CUSTOMIZED-COLOR COMPUTER PRINTING ANALYSIS

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Abstract: A multiple-patch color test target is printed and scanned with a pulsed-xenon spectrophotometer. A computer is used to derive press performance along with prepress requirements for various lithographic printing conditions of inks, paper, plates, undercolor removal, etc., and for various types of copy. It is particularly advantageous to compare presses both within a plant and between plants, as in the case when service-house proofs and production printing must be coordinated. Color measurements are provided for comparison with standards and quality control.

The results of the analysis are presented graphically as well as in tabular form for easy understanding and application. Presently, three categories of information are provided: prepress preparation, ink/press performance, and color measurements. A fourth category, color rendition, is possible in the future. The technique is not restricted to lithography. Excellent results have been obtained for flexography printing, and with modifications, analyses could be made for gravure and screenless printing. It is adaptable to any process where the amount of subtractive primary colorants must be known in relation to an application parameter: ink jet and electrophotography are reasonable examples.

The equipment described here is designed for central service operation rather than for individual plant installation.

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Introduction

The scientific and technological advancements in how to perform the prepress operations for graphic arts have been dramatic. Less dramatic have been the advancements in determining what is needed for optimum quality color reproduction, probably because of the complexity of the reproduction process and difficulty in making the necessary color measurements.

The full lithographic printing process can now be analyzed by printing a multi-patch color test target and then automatically measuring and computing the optimum requirements for various printing conditions and types of copy. The printed target is scanned with a spectrophotometer; from these measurements a computer program produces graphics and tabular data which can be easily interpreted and applied. Presently, the analysis consists of three categories: prepress preparation, ink/press performance, and color measurements. A fourth category, color rendition, is possible with this technology.

In normal operation, data from the printed test object, as read by the spectrophotometer and transmitted to the computer central processing unit, are entered into the special program, which then:

1. Characterizes the significant performance parameters of the press/ink/paper combination, such as slur, trapping, and dot gain.

2. Calculates halftone separation aims, which provide gray balance in combination with a preferred tone reproduction aim, even, if desired, for a specific amount of undercolor removal.

3. Provides color measurements for comparison with standards and quality control.

Although the system combines precise measurements and sophisticated computer calculations, the equipment and the program are designed for efficient, convenient use. Effective interactive prompting combined with internal self-checking in the program are major elements which make this possible. Because of the hardware requirements, it is designed for a central service operation rather than for in-plant use.

Test Target

The test target is printed from specially prepared hard-dot halftone negatives or positives. The printed target (Figure 1) consists of 144 5/8-inch square patches with an overall square dimension of 4-1/2 inches. The purposes of the patches are as follows:

	Patches	Primary Use
1.	Black circles	Registration
2.	Color solids	Solid ink densities, spectrophotometric curves, dot gain, trapping, and color space measurements.
3.	3-color and 4-color	Maximum printing density and tone reproduction
4.	Near neutrals	Gray balance, tone reproduction, and effective black.
5.	Color scales	Dot gain, color rendition
6.	Black scales	Effective black
7.	Color tints	Color rendition
8.	Parallel lines	Slur measurements
9.	Concentric circles	Visual slur assessment

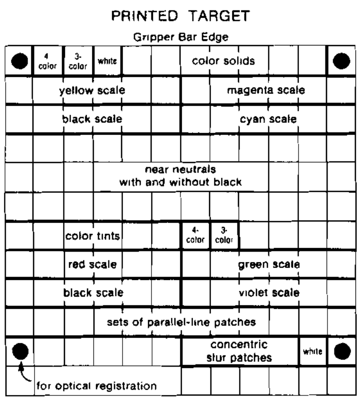


Figure 1. Illustration of printed target.

Presently, only 126 of the possible 144 patches are being used.

The precise dot areas in the target halftone separations are stored in the computer. The separations must be stripped into a layout with the proper gripper bar orientation, so the parallel-line patches are aligned properly for measuring the angle of slur, which will be discussed later.

The analysis gives optimum results when the production printing matches the target printing conditions. Thus, the ability to print reproducibly is important. Conventional color control bars will provide adequate quality control. The target should be printed periodically along with production, if possible, to monitor the press performance.

A record and specification sheet (see Appendix) is filled out at the time of printing the target. The specifications are entered into the computer program, and then the computations are applied to a specific process. The specifications include the following:

1. Scanner or photographic process

2. Negative or positive halftone

3. Copy mode: transparent or reflection

4. Aim points: AMB or HPS/TR

5. Tone reproduction: average, high or low key

6. Undercolor removal: amount, if desired

7. Black printer: starting point on original scale above highlight, and percent dot area in the shadow step.

Hardware

The hardware consists of the following units:

A - Western Union teletype (TTY) Model 43 - operator control plus printing of tabular data.

B - Motorola 6800 based microcomputer - channels the communication.

C - Host computer - General Electric Information Services via telephone.

D - Macbeth pulsed-xenon spectrophotometer, MS-4045.

E - Controller - operates x-y positioning table.

F - Hewlett-Packard color plotter - graphics.

Figure 2 is a picture of the hardware in operation. The operator is receiving tabular data on the teletype printer. The tall console to the left is the spectrophotometer with the x-y positioning table and target in the loading position. The plotter is in the center rear, and the telephone MODEM is on the right.

Figure 2. Hardware in operation.

Figure 3 is a block diagram showing how the units are connected and the possible directions of communications. The operator with the teletype, A, can communicate with any of the units directly through B, the "gateway" microcomputer. However, a complete analysis is made by signaling the host computer (C), and except for a few commands by the operator, table movement (E), measuring (D), graphing (F), and printing (A) are all directed by the host computer.

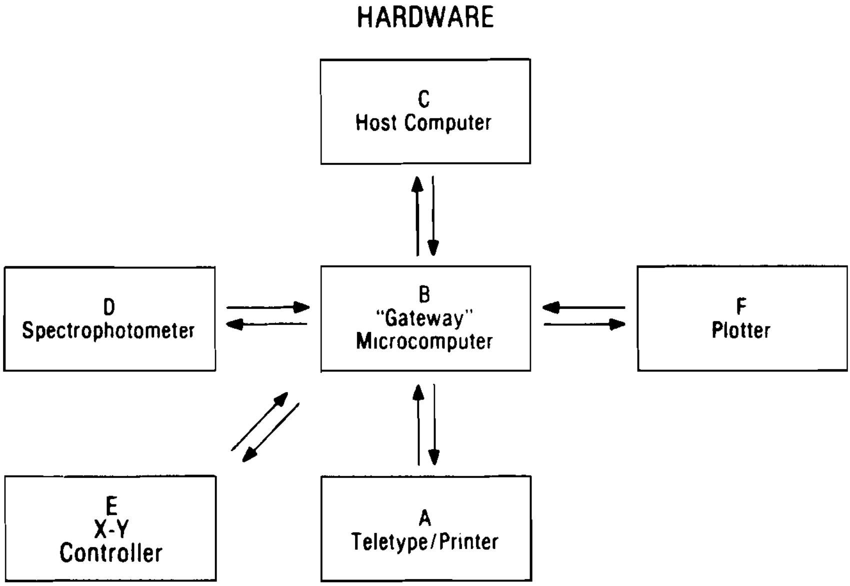


Figure 3. Block diagram of hardware units showing.

Spectrophotometer

The Macbeth MS-4045 spectrophotometer has a pulsed-xenon light source. The sample is positioned 3/8 inch from the port and is illuminated annularly at 45° with a pick-up at 0° angle. Two flashes are needed to read each patch. It makes 16 diffuse reflectance measurements simultaneously throughout the visible spectrum at 20-nm intervals (400, 420,... 680, 700 nm) by means of a spectral analyzer consisting of a diffraction grating with a solid-state silicon array of 16 channels. The bandwidth of each measurement is 10 nm.

From these data a wide range of color specification and densitometry data can be generated. Reflection densities are calculated based on the response of the Macbeth RD514 densitometer, and CLAB color space measurements, discussed later, based on the graphic arts viewing standard, D5000 illumination.

At present, it takes ~30 min to scan the printed target and transmit the measured data and 20 min more to complete an analysis. However, it is expected that these times will be reduced.

Analysis

The cover of the packet, containing the analysis which is returned to the printer, is shown in Figure 4. A description of the results is included and contains much of the material discussed in this paper. Most of the tabular data are shown graphically for easy interpretation.

