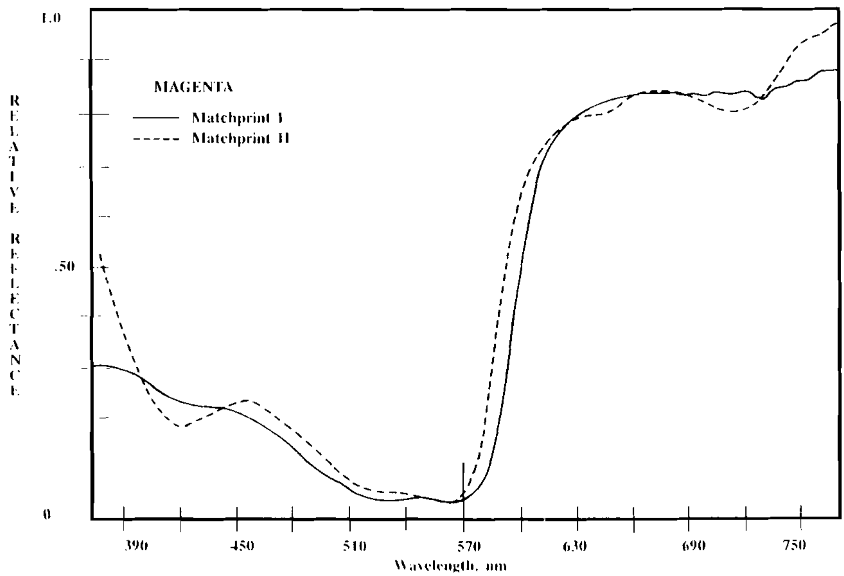

Figure 4b. Comparison of magenta laminate for Matchprints I and II.

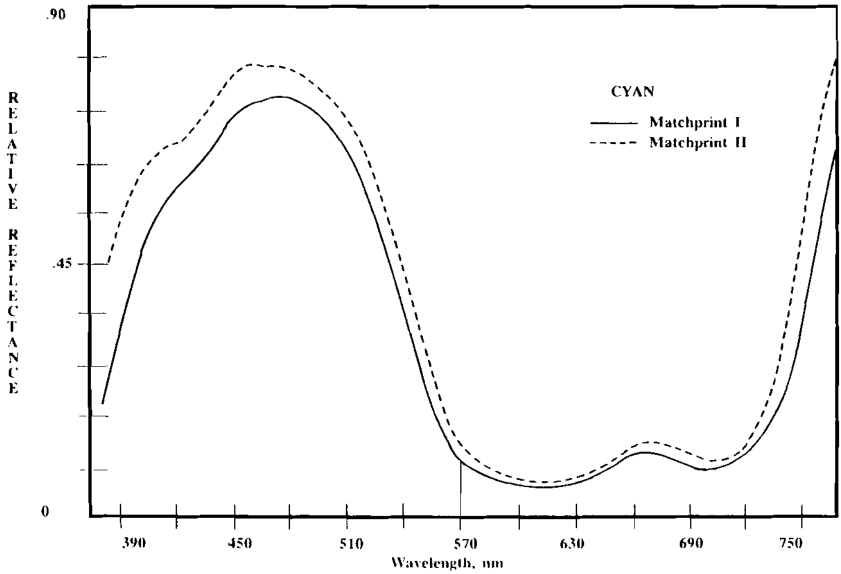

Figure 4c. Comparison of cyan laminate for Matchprints I and II.

This is also true of the black laminates, shown in Figure 5a. The most significant difference occurs at the short wave end of the spectrum, where the reflectance of Matchprint II rises rapidly. Figure 5a also shows spectra for the 400% solids, laid down in the sequence Y M C K, bottom to top. Figure 5b replots the four-color overprint with an abbreviated abscissa to achieve better resolution. Added is the spectrum of Y M C K K, or 500% of Matchprint I.

Several inferences can be made from Figures 4 and 5:

(a) The enhanced gamut of Matchprint II is largely due to the gloss of its finish. This gloss greatly reduces the diffuse component of first surface reflection and increases the specular component, which is not collected by the measuring instrument in 0/45 degree measuring geometry. The difference between 400% of Matchprint II and Matchprint I (.3 to .5% reflec-

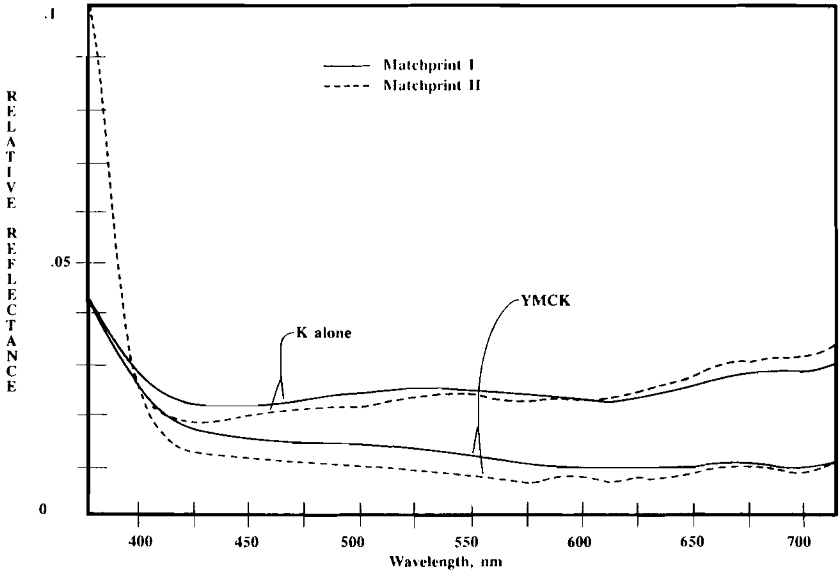

Figure 5. a: Comparison of black laminate and 400% overprint for Matchprints I and II.

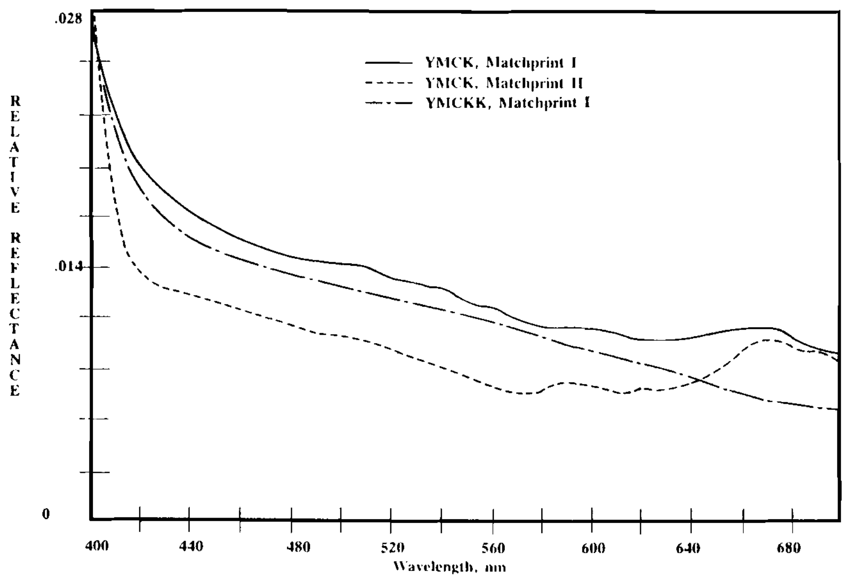

Figure 5. b: Comparison of YMCK and YMCKK at better resolution than a.

tance across the spectrum) probably accounts for most of effects due to first surface reflections.

(b) If first surface reflections were limiting reflection density in these systems, then the spectra would be flat at a level of about .003 to .005 reflectance. Furthermore, it would not be possible to decrease reflectance by adding another layer of black.

(c) Since the spectra for black ink alone essentially superimpose on those for 400% ink in the region of 400 nm, it is reasonable to suppose that the black laminates are opaque to short waves and control the reflectance of the sample; recall that they are laid down last.

(d) The difference between Y M C K and Y M C K K is much less (by about an order of magnitude) than would be expected for additive reflection densities. This is suggestive of multiple internal reflections.

2. Multiple internal reflections where absorption bands overlap.

These inferences can be pursued further with reference to Figures 6 and 7. Figure 6 presents the progression of overprints _ M C _, Y M C _, Y M C K for Matchprint II, bottom up (underscores are intended to emphasize the presence of a clear layer of laminate). The solid line represents the spectrum as measured directly and the dashed line the "product" of separate C and M spectra. Likewise for parts B and C of the figure. In all cases, the chromaticity coordinates cited in the legends are u,v,L, but the delta E is color difference in L*,a*,b*. In each frame, delta r (difference in reflectance between measured and calculated) and delta D (difference in reflection density) values are given for 450, 550, and 650 nm. The calculated spectra did not benefit from any corrective modeling. The following points can be made:

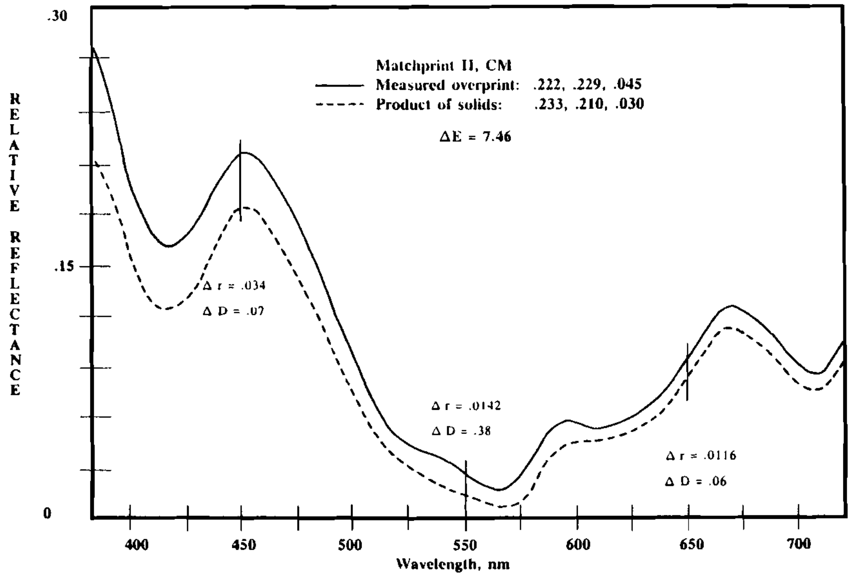

Figure 6a. Matchprint II: Comparison of measured spectrum of C-M overprint with spectrum which is product of separate C and M reflectances at each wavelength. u, v, and L values at upper right. ΔE is difference in L*, a*, and b*. r and D are reflectance and density.