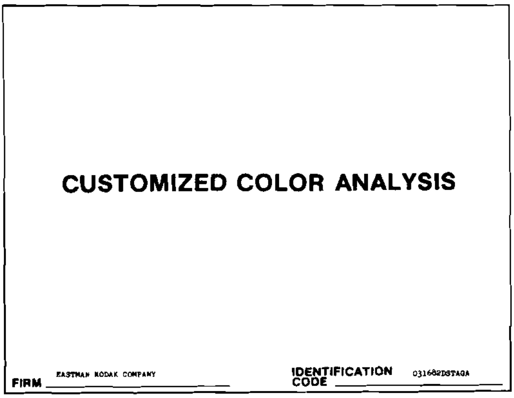


Figure 4. Cover of packet containing results of analysis.

I. Prepress Preparation Category

Halftone Separation Aims - Graph and Tabular Data 1 (Figures 5a and 5b).

The curves in Figure 5a show the required relationship of the 3-color printers for gray balance and for preferred 4-color tone reproduction with the required black printer for the average copy specified. The percent dot areas of the halftone positives are plotted against the density of original.

The principal calculation procedure is to compute the 4-color preferred tone reproduction based on the permissible D-max of the reproduction and type of copy (discussed

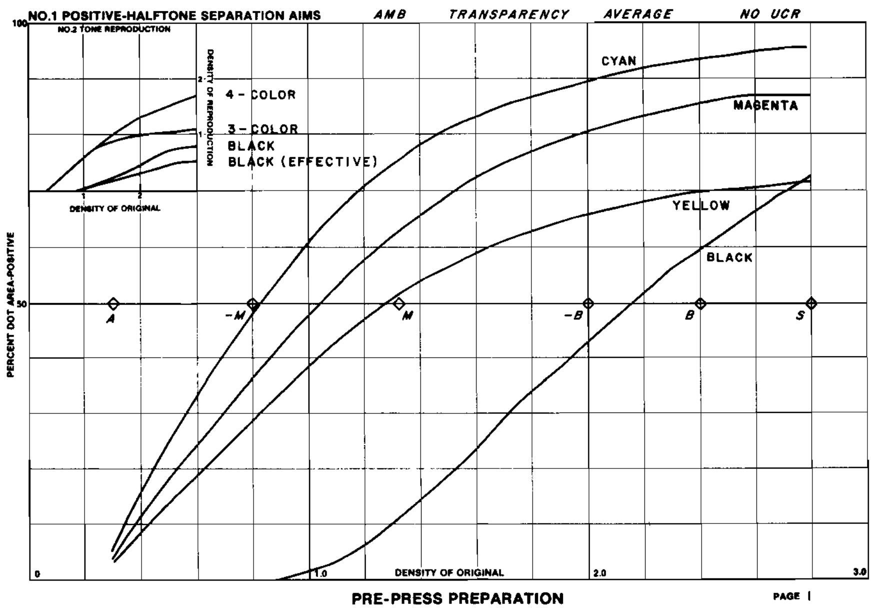


Figure 5a. Graphs 1 and 2. Prepress preparation for average transparent copy and skeleton black printer.

PREPRESS PREPARATION

NO.1 POSITIVE-HALFTONE SEPARATION AIMS

DENSITY OF ORIGINAL	HALFTONE POSITIVE DOT PERCENTAGES			
	CYAN	MAG	YEL	BLK
0.30	5.	3.	3.	0.
0.40	15.	11.	9.	0.
0.50	24.	17.	14.	0.
0.60	33.	24.	19.	0.
0.70	41.	30.	24.	0.
0.80	48.	36.	29.	0.
0.90	55.	42.	34.	0.
1.00	61.	48.	39.	1.
1.10	66.	53.	43.	3.
1.20	71.	58.	47.	7.
1.30	75.	62.	51.	11.
1.40	78.	66.	54.	15.
1.50	81.	69.	56.	20.
1.60	83.	72.	59.	24.
1.70	86.	74.	61.	29.
1.80	87.	77.	63.	34.
1.90	89.	79.	64.	39.
2.00	90.	80.	66.	44.
2.10	91.	82.	67.	48.
2.20	92.	83.	68.	52.
2.30	93.	84.	69.	56.
2.40	94.	85.	70.	60.
2.50	94.	85.	70.	63.
2.60	95.	86.	70.	67.
2.70	95.	86.	71.	70.
2.80	95.	86.	71.	70

NO.2 TONE REPRODUCTION

DENSITY OF REPRODUCTION -4- COLOR	-3- COLOR	EFFECT BLACK	ACTUAL BLACK
0.00	0.00	0.00	0.00
0.09	0.09	0.00	0.00
0.18	0.18	0.00	0.00
0.27	0.27	0.00	0.00
0.36	0.36	0.00	0.00
0.44	0.44	0.00	0.00
0.53	0.53	0.00	0.00
0.61	0.61	0.00	0.01
0.69	0.68	0.02	0.02
0.77	0.74	0.04	0.04
0.85	0.79	0.06	0.07
0.93	0.84	0.09	0.10
1.00	0.88	0.12	0.14
1.07	0.92	0.15	0.19
1.14	0.95	0.18	0.23
1.20	0.98	0.22	0.29
1.26	1.01	0.26	0.34
1.32	1.03	0.29	0.39
1.37	1.04	0.32	0.45
1.42	1.06	0.36	0.51
1.46	1.07	0.39	0.56
1.50	1.08	0.41	0.61
1.53	1.09	0.44	0.66
1.56	1.09	0.46	0.71
1.58	1.10	0.49	0.76
1.58	1.10	0.49	0.76

NO.1 SUMMARY

REFER-ENCE STEP	DENS OF ORIG	AIM DOT PERCENTAGES CYAN	MAG	YEL	SPECIFIED BLACK PRINTER
A	0.30	5.	3.	3.	0.
-M	0.70	41.	30.	24.	0.
M	1.00	61.	48.	39.	1.
-B	2.00	90.	80.	66.	44.
B	2.40	94.	85.	70.	60.

Figure 5b. Tabular data 1 and 2. Corresponds to graphs in Figure 5a.

again later), then the 3-color tone reproduction and the necessary color printers, and finally, the black printer to produce the desired 4-color tone reproduction.

Another technique is to input a desired black printer and then to calculate the color printers. However, this often produced unrealistic separations with reversals in the printer curves and/or negative percent dot areas.

To produce Graph 1, certain specifications had to be inserted into the program, as discussed below:

Control Points - The AMB control points were specified and are marked along the horizontal density-of-original scale. Two intermediate points, -M and -B, are included for setting up a new process, and an S, shadow point, used in the analysis. The new HPS/TR control points could have been specified and would then have been designated instead of the AMB points. Table I lists the control points for each system. The AMB points have been used for years with good success and will continue to have many applications. They have been updated for this analysis application as shown in Table I. The HPS/TR system was introduced with the Kodak Q-700 Data Center Direct Screen Program, primarily to simplify making tone-reproduction changes for different copy.

Table I. Control Point Densities

	AMB						HPS/TR				
Copy	A	-M	M	-B	B	S	H	-P	P	-S	S
Transparent (average and low key)	0.3*	0.6	1.3	2.0	2.4	2.8	0.3	0.6	1.0	2.0	2.8
Transparent (high key)	0.3	0.6	1.3	2.0	---	2.5	0.3	0.6	1.0	---	2.5
Reflection** (average and low key)	0.1	0.4	0.7	1.3	1.6	1.8	0.1	0.4	0.7	1.3	1.8
Reflection (high key)	0.1	0.4	0.7	1.3	---	1.5	0.1	0.4	0.7	---	1.5

*The old A control point was 0.4. It has been changed to 0.3, which better reflects the average highlight in transparencies today.

**The AMB reflection control points have been changed to better correspond to today's procedures in zeroing reflection densitometers with manufacturers' plaques and in the higher maximum densities of reflective copy.

Gray Balance - The gray balance is calculated from the highlight to shadow near-neutral patches in the target by a mathematical least squares method. It is not necessary to have actual neutral patches as was the case with previous gray balance test objects. In figure 5a a scanner process was specified, so the three separations at any point on the density-of-original scale will produce a gray or a neutral. However, the gray balance has been biased, in the extreme highlight, towards the color of the paper: $a^* = 0.1$ and $b^* = 3.0$ in the CLAB notation discussed later. If a photographic process had been specified, an additional bias would have been applied from a neutral middletone to a brown color in the S step: $a^* = 3.0$ and $b^* = 3.0$. The brown bias is desirable for a photographic process for proper color balance and to ensure that the magenta and yellow inks print with sufficient color strengths for the saturated colors.