(a) Although the errors in reflectance actually decrease from A-C, the color errors increase dramatically due to the reduction in signal level.

(b) In all cases, the errors in color are unacceptably large. Consistent with the fact that the underestimation of reflectance is worst in the blue region, estimated chromaticities are shifted toward magenta in frame A and toward red in B and C where both magenta and yellow are present.

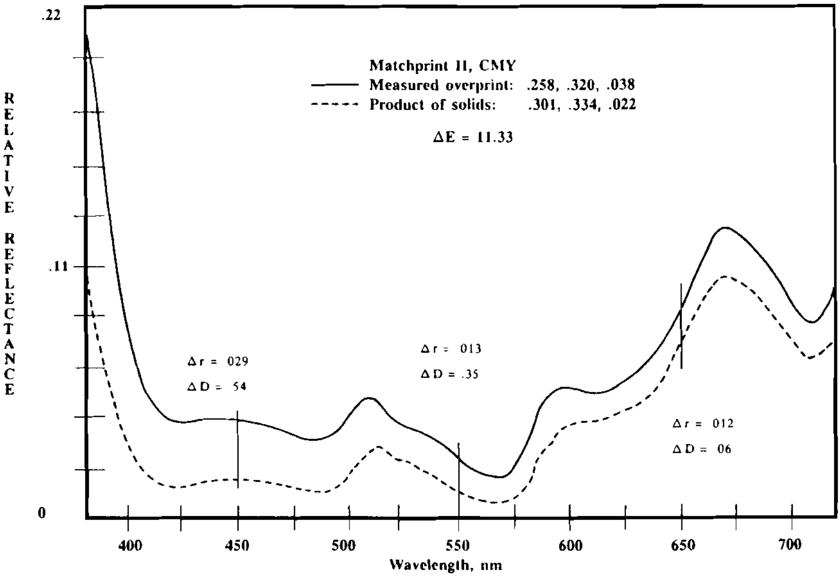

Figure 6b. Matchprint II: Comparison of measured spectrum of C-M-Y overprint with spectrum which is product of separate C, M, and Y reflectances at each wavelength. u, v, and L values at upper right. ΔE is difference in L*, a*, and b*. r and D are reflectance and density.

(c) The errors in estimated reflectance cannot be ascribed primarily to first surface reflections, except, perhaps in the long-wave region of the 400% overprint.

(d) Errors in reflection density are much more informative. The largest error in frame A occurs where both C and M are absorbing appreciably. In frame B, the error at 550 nm is essentially unchanged with the addition of yellow (which transmits at 550 nm), while the error at 450 is increased because both M and Y are absorbing. In frame C, the errors are worst below 600 nm, where more than two laminates are

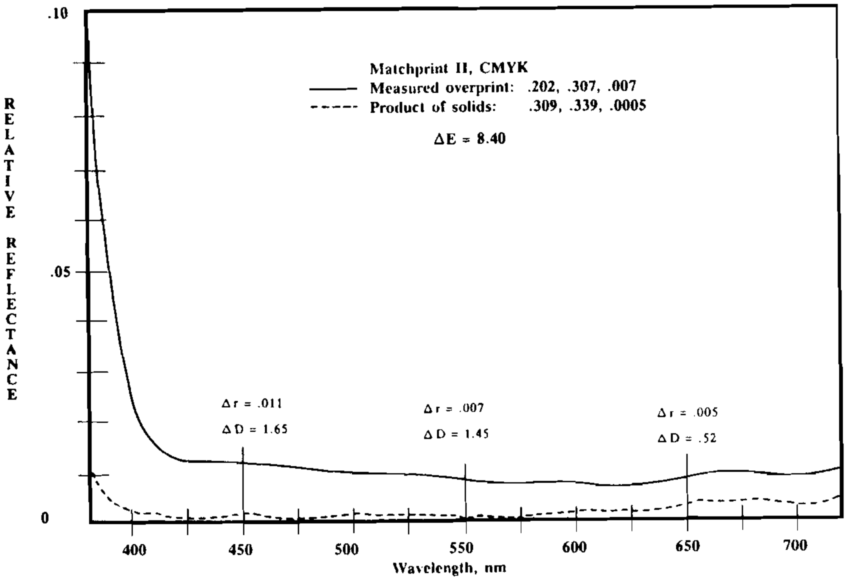

Figure 6c. Matchprint II: Comparison of measured spectrum of CMYK overprint with spectrum which is product of separate C, M, Y, and K reflectances at each wavelength. u, v, and L values at upper right. ΔE is difference in L*, a*, and b*. r and D are reflectance and density.

absorbing appreciably at the same time. This is what would be expected according to Williams and Clapper's analysis.

(e) The relatively high reflectance of the actual 400% overprint below 475 nm is of some interest, since Y M and K are all absorbing in this range. This is probably not attributable to multiple internal reflections, but rather to opacity. Both of these effects, however, would be expected to be enhanced with short-wave light.

3. Sequence and opacity.

Figure 7 shows some results for Matchprint I. In part a, measured and calculated results are shown for the cyan-yellow overprint. Absorption bands of these laminates do not overlap spectrally; consistent with thoughts of the preceding section, simple-minded prediction of the overprint spectrum works very well.

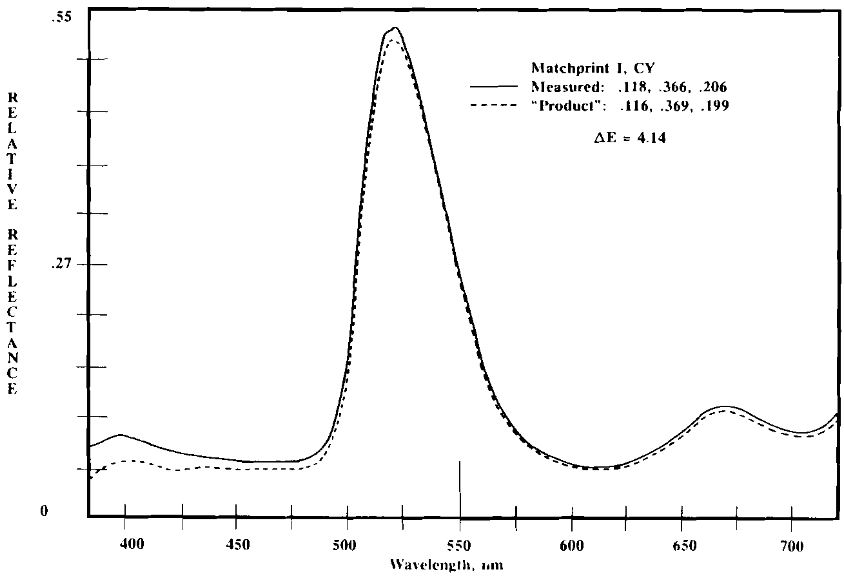

Figure 7a. Matchprint I: Comparison of measured spectrum of CY overprint with spectrum which is product of separate C and Y reflectances at each wavelength. u, v, and L values at upper right. ΔE is difference in L*, a*, and b*.

Figure 7b shows the spectrum of black alone along with calculated and measured versions of the _ _ C K overprint. Comparable data for the sequence _ K _ C were gathered to demonstrate that black becomes increasingly opaque to short wave light and controls reflectance. These data

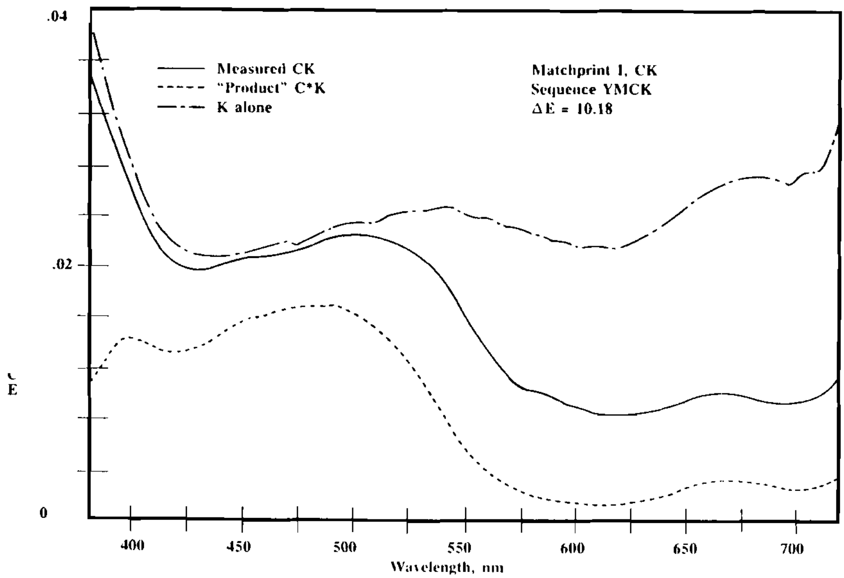

Figure 7b. Matchprint I: Comparison of measured and computed spectra based on CK overprint with spectrum of black only. Sequence YMCK, bottom to top.

appear in Figure 7c. While they support our claim, they also point to complicated interlayer reflections which are probably not characteristic of presses. Note that the spectrum of black alone is markedly different in the band 400 - 500 nm for the two sequences and that the slope of measured _ K _ C is opposite that of both _ K _ _ and _ _ _ C in the range of 400 to 500 nm. All the scans used to produce parts b and c of the figure were replicated at various points in time to ensure their validity.