Preferred Tone Reproduction - The curves in Figure 5a are for average copy taking into account the 4-color maximum density of the printed target and the shadow dot area specifications of the cyan and black printers at the S-step. For the calculations, the densities of the original and the reproduction are converted to darkness by the simplified Bartleson-Breneman equation:

$$D_K = 116 - C1[10^{(2-D)} + C2]^{C3}$$

where D_K = darkness (darkness = 100 - L**, where L** = lightness)

D = density

and $C1 = 11.5$, $C2 = 1$ and $C3 = 0.5$

These later coefficients are for viewing the original and the reproduction with light surrounds; they can be altered independently for other types of surrounds. By use of a linear relationship between the darkness of the original and darkness of the reproduction, a uniform visual tone compression is obtained in the reproduction. For high-key copy, a nonlinear relationship is used. It is adjusted to give an increase in highlight contrast and lower shadow contrast than for average copy. For low-key copy, the adjustment is reversed to produce a decrease in highlight contrast and an increase in shadow contrast.

Black Printer - For Figure 5a the normal skeleton, or one-half scale black printer, was specified (start 0.9 above the highlight with an S-step of 70%). Other black printers are discussed later for comparison.

The tabular data in Figure 5b correspond to the separation curves in Figure 5a. The dot areas for the control points are summarized in a small table for easy reference.

Tone Reproduction - Graph and Tabular Data 2 (Figures 5a and 5b).

This is the small graph inserted in Graph 1. The tone reproduction here is plotted in terms of familiar density terms. The density-of-original is plotted vs the density-of-reproduction for 4-color, 3-color, actual black over paper, and effective black over the color inks; the latter is used to calculate the black printer. The difference between the two blacks is due to optical properties and the trapping of the black ink over the color inks. The 4-color densities are equal to the corresponding 3-color plus the effective black densities. The graph is useful in comparing the blacks and observing where the effective black begins to shoulder. A heavier black beyond this point usually adds little to increase the maximum density of the reproduction. Incidentally, for this reason a black progressive printed on paper can be misleading in judging the effect of the black printer. Figure 5b contains tabular data corresponding to Graph 2.

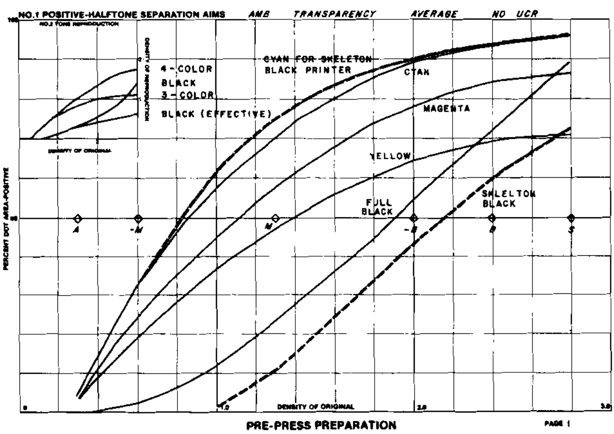


Figure 6. Graphs 1 and 2. Conditions the same as for Figure 5a but with full black printer.

In Figure 6, a full black printer was specified rather than the skeleton black used for Figure 5a. The color printers have been changed (only the effect on the cyan is shown), but the 4-color tone reproduction curve in Graph 2 is affected only slightly.

The effect on the cyan and black printers of different tone reproductions for high-key, average, and low-key copy are shown in Figure 7. The curve for average copy is the same as in Figure 6. When an actual analysis is made, the magenta and yellow printers are plotted as well. Graph 2 shows the difference in the 4-color tone-reproduction curves.

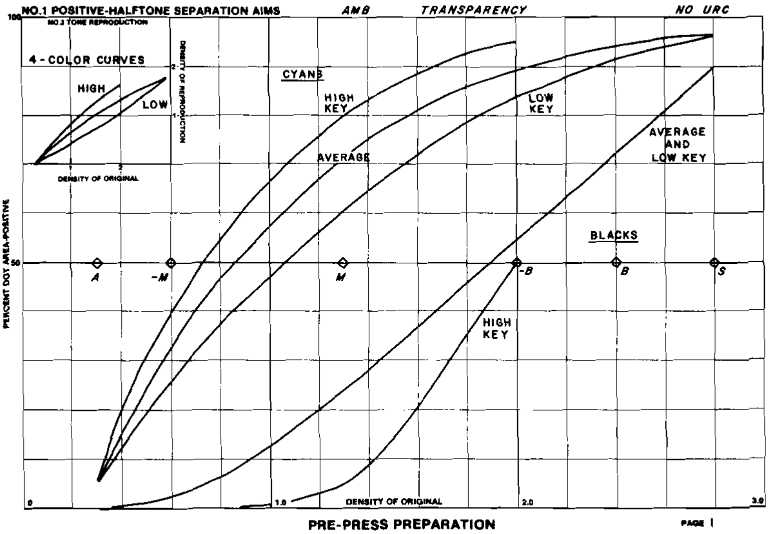


Figure 7. Graphs 1 and 2. Comparison of cyan and black printers for high-key, average, and low-key etc.

Undercolor Removal (UCR)

UCR is defined as the removal of some of the normal 3-color inks, which contribute a neutral component to the colors, and replacing them with black ink. This is desirable to reduce ink costs and prevent printing problems.

Graphs 1 and 2 in Figure 8a and the tabular data 1 and 2 in Figure 8b give the results of an analysis for undercolor removal. These results should be compared with the results in Figure 6 with no undercolor removal. The 4-color tone-reproduction curves are very similar; only the maximum density of the UCR reproduction is slightly lower.

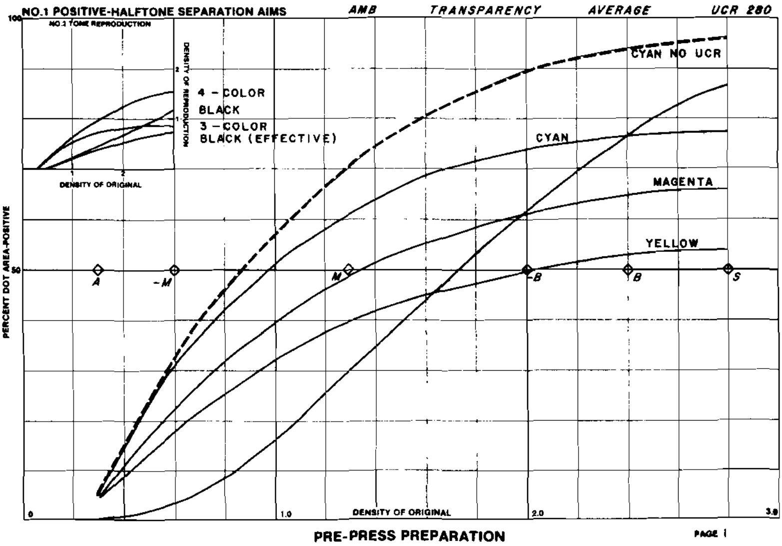


Figure 8a. Graphs 1 and 2. UCR Analysis. Compare with Figure 6.