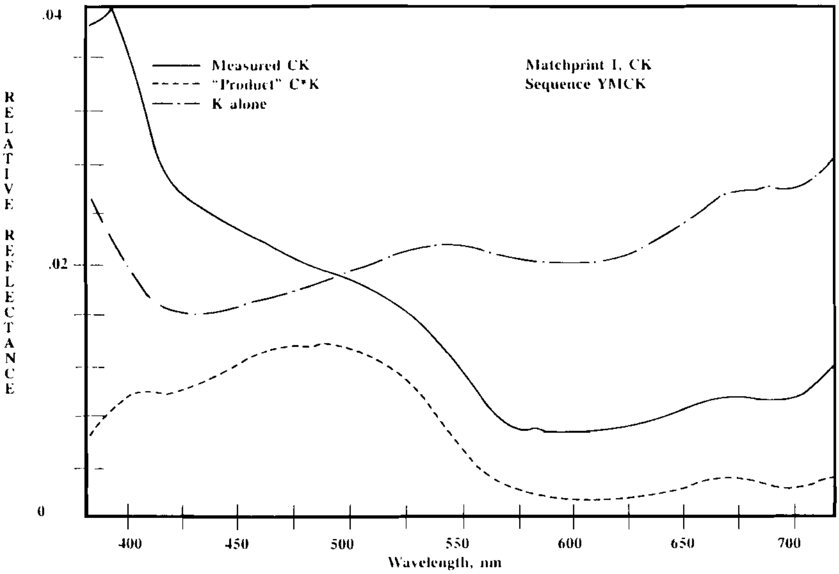

Figure 7c. Matchprint I: Comparison of measured and computed spectra based on CK overprint with spectrum of black only. Sequence YKMC, bottom to top.

4. Yule's composite model of additivity failure.

Yule (Yule, 1967, p. 231) argued that the combination of effects discussed in the preceding sections could be summarized by the following equation

$$D = D_{max}\left[1 - \left(1 - \frac{D_1}{D_{max}}\right)\left(1 - \frac{D_2}{D_{max}}\right)\cdots\left(1 - \frac{D_n}{D_{max}}\right)\right] \quad (5)$$

where D is the predicted reflection density of a print with n layers of colorant, D_{max} is the maximum reflection density attainable with the given reproduction medium and D_1, D_2, etc. are reflection densities of constituent layers measured individually. In our approach, all of these terms depend on wavelength, although Yule probably viewed the Ds as results of densitometric readings made with a filter complementary to the color of the layer of variable density. Although the density of a layer of colorant in halftone is fixed and we have been considering only completely filled (solid) dot domains, we designed a simple experiment for evaluating the applicability of Yule's equation to our data. The essence of the experiment is captured in Figure 8. Frame a

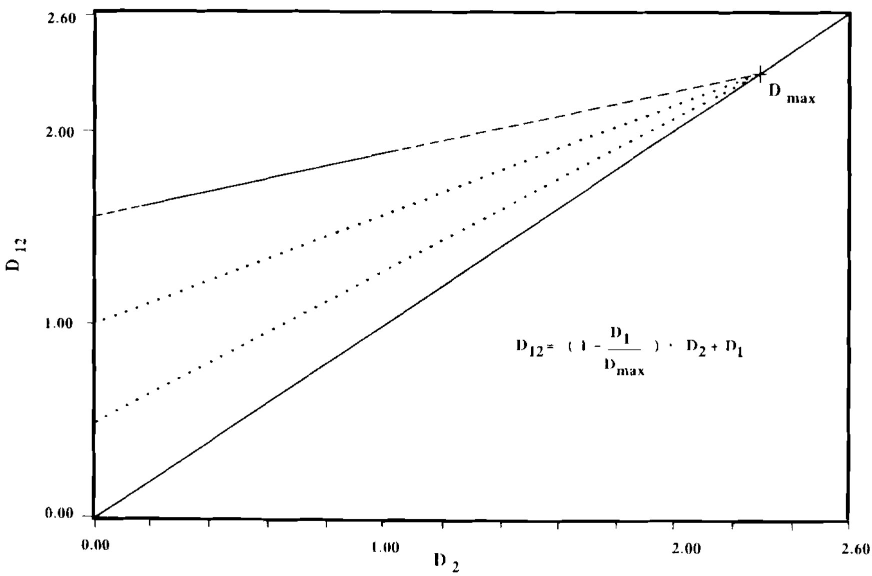

Figure 8a. Density of two layers versus density of added component for Yule's "composite" model of additivity failure of reflection densities.

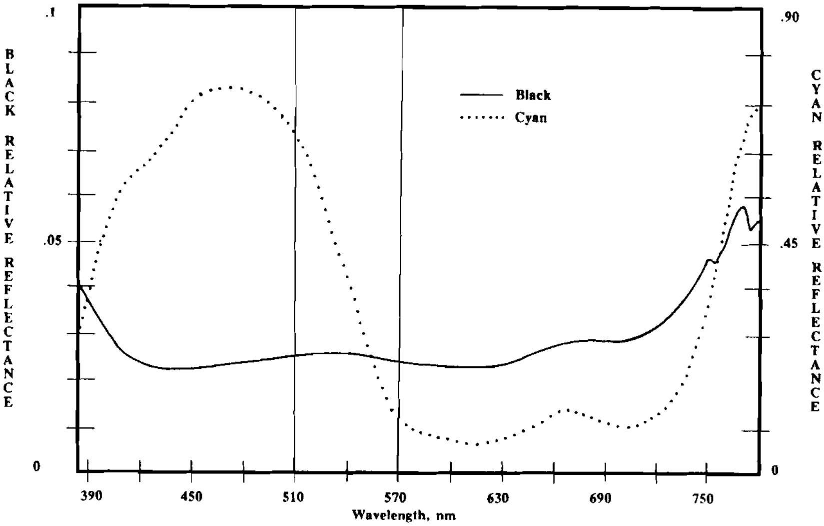

Figure 8b. Matchprint I: Cyan and black spectra used to test Yule's model for two layers. Black density fairly constant between 510 and 570 while cyan varies monotomically.