PREPRESS PREPARATION

NO. 1 POSITIVE-HALFTONE SEPARATION AIMS — NO. 2 TONE REPRODUCTION

DENSITY OF ORIGINAL	HALFTONE POSITIVE DOT PERCENTAGES CYAN	MAG	YEL	BLK	DENSITY OF REPRODUCTION -4- COLOR	-3- COLOR	EFFECT BLACK	ACTUAL BLACK
0.30	5.	3.	3.	0.	0.00	0.00	0.00	0.00
0.40	15.	11.	9.	0.	0.09	0.09	0.00	0.00
0.50	23.	17.	14.	1.	0.18	0.17	0.00	0.00
0.60	31.	22.	18.	3.	0.26	0.25	0.02	0.02
0.70	37.	27.	22.	6.	0.35	0.32	0.03	0.03
0.80	42.	32.	25.	9.	0.43	0.38	0.06	0.06
0.90	47.	35.	29.	13.	0.52	0.43	0.08	0.09
1.00	51.	39.	32.	17.	0.60	0.48	0.11	0.12
1.10	55.	42.	34.	22.	0.68	0.53	0.15	0.16
1.20	58.	45.	37.	26.	0.75	0.57	0.18	0.21
1.30	61.	48.	39.	31.	0.83	0.61	0.22	0.25
1.40	64.	51.	41.	36.	0.90	0.64	0.26	0.30
1.50	66.	53.	43.	40.	0.97	0.67	0.30	0.36
1.60	68.	55.	44.	45.	1.03	0.70	0.34	0.41
1.70	69.	56.	46.	49.	1.09	0.72	2.38	0.47
1.80	71.	58.	47.	54.	1.15	0.74	0.41	0.53
1.90	72.	59.	48.	58.	1.21	0.76	0.45	0.59
2.00	73.	61.	49.	62.	1.26	0.77	0.49	0.65
2.10	74.	62.	50.	66.	1.31	0.79	0.52	0.71
2.20	75.	62.	51.	70.	1.35	0.80	0.55	0.76
2.30	76.	63.	52.	74.	1.39	0.81	0.58	0.82
2.40	76.	64.	52.	77.	1.42	0.82	0.60	0.87
2.50	77.	64.	52.	80.	1.45	0.82	0.63	0.92
2.60	77.	65.	53.	82.	1.47	0.83	0.65	0.96
2.70	77.	65.	53.	85.	1.50	0.83	0.67	1.01
2.80	77.	65.	53.	85.	1.50	0.83	0.67	1.01

NO. 1 SUMMARY

REFER-ENCE STEP	DENS OF ORIG	AIM DOT PERCENTAGES CYAN	MAG	YEL	SPECIFIED BLACK PRINTER
A	0.30	5.	3.	3.	0.
-M	0.70	37.	27.	22.	6.
M	1.00	51.	39.	32.	17.
-B	2.00	73.	61.	49.	62.
B	2.40	76.	64.	52.	77.

Figure 8b. Tabular data 1 and 2. Corresponds to graphs.

For the UCR analysis, a UCR of 280% and an 85% black dot at the S control point were specified. The 280% is the SWOP (Standard Web Offset Publications) standard and means that the total of the dot areas in the four printers at S should equal 280%. (For example, in Figure 8b: 77 cyan, 65 magenta, 53 yellow, and 85, the specified black.) A potential 400% can be printed, but the normal without any UCR is 337% for the conditions in Figure 6. The normal will vary, depending on gray balance and the amount of black specified in the shadows.

The program calculation procedure for UCR is:

1. The dot areas of the color printers at S are calculated for the specified total of 280% with proper gray-balance requirements. The gray balance is never biased for UCR, even for the photographic process.

2. Four-color and three-color darkness values at step S are determined.

3. Then, 4-color and 3-color tone-reproduction curves are calculated. The 3-color is uniquely determined to have the correct shadow contrast and a smooth transition into the 4-color curve in the highlights.

4. Finally, the black printer is calculated so the 3-color and effective black will equal the 4-color.

This is a sophisticated procedure and represents, for the first time in graphic arts, an ability to calculate the requirements for UCR without resorting to trial and error. The tabular data corresponding to Figure 8a are given in Figure 8b.

II. Ink/Press Performance Category

Densities of Solid Patches - Graph and Tabular Data 3 (Figures 9a and 9b).

Solid ink densities are calculated from the spectrophotometric data both as conventional reflection and as the new SPI densities (spectrophotometric process ink densities). Conventional densities are ~40-nm red, green, and blue broadband filter measurements; the SPI densities are 20-nm narrowband filter measurements at 657, 527, and 440 nm. All calculated densities listed in Figure 9b agree well with average Macbeth instrument readings.

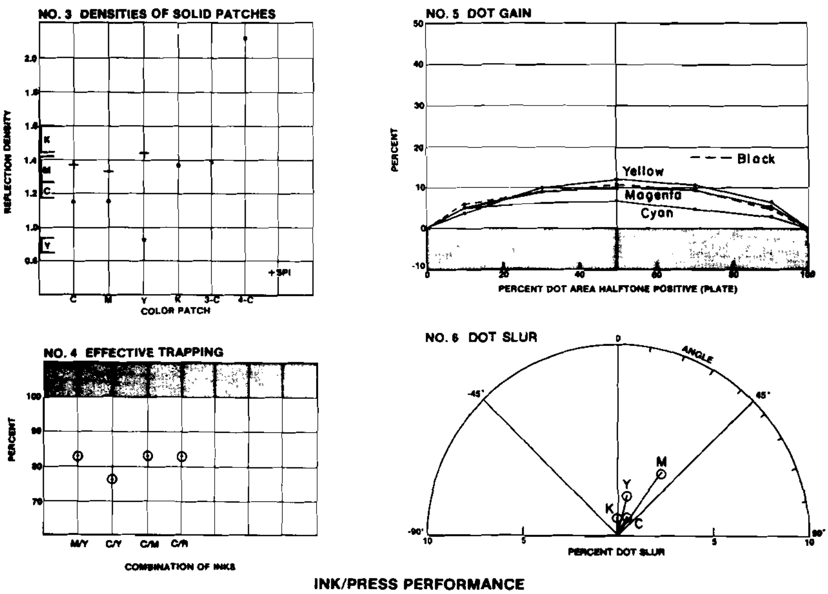


Figure 9a. Graphs 3, 4, 5 and 6. Ink/press performance.

INK/PRESS PERFORMANCE

NO. 3 REFLECTION DENSITIES OF SOLID PATCHES

PATCH	CONVENTIONAL DENSITIES PRINCIPAL PLANT	PRINCIPAL ANALYSIS	3-FILTER ANALYSIS BLU	GRN	RED	SPI DENSITIES PRINCIPAL PLANT	PRINCIPAL ANALYSIS	TARGET PATCHES
C	1.26	1.29	0.18	0.40	1.29	1.28	1.28	K
M	1.11	1.12	0.67	1.12	0.15	1.33	1.34	M
Y	1.05	1.04	1.04	0.13	0.06	1.42	1.42	R
R			1.46	1.10	0.15			Y
G			1.09	0.42	1.03			G
V			0.74	1.37	1.18			C
								V
W	.04	0.05(VIS)	0.07	0.05	0.05		-	W
K	1.30	1.30(VIS)	-	-	-		-	3-C
3-C	1.35	1.34(VIS)	1.58	1.34	1.17		-	4-C
4-C	1.92	1.93(VIS)	2.04	1.93	1.85		-	

NO. 4 EFFECTIVE TRAPPING FOR SOLID PATCHES

POSITION	PERCENT
M OVER Y	82.9
C OVER Y	77.0
C OVER M	83.4
C OVER R	82.6

NO. 5 DOT GAIN

HALFTONE DOT(POS)	CYAN	MAG	YEL	BLK
10.	5.	5.	4.	6.
30.	6.	9.	10.	9.
50.	7.	10.	12.	11.
70.	5.	9.	11.	9.
90.	3.	5.	7.	6.

NO. 6 DOT SLUR

	PERCENT	ANGLE
CYAN	1.	26.
MAG	4.	36.
YEL	2.	13.
BLK	1.	-3.

Figure 9b. Tabular data 3, 4, 5 and 6. Corresponds to graphs in Figure 9a.

The principal conventional reflection and SPI densities calculated from the analysis are plotted in Graph 3 (Figure 9a). SWOP standard conventional reflection density tolerances are indicated on the vertical scale for reference. These tolerances were obtained from SWOP Hi/Lo standard ink patches, by measuring with the spectrophotometer and using the same calculation procedure as used to obtain other target densities. Only the yellow ink is in tolerance; the others are too low.

Because reflection color densitometers may vary considerably, a set of solid ink patches from the target analyzed is returned to the printer (see Figure 9b); he can then read them with his densitometer and thus relate his readings to those of the analysis. SPI densitometers are designed to have little variation among instruments, but they can be checked as well with the returned patches.

Table II lists the average conventional and SPI densities from the measurements of Hi/Lo SWOP standard ink patches. Note that the magenta measures higher than the cyan for these web offset standards. For commercial sheet-fed printing where SWOP standards may not be used, the reverse is often the case, as shown in a typical example in Table III. The difference in these sets reflects the inks, paper, and trapping differences in the processes. There has been little published on the correct solid ink densities for a given set of inks and paper. It is hoped that with more experience from customized color analyses that the differences in ink sets and solid ink densities will be better understood, which may then lead to a calculation of the optimum densities along with new prepress requirements.

<u>Effective Trapping - Graph and Tabular Data 4 (Figure 9a and 9b)</u>.