plots the density of two layers of colorant (where one has fixed density) against the density of a layer of variable density. The solid line with slope 1 and intercept 0 represents the density of the variable layer alone. Finely dotted lines represent densities of the fixed layer of .5 and 1.0 respectively. The uppermost line consists partially of data from the experimental conditions depicted in frame b, but the data are extrapolated in either direction by a dashed line. The lines all converge, more or less, to intersect the line of slope 1 at our estimate of D_{max} for Matchprint I, or 2.3.

The solid segment of the uppermost line in part a of the figure is based on a fixed density of black of approximately 1.5, and variable densities of cyan read from the spectrum shown in part b and fed to equation 3 with D_{max} equal to 2.3.

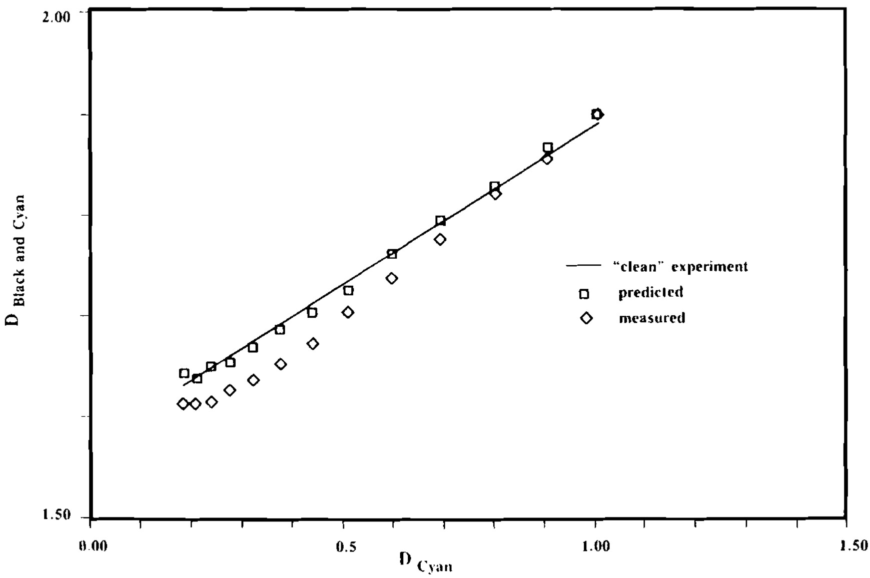

Figure 8c. Comparison of reflection density of CK overprint with values calculated by Yule model assuming constant black (solid line) and using actual black density (square symbols).

As can be seen in part b, black does not have constant density over the range of wavelengths (510 through 570 nm) sampled for cyan density values. Figure 8c shows actual, expected results of the experiment compared to (solid line) results of the "clean" experiment and to actual measured densities of the cyan-black overprint. We recapitulate the experiment as follows:

(a) We have used data on cyan and black to illustrate graphically the implications of equation 3. Caution should be used in drawing conclusions from Figure 8 since it was prepared under the assumption that changes in density of cyan were due to concentration or layer thickness and not to wavelength as was actually the case. As noted, we have no other way to evaluate the applicability of the model to halftone within the framework of Yule's graphical analysis, mimicked in Figure 8.

(b) A better, but less heuristic, evaluation of the model can be had by applying it without the kind of assumptions noted above to the calculation of overprint spectra. The colors (L,u,v and L^*,a^*,b^*) derived from these spectra can be compared to those derived from the measured overprint spectra. The criterion for a favorable comparison is perceptual closeness, the criterion most relevant to our application. Chromaticities based on measured Matchprint I overprints are assembled in Table 1, in which the first column identifies the solid overprint and the next six give 1961 CIE UCS chromaticities and CIELab coordinates computed from the measured spectrum. Delta E values computed from differences in L^*,a^*,b^* for measured and computed spectra appear in the last two columns. One is based on direct multiplication of constituent spectra to get the overprint spectrum, while the other employs Yule's model. In this application of the model the density of the 400% overprint was used as D_{max} rather than the fixed value, 2.3; the delta Es were greater on the whole for the latter case. Tabular data for Matchprint II are not presented because they are very similar to those for Matchprint I. It is clear from Table 1 that Yule's model greatly improves color prediction for the proofing system, but that overall it is not adequate for exacting color reproduction.

C. Data from sheet fed press.

The finding that proofing systems may exhibit interlayer effects of the sort shown by Figure 7c is disappointing, if not surprising, because it means that we have no baseline against which to evaluate ink trap on press. Another factor limiting our ability to make comparisons between press and proofing system is the difference in default sequence, the press being run at K C M Y, bottom to top. Nevertheless, we will present data which illustrates salient aspects of the ink and press, concluding with a

Table I

Chromaticities of Matchprint I overprints with Delta-Eabs between measured and predicted values by two models.

	Measured						Delta-Eab	
	L	u	v	L*	a*	b*	Simple	Yule
____	0.9919	0.2143	0.3268	99.6862	0.0207	-0.1159		
C___	0.2482	0.1290	0.2679	56.8951	-30.7221	-51.7959		
_M__	0.1907	0.4028	0.3116	50.7679	73.0871	0.9297		
CM__	0.0336	0.2380	0.2150	21.4151	30.7652	-43.8833	6.2717	5.6492
__Y_	0.9349	0.2297	0.3706	97.4242	-9.0417	101.9254		
C_Y_	0.2064	0.1175	0.3655	52.5576	-62.4691	31.6029	4.1422	1.3290
_MY_	0.1819	0.4343	0.3470	49.7212	68.1410	50.0857	15.2051	3.3478
CMY_	0.0270	0.2688	0.3169	18.7828	13.4486	-2.3447	12.0056	2.6379
___K	0.0258	0.2097	0.3308	18.2862	-1.6426	1.5625		
C__K	0.0160	0.1688	0.3128	13.2370	-7.9134	-6.2763	10.1771	3.8901
_M_K	0.1445	0.2501	0.3155	12.2818	7.9624	-2.9543	13.1055	1.9446
CM_K	0.0114	0.1994	0.3077	10.0776	-0.4301	-6.3814	10.1422	2.2855
__YK	0.0243	0.2158	0.3424	17.5781	-1.8961	7.3516	19.0572	1.3538
C_YK	0.0151	0.1758	0.3279	12.6789	-8.0234	-0.8380	10.6607	2.8916
_MYK	0.0146	0.2482	0.3206	12.3482	6.9532	-1.2181	14.7789	1.7246
CMYK	0.0112	0.2000	0.3133	9.9478	-0.9822	-4.6708	10.9083	2.5048

table of data summarizing the applicability of equation 3.

Figure 9a is a composite plot of spectra of C, M, and Y inks. If anything, they would lead one to expect somewhat more saturation than the proofing system, a consideration which is borne out by Table 2, which shows colorimetric data derived from measured spectra. Figure 9b shows spectra for the black ink and 400% overprint from the press with comparable spectra from Matchprint I. Here, the two systems part ways with the most striking difference being in dynamic range. However, the spectrum for the 400% press solid actually touches the spectrum of black alone. Figure 10 affords a better look at the cumulation of density as layers of ink go down and suggests that the upper two layers of ink, magenta, and yellow have some opacity. This may account for the significantly larger delta E values obtained by applying Yule's model to the press than to the proofing system.

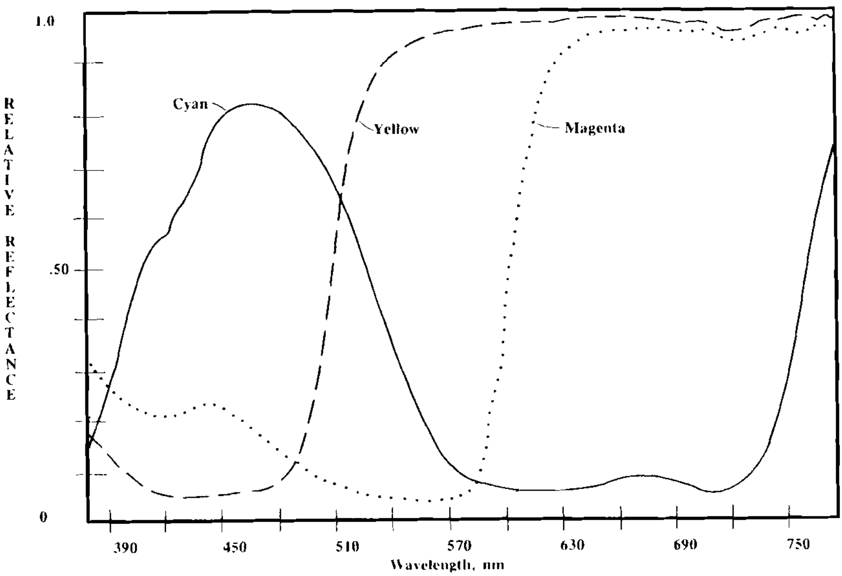

Figure 9a. Spectra for cyan, magenta, and yellow ink solids on sheet fed press.