The SPI densities of the solid density patches are used for the trapping measurements. The patches in terms of the "combination of inks", such as M/Y (magenta over yellow), are shown along the horizontal scale. The percentage of the second ink over the first ink compared with over paper alone is plotted on the vertical scale. For example, an 80% effective trapping (undertrapping) of a magenta ink printed over a yellow ink to produce a red means that there is a "visual response" loss of 20% in the magenta ink when printed over yellow, compared to being printed over paper. Therefore, we can state that the magenta ink is only 80% effective when printed over yellow.

Table II. SWOP Average Standard Solid Ink Reflection Densities from the Analyses.

	Conventional	SPI
cyan	1.20	1.39
magenta	1.30	1.56
yellow	0.90	1.29

Table III. Typical Solid Ink Conventional Densities for Sheet-Fed Printing

cyan	1.35
magenta	1.25
yellow	0.90
black	1.50

The term "visual response" used above is not strictly correct because the measurements are densitometric measurements, which only approximate the visual response of the standard observer. The loss of 20% is due to optical and physical properties: optical, in that the second ink is not completely transparent, and the gloss of the ink may be altered; physical, in that the second ink usually does not adhere as well to the first ink as to the paper. Occasionally, however, the adhesion properties are reversed and what is called overtrapping occurs--greater than 100%.

This densitometric measurement is good for comparison and quality control, for assessing a change in color correction needed in terms of percent dot area, and for making changes in the solid ink densities. The latter two can best be done with a subjective measurement made with density measurements rather than one which might relate better to actual ink-film thickness. However, one improvement in the accuracy of the conventional density measurement would be to compensate for surface reflection; ink densities are not rigorously additive in the double ink layer as conventionally assumed.

Data from the analysis are available to calculate effective trapping of one tint over another. This is a future possibility. The hue shift caused by trapping and any effect on gloss can be evaluated further by means of the color triangle graph discussed later.

Dot Gain Graph and Tabular Data 5 (Figure 9a and 9b).

Dot gain is the percentage increase of the dot in the printing plate when printed onto paper. There are two main reasons for dot gain: growth, a uniform enlargement of the printed dot because of pressure and ink spreading, and slur, a distortion in the shape of the printed dot caused by tensions and dot doubling, a multiple impression.

Dot gain is measured at five dot sizes in the analysis: 10, 30, 50, 70, and 90%. The conventional method is used. The reflection density of a tint is compared with a corresponding solid ink density using the well-known Yule-Nielson equation. The density of the tint without dot gain is assumed to be predictable, so any deviation is attributed to dot gain. SPI densities are used for maximum accuracy. However, the method assumes a number of optical properties which always produce some error, and it would be more accurate to call it an "effective dot gain" measurement. Three assumptions are:

1. That the density within each dot in the tint is perfectly uniform and equal to the density of the solid.

2. That the light which enters the paper between the dots, and which is scattered and partially trapped, is perfectly compensated for by the average "n" factor of 1.70 used in the equation.

3. That the dot area in the halftone corresponds exactly to the dot in the printing plates. Usually, there is little change in the plate dot due to exposure of the halftone. However, any change in the plate dot is included in the dot gain measurement. Therefore, any plate dot decrease minimizes press dot gain and vice versa. In fact, if the decrease of the plate dot should be greater than the dot gain of the press, the dot gain measurement would be

negative. Provisions for graphing the latter, if it should occur, have been given in Graph 5a.

We believe that the above assumptions, both optical and physical, usually cause small errors and remain fairly constant, having a small effect on the measurement's use for comparison and quality control.

Dot Slur - Graph and Tabular Data 6 (Figure 9a and 9b).

Dot slur is a distortion of the shape of the dots; it can be caused by dot doubling from the blanket as well as by a smear of the dot on the paper. The PIE graph shows the percent dot increase due to slur of the 50% dot and direction of the slur. A slur greater than 3% in any direction will be detected throughout a press run. The magenta at 4% is outside this tolerance.

It is important to know slur at the time of the analysis, even though its nature is to vary in cyclical patterns on the press, because of tensions. If the measured value is excessive, the analysis should be discarded and the test repeated after the cause is corrected. Slur can be judged throughout the printing run visually by observing the concentric circle patches in the target.

The measurement is made by comparing the densities in three parallel-line patches printed with the same ink. In each patch the lines run at different angles to the gripper bar (30°, 90°, and 120°). Any density difference in the patches is due to slur, because any "dot gain" of the parallel lines is assumed to be independent of direction.

If slur cannot be eliminated entirely, it is possible to pick two samples from a press run with maximum and minimum slur and average the results. Another possibility is to calculate the average results from one analysis, knowing the slur at the time of analysis and the degree of slur throughout the run by other means.

III. Color Measurement Category

Spectrophotometric Curves - Graph and Tabular Data 7 (Figure 10 and 11b).

The curves in Figure 10 show density vs wavelength for each ink, their overlaps, paper, black, 3-color, and 4-color. They characterize the inks and provide an excellent

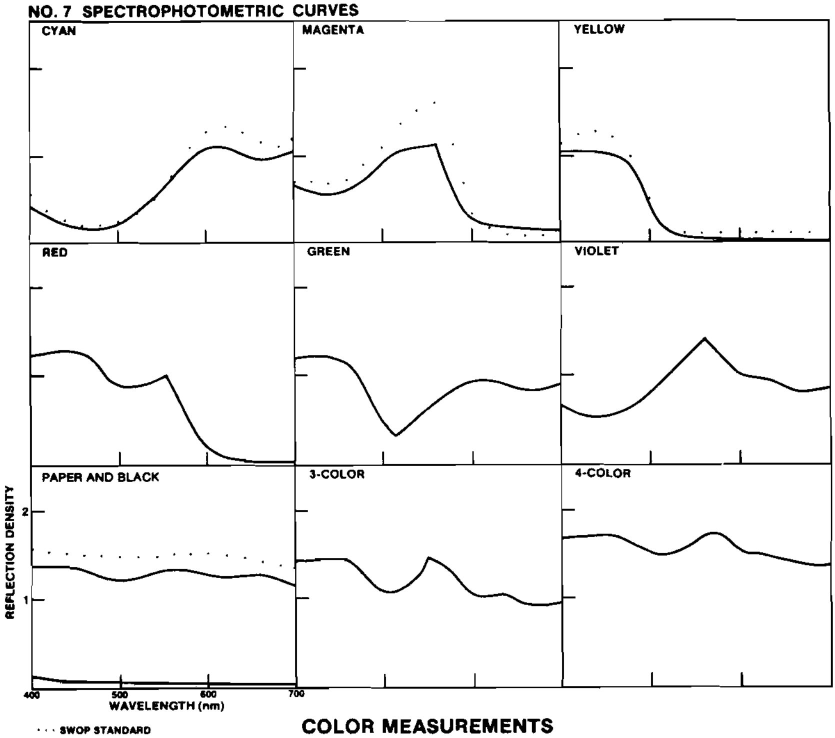


Figure 10. Graph 7. Color measurements. Spectrophotometric curves.

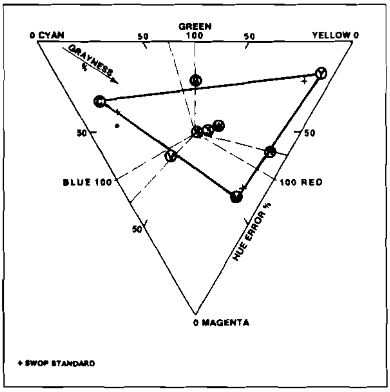
tool for quality control of raw materials and for comparison with standards. Thus, SWOP spectrophotometric average curves from Hi/Lo patches are plotted with dotted curves for comparison. The corresponding tabular data are in Figure 11b.

Color Triangle - Graph and Tabular Data 8 (Figures 11a and 11b).

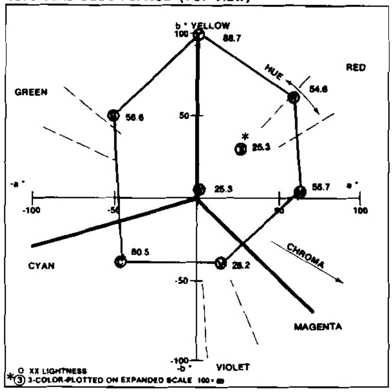
The color triangle is a color space representation that has been found useful in graphic arts, even though it is not a "standard system", since it is based on densitometry which has not been consistent in the trade. However, the measurements and calculations of the analyses are consistent, which makes the color triangle even more useful.