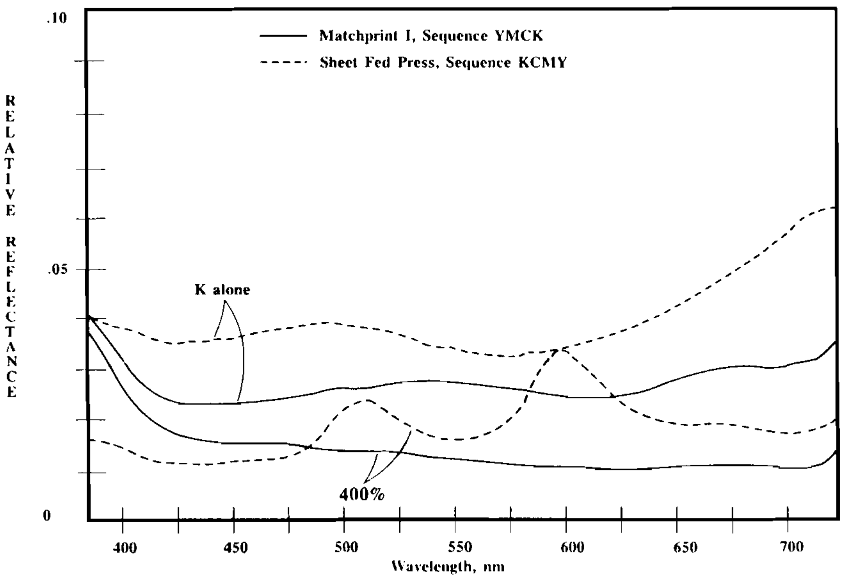

Figure 9b. Spectra for black ink and 400% overprint of press in comparison to Matchprint I.

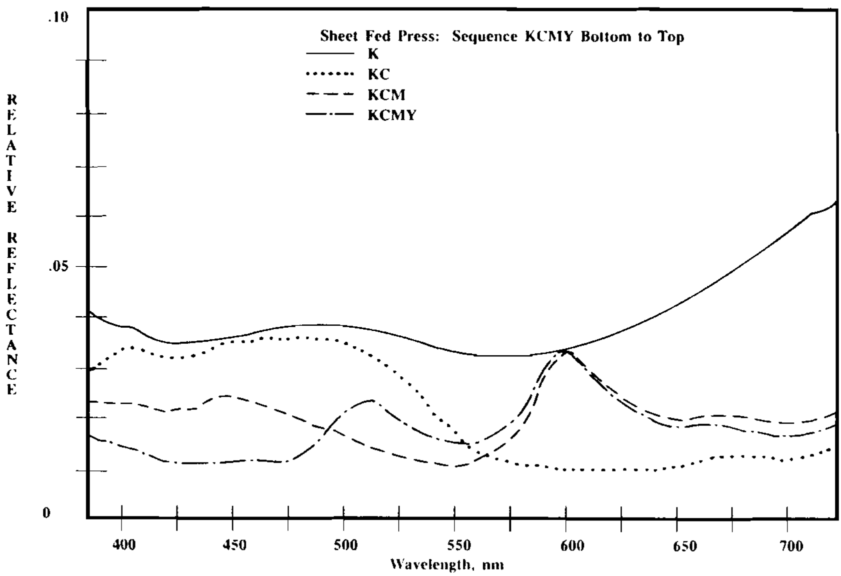

Figure 10. Spectra for progression of solid inks on sheet fed press.

Table II

Chromaticities of press overprints with Delta-Eabs between measured and predicted values by two models.

	Measured						Delta-Eab	
	L	u	v	L*	a*	b*	Simple	Yule
____	1.0201	0.2121	0.3247	100.7715	-0.1093	0.0802		
C___	0.2720	0.1320	0.2588	59.1618	-25.6876	-56.5521		
_M__	0.2174	0.4026	0.3070	53.7570	78.5438	-1.1392		
CM__	0.0348	0.2209	0.1914	21.8745	34.0616	-52.2832	8.4644	17.6791
__Y_	0.9553	0.2226	0.3697	98.2462	-13.3058	96.9942		
C_Y_	0.2160	0.1060	0.3609	53.6065	-70.2433	26.4632	14.6354	12.0467
_MY_	0.2014	0.4372	0.3460	52.0005	72.0262	51.3023	20.0640	4.1443
CMY_	0.0307	0.2376	0.3084	20.3492	8.8210	-6.0290	19.1245	12.6649
___K	0.0552	0.2128	0.3228	28.1927	0.5273	-0.9316		
C__K	0.0262	0.1484	0.2875	18.4957	-11.2710	-15.8968	11.4012	16.2245
_M_K	0.0192	0.3215	0.3017	15.0799	23.7039	-5.0891	10.6708	16.4329
CM_K	0.0096	0.2094	0.2628	8.7145	7.2722	-16.3733	13.8036	18.0977
__YK	0.0479	0.2198	0.3583	26.1412	-3.7936	22.4200	10.3424	10.5685
C_YK	0.0225	0.1420	0.3446	16.7714	-20.1368	5.9403	13.6138	17.1605
_MYK	0.0181	0.3348	0.3334	14.4725	20.2039	8.3511	9.2993	13.8803
CMYK	0.0090	0.2124	0.3127	8.1902	1.3363	-3.3993	8.6611	13.5761

VI. Conclusions

1. Although spectral scanning instruments enable accurate colorimetry with the use of exact color matching functions, care must be taken to perform tristimulus integrations with adequate precision.

2. Fluorescence of samples poses a limitation on the ability to make source independent measurements with spectral scanning colorimeters.

3. Yule's composite model for predicting reflection densities in multi-layer color reproduction systems improves the accuracy of prediction of overprint spectra compared to a simple linear model when applied to Matchprint proofing systems. However, it does not greatly improve predictions for presses and in neither case is it adequate for the exacting color reproduction required in modern CEPPS.

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