Hue and grayness are computed from densitometry of solid ink patches. Subtractive primary inks with no hue error or grayness, both 0% (ideal inks and suitable filter

NO.8 COLOR TRIANGLE



NO. 9 CLAB COLOR SPACE (TOP VIEW)



COLOR MEASUREMENTS

Figure 11a. Graphs 8 and 9. Color measurements - color triangle and CLAB color space.

COLOR MEASUREMENTS

NO. 7 SPECTROPHOTOMETRIC DATA (NANOMETERS/DENSITY)

WAVELENGTH	C	M	Y	R	G	V	K	W	3-C	4-C
400	0.57	0.71	1.28	1.51	1.42	0.90	1.34	0.26	1.66	2.10
420	0.32	0.60	1.33	1.57	1.42	0.72	1.28	0.11	1.70	2.10
440	0.20	0.56	1.34	1.59	1.42	0.64	1.27	0.07	1.70	2.10
460	0.15	0.61	1.29	1.57	1.36	0.67	1.25	0.07	1.66	2.10
480	0.15	0.77	1.10	1.47	1.13	0.83	1.24	0.06	1.66	2.05
500	0.18	0.91	0.55	1.15	0.59	1.00	1.24	0.06	1.22	1.85
520	0.28	1.14	0.14	1.07	0.29	1.28	1.25	0.06	1.17	1.82
540	0.44	1.22	0.09	1.13	0.38	1.47	1.27	0.06	1.31	1.92
560	0.75	1.31	0.07	1.26	0.61	1.75	1.28	0.06	1.62	2.16
580	1.08	0.86	0.06	0.83	0.86	1.57	1.29	0.06	1.50	2.10
600	1.28	0.23	0.06	0.22	1.02	1.21	1.28	0.05	1.16	1.85
620	1.34	0.09	0.06	0.09	1.08	1.19	1.27	0.05	1.15	1.82
640	1.29	0.06	0.05	0.07	1.05	1.14	1.25	0.04	1.11	1.80
660	1.15	0.06	0.05	0.06	0.93	1.01	1.22	0.04	0.99	1.68
680	1.12	0.06	0.05	0.06	0.91	0.98	1.18	0.04	0.96	1.64
700	1.21	0.05	0.05	0.06	0.98	1.07	1.14	0.04	1.04	1.68

NO. 8 COLOR TRIANGLE / NO. 9 CIELAB COORDINATES

	PERCENT HUE	PERCENT GRAYNESS	PERCENT EFFICIENCY	L*	a*	b*	CHROMA	HUE ANGLE
C	19.8	14.3	.78	60.5	-44.0	-41.1	44.2	227.0
M	53.2	13.0	.63	55.7	63.2	0.3	63.2	89.7
Y	7.6	5.5	.82	88.7	3.2	96.3	96.3	1.9
R	72.2	9.1		54.6	59.4	59.2	83.9	45.1
G	91.2	38.1		56.6	-50.9	45.8	45.8	312.0
V	70.1	54.2		28.2	16.4	-40.3	43.5	157.9
W	28.9	64.3		95.3	0.1	3.0	3.0	1.9
K	-	-		-	-	-	-	-
3-C	40.6	73.9		25.3	2.8	14.3	14.6	11.1
4-C	44.4	90.4		10.0	0.4	3.8	3.8	6.0

Figure 11b. Tabular data 7, 8, and 9. Corresponds to Figures 10 and 11a.

response measurements), would plot at the apexes of the triangle. All neutrals with 100% grayness plot at the center of the triangle. Plots of real inks can be judged for their hue and grayness and compared with standards. A line drawn between the subtractive ink primaries defines the gamut triangle of the ink set. One advantage this graph has over other diagrams for graphic arts is that the parameters are not very sensitive to the solid ink density levels. Other features of the triangle are:

1. The overlap colors, or secondaries, should plot on straight lines between primaries and preferably, especially for the photographic process, in the tolerance dotted line areas. In this latter respect, there is more leeway in a scanner process, because the color correction and gray balance are not dependent on each other and can be adjusted separately. Overlaps that plot outside of the solid line connecting the primaries (away from the center), show an increase in gloss with an improvement of grayness; a plot inside of the solid line shows the reverse.

2. The SWOP standards averaged from Hi/Lo patches are plotted for comparison (see crosses).

3. If the overlaps do not plot correctly, the color balance of the reproduction must be corrected by solid ink density changes, color correction adjustments, and/or tone reproduction. It is hoped that the customized color measurements will give more insight into these variables.

The tabular data 8 for the color triangle measurements (Figure 11b) include percent efficiency data. The efficiency of a process color ink is a measure of how well the ink reflects and absorbs the proper wavelengths of light, which affects the color gamut it will produce when used with the other inks. With experience, the efficiency ratings can be related to the ability of a set of inks to produce certain hues. Yellow inks always have the highest efficiencies, close to 100%. An efficiency of 60% for any ink is poor.

<u>CLAB Color Space - Graph and Tabular Data 9 (Figure 11a and 11b)</u>.

This color space is sometimes referred to as the 1976 C.I.E. LAB L*a*b* system, because in that year it was standardized by the International Commission on Illumination. It relates very well to visual response and is well suited to graphic arts applications. For the analysis the conventional labelling has been modified. Normally, the horizontal axis is labelled -a* = green and a* = red. For graphic arts use, three axes have been added to designate the hues of "ideal block cyan, magenta, and yellow inks. (The yellow corresponds to the normal vertical axis.) The block inks used absorb at 400-500, 500-600, and 600-700 nm with densities of 1.30. For simplicity, the axes are drawn straight from single CLAB points to the center. The lines would curve slightly if the densities were varied and if more than one point were used to define each line. The normal positions of the overlaps have been designated, and tolerances (dotted lines) have been suggested for the hue of the overlaps corresponding to the tolerances for the color triangle.

Since this color space is three-dimensional, the "lightness" values of the colors are written beside the plotted points. The reference white, $BaSO_4$, has a lightness value of 100. It would plot on an axis projecting out of the paper from the intersection of the two axes. Unlike the color triangle, the straight lines drawn between the plotted points do not define the color gamut. More intermediate points would reveal the gamut to be larger.

Data points here are calculated from the D5000 spectrophotometric data. At present, the use of this color space could be the documentation for quality control purposes, comparison with standard inks, and generally becoming familiar with a potential powerful evaluation tool for comparing a reproduction with the original, adjusting color and tone correction, and quality control of printed colors.

Many industries have long been using this and other C.I.E. standard color spaces for control and to communicate in a standard color language in applications such as the manufacture of paints, clothing, and ceramics. Graphic arts is one of the last large industries using color that has not adopted a standard for routine use, probably because of the complexity of the application. However, this complexity also creates a greater need.

IV. Color Rendition Category

A fourth category of obvious interest would be to define the customized aims for the color tone scales and color correction requirements. This is possible in principle but has not been included in the present analysis.

Application Results

About 150 analyses have been made to date for various experiments. They have proven the consistency and reliability of the system. The spectrophotometric measurements, calculated densities, and color space coordinates have been compared with those made by other accepted instruments, and the agreement is excellent in all cases. Some interesting applications and results follow:

1. The aim and achieved 4-color tone reproduction curves are shown in Figure 12 for a typical analysis printed result. Darkness values of the original and the reproduction, discussed earlier, are plotted in this graph. The agreement is good. A slight error in the extreme highlights was caused by the color of the paper, which has now been corrected by biasing the gray balance. Gray-balance results at three control points are given in terms of CLAB coordinates and are within acceptable tolerances. There is no simpler or better method to obtain prepress preparation aims for various amounts of UCR.

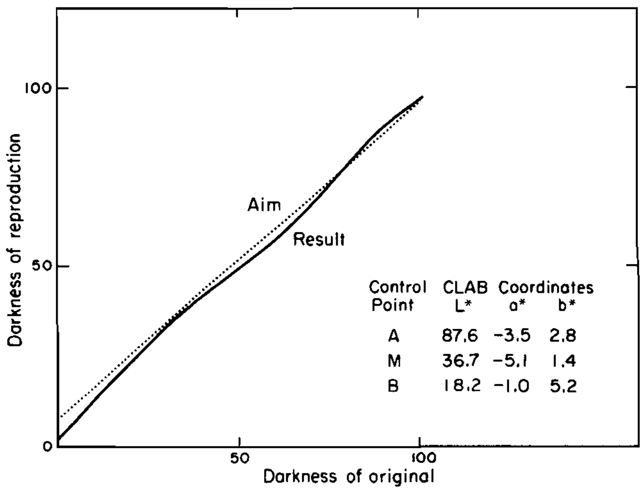


Figure 12. Typical tone reproduction and gray balance results.

2. Good success has been obtained with analysis for flexography printing. Figures 13a and 13b show results from an analysis which revealed press problems that had to be corrected. Excessive dot gain is shown in

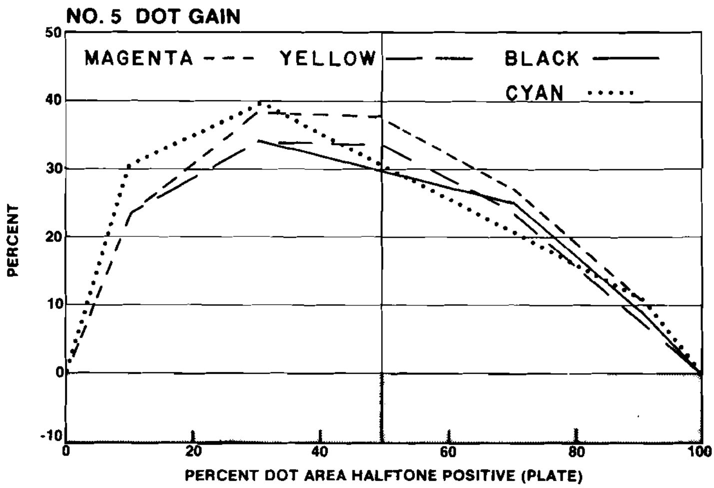


Figure 13a. Graph 5. Dot gain for flexography.

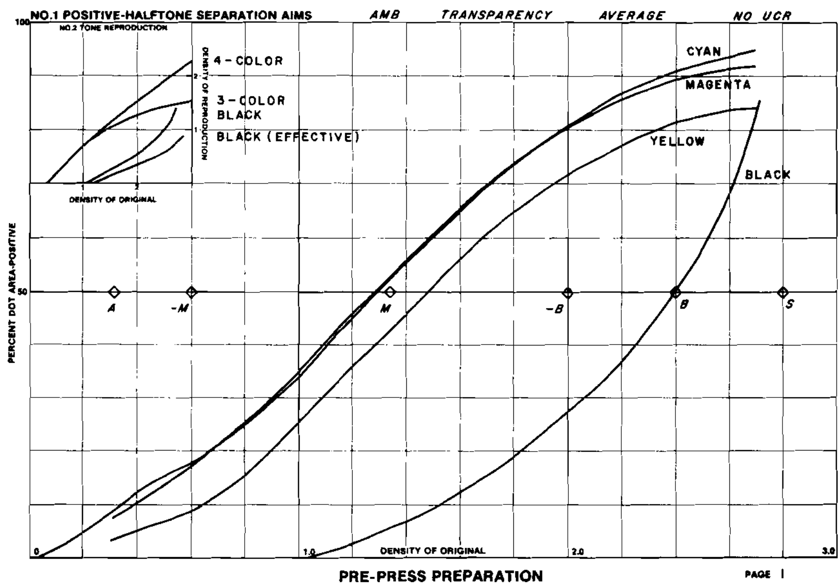


Figure 13b. Graph 1 and 2 for flexography printing onto an opaque white plastic substrate.

Figure 13a, which would not be practical to control at that level. The substrate was an opaque white plastic which permitted a high 4-color maximum density. The amount of magenta and cyan required for gray balance is the same as shown in Figure 13b, and the low highlight contrast required in the separations is caused by the excessive dot gain. The black printer required has an interesting curve shape.

3. The wide variation in solid ink densities and the resulting variation in percent dot area requirements for proper gray balance and tone reproduction are given in Table IV from 25 experimental analyses picked at random. The wide variation shows the need for customized analyses.

4. Analyses were made using two types of proofing papers and one type of production paper to see which proofing paper best matches a production paper. This was for web-offset publication printing; the experiments were done in cooperation with the Graphic Communication Association (GCA). Figure 14 shows the results and usefulness of the CLAB diagram. A new Appleton GCA proofing paper matched the production Groundwood paper better in color gamut, chroma, and lightness than the present proofing paper, Fortune Gloss. The press proof on Fortune Gloss is too good and not representative of production.

Table IV. Variation in Solid Ink Densities and Halftone Requirements from 25 Analyses.

	Cyan	Magenta	Yellow	Black	3-Color
Solid Ink Density	0.98-1.50	0.70-147	0.53-1.03	0.93-1.99	1.35-2.06
Percent Dot Area at M Step	66-83	61-77	44-72	---	---

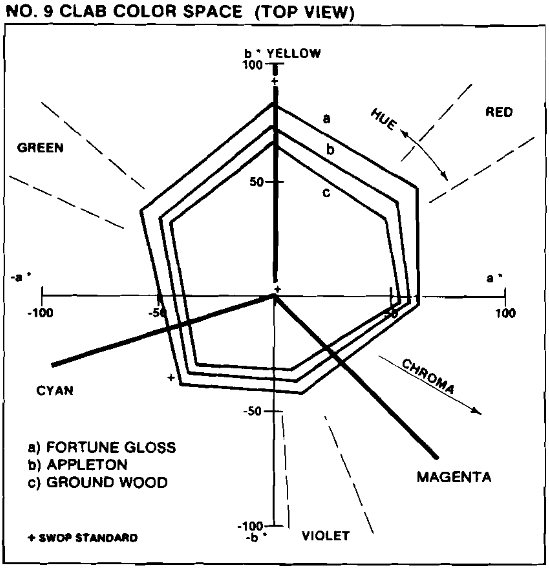


Figure 14. CLAB plot comparing two proof papers, (a) Fortune Gloss and (b) Appleton, with a production paper, (c) Groundwood for web-offset printing.

5. In another experiment with GCA, analyses were made and compared from press proofs from seven service houses, one production printing, and a Cromalin proof. Results are summarized in Figures 15a and 15b.

The solid ink densities are generally below the SWOP tolerances that applied. The Cromalin proof was better in this respect. The hue error of the inks was more consistent than of the overlaps; the violet is particularly poor, mainly because of trapping and dot gain. These are all problems that the analyses revealed and which can be monitored for improvement. The production press (16) shows more trapping (Figure 15b) than the proof presses. Dot gains for the various presses vary considerably, averaging about 8%. This suggests that for a better match, the trapping and possibly the dot gain should be made poorer on the proof presses. The percent dot areas for gray balance in the midtones for presses 11 and 13 vary considerably.

This experiment shows how the analysis can be used to compare press performances and prepress proofs, to help solve interplant problems.

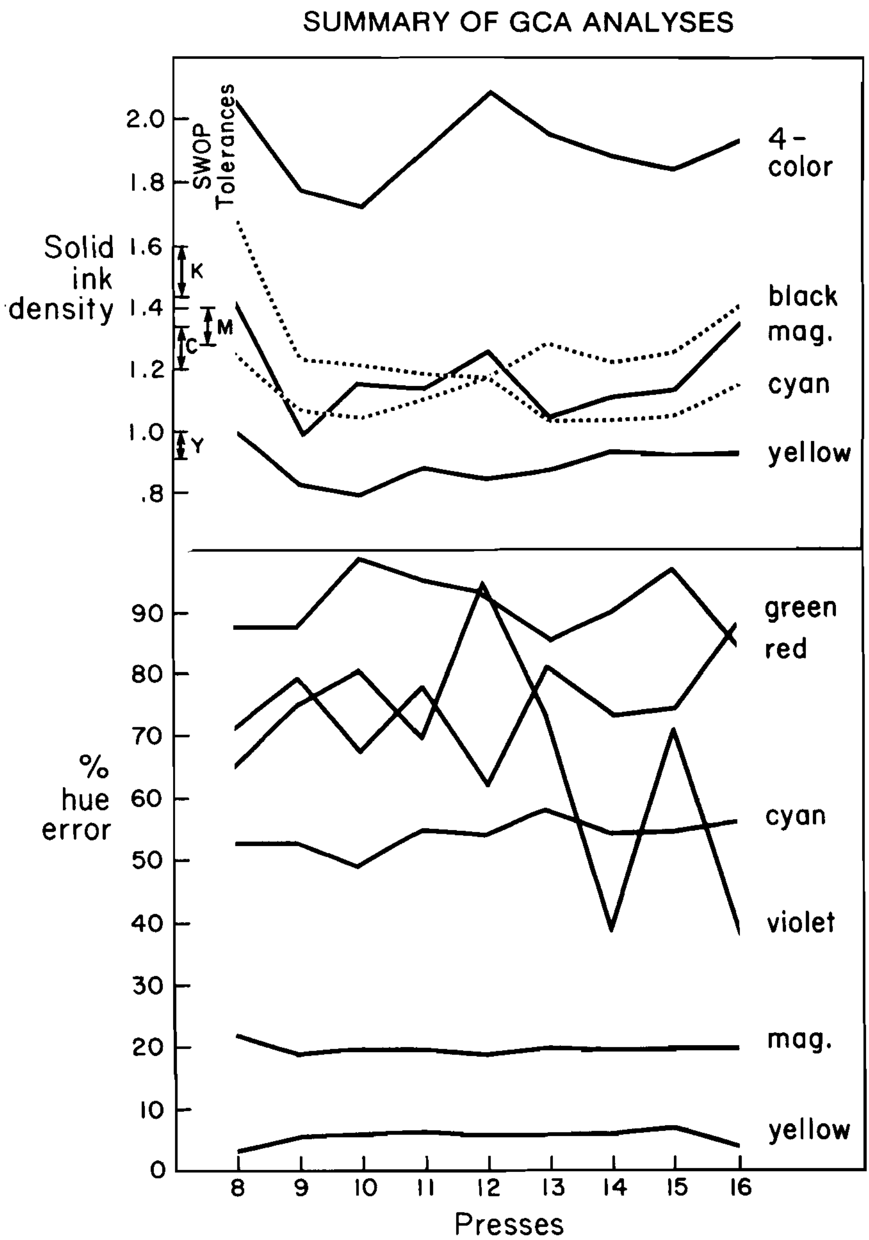


Figure 15a. Summary of GCA analysis of web-offset press proofs from 7 service houses (Presses 9, 10, 11, 12, 13, 14 and 15), a production plant (16), and a service house Cromalin proof (8).

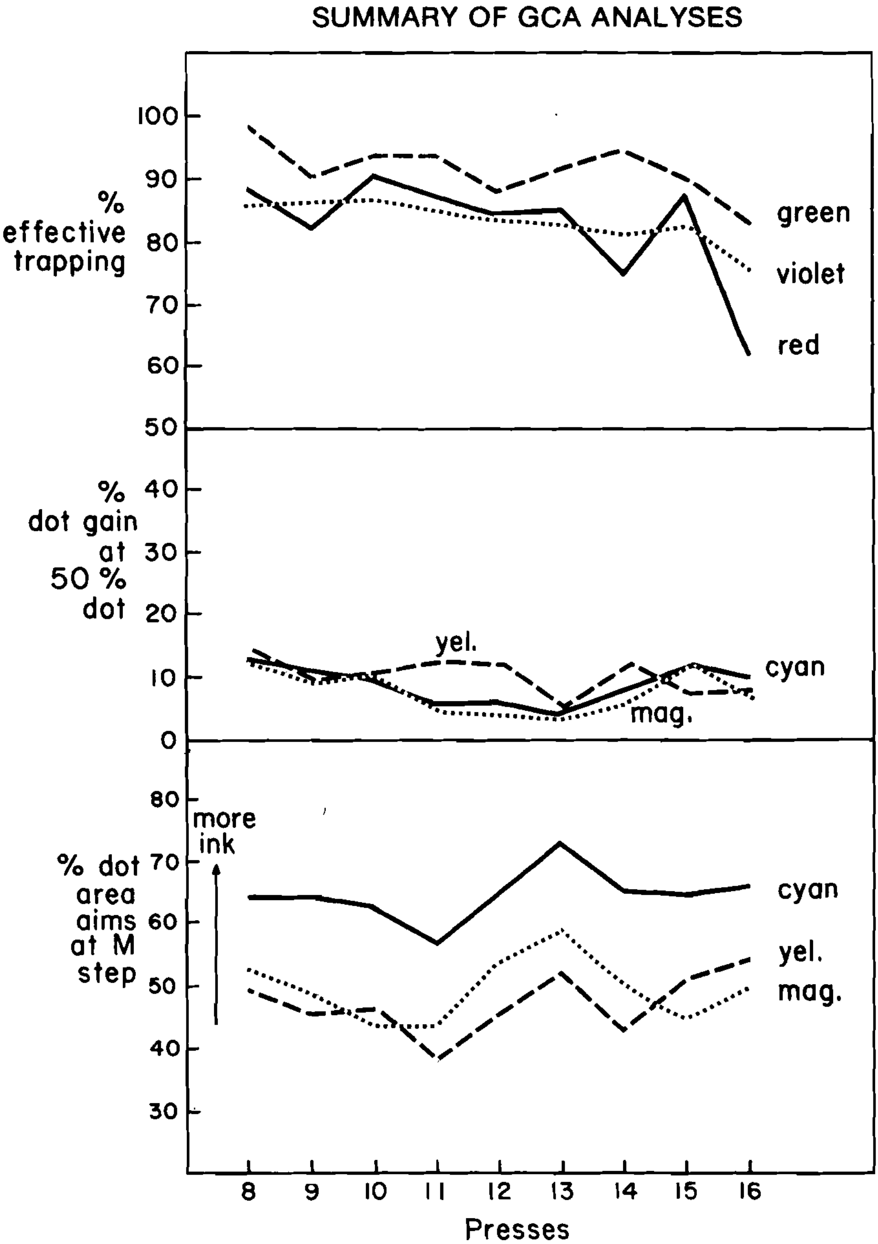


Figure 15b. Summary of GCA analyses continued from Figure 15a.

Conclusion

This project is a significant development in graphic arts, since it provides the first capability to analyze objectively the complete printing process. There can now be a true integration of the press and prepress components and monitoring of the printing conditions. It is probably only the beginning of even more elaborate analysis systems, which the industry needs to ensure consistent and efficient high-quality output. One can foresee that this type of analysis will be used to define scanner output optimized for the specific printing conditions for each job. The press performance measurements, on the other hand, should provide useful data and encourage improved control of the printing conditions, maybe by making some of the analysis measurements directly on the press. The color measurements can be the basis of better color control and communication in the industry. Possible color rendition data could provide dot area aims for control color patches for use in adjusting color correction and also provide means of calculating dot area aims for specific colors in the copy, either to reproduce them faithfully or to some other aim. All the results of the analysis should work together to improve quality and efficiency.

Acknowledgments

John Hamilton, Jr. is responsible for the software and assisted in the design of the hardware along with Ray Limoges and Dale Kempf. I am grateful also to Marge Taylor, who assisted with the development work. Chuck Rinehart of the Graphics Markets Division coordinated many successful trade tests.

Appendix

Customized Color Analysis Record and Specification Worksheet

Record

1. Date__________________
2. Firm_____________ Identification Code__________________ (for office use only)
3. Test Target No._____________
4. Press_______________
5. Plates______________

6. Inks:

	Order*	Solid Densities***	Name
Yellow	☐	☐	______
Magenta	☐	☐	______
Cyan	☐	☐	______
Black	☐	☐	______

*7. Order of Printing: Place numbers in boxes.

**8. Solid ink densities: Record in boxes.

Specify type of densities:

☐ SPI (Macbeth Spectrophotometer Process Ink Densities)

☐ Conventional

9. Paper ______________________

10. Fountain Solution __________________

11. Blanket ____________________

Specifications for Analysis

12. Title (reason or description of analysis)

____

Examples: "First analysis," "Compare presses"

13. Copy Mode

Transparency ☐
Reflection ☐
Both ☐

14. Aim Points

AMB ☐
HPS ☐

15. Tone Reproduction

- High Key ☐
- Average ☐
- Low Key ☐
- All Three ☐

16. Undercolor Removal (UCR)

- ☐ None
- ☐ Yes. Specify total percent shadow dot area of all four printers (280 normal)________________
- ☐ Both

17. Black Printer

Specify the density starting point above highlight, on the original density scale.

☐ 0.30 Very full back ☐ 0.90 Normal skeleton black

☐ 0.50 Normal full black ☐ __________Other

Specify the percent dot area in the B step in the AMB method <u>or</u> S step in the HPS method.

☐ 50 normal without UCR ☐ 85 normal with UCR

☐ ________other without UCR ☐ ______other with UCR

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