EFFECTS OF INK INPUT VOLUME CHANGES ON PRINTED QUALITY DURING KEYLESS LITHOGRAPHY

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ABSTRACT

A conventional heatset offset web press was made ready for printing a group of process color graphic images by setting keys until the predetermined printed target single-color densities across the web were achieved. While continuing at constant speed and dampener input, the overall rate of ink input was increased or decreased by significant amounts both individually and for combinations of inks by increasing or decreasing overall cross-press ink input rates. The intent was to simulate the effects of inadvertent differences in ink delivery during keyless inking due to doctoring errors or because of metering roller wear or because of batch-to-batch ink differences. The only significant apparent quality variation was hue of the prints when compared to a standard. Optical densities, dot gains will be presented.

CONCLUSIONS

This study of purposeful variation in overall input rates of process color inks using a fixed-keys conventional press verified that achieving optimal gray balance and least hue error in keyless systems is a realistic objective despite high probability of rather wide ink-related variations in the field. To best do so, keyless press systems may need to be modified to allow control of overall (cross-press) variation in ink input rates, termed shade control. Means for doing so need not be complicated but are beyond the scope of this paper.

Several interesting, perhaps basic printing factors became evident as a result of this study.

1. The volume of ink delivered to the substrate as measured by solid optical densities was in direct proportion to the ink input rate for all image contents. That proportion varied with percent image (tone value) but was constant for each tone value independent of ink input rate. The physical explanation for this result is that there was no dot gain during the process of inking the printing plate.

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2. The volume of ink that could be printed in a previously printed region containing one or two inks increased as the volume of the last down ink increased and decreased as the already-printed volume of the first-down ink(s) increased. This result was qualitatively consistent at all measured image contents from 25% to 100% and for all of the process colors.

3. In transferring ink from plate to blanket to paper, dot gain at all measured tone values increased as the volume of ink being transferred increased. Consequently, for quality printing there is not only an image content (tone value) dot gain factor to consider in pre-press operations but an ink input volume factor as well.

BACKGROUND

In keyless systems designed to meter a fixed volume of viscous inks to a printing press, variation in the expected ink input volume can occur for any of several reasons. Some of these are change in mechanical efficiency of ink metering action, change in ink volume transferred by the metering roller due to temperature or shear condition changes, change in rheology profile or tint value of a new batch of ink. With most oil-ink keyless systems, the volume of ink being delivered cannot readily be modulated as a control means. In keyless lithography it is impractical to attempt control of printed optical density by means of press-side pigment content changes. Consequently, it appeared important to simulate inadvertent changes in delivered ink input volumes during keyless process color printing and to measure the resulting printed output quality differences.

Printing presses outfitted with keyless inkers were inappropriate for this evaluation since at the time of this study none of them could be used to accurately and uniformly vary ink input volumes over a significant range. As yet, no one prints process color formats consistently with keyless systems. However, keyed presses are well-suited for the required simulation provided that all of the keys at a given couple can be opened or closed uniformly across the press width.

EXPERIMENTAL APPROACH

This report conveys the results of a multiple-condition one-day press test in which purposeful press-wide changes in ink input rates from the OK values were used to produce prints to be judged both densitometrically and visually. The densitometric results are reported in this paper.

Printing Press - The four-unit Harris M-110 heatset web offset lithographic press at Graphic Arts Technical Foundation fitted with a Tec dryer was used. A quarter-folder delivered convenient printed samples for subsequent measurements.

Press Characteristics

Cut-off	17 5/8 in.
Width	22 in.
Speed[a]	17,000 imp/hour
Color Sequence	M, K, C, Y

a. Purposeful slow speed was used to minimize paper waste during the multiple-condition test program.

Printing Materials - A 34 pound/ream No. 5 coated magazine paper was used together with suitable inks and dampening materials. No attempt was made to select specific materials other than those that seemed suitable for the printing system based on GATF's experience with this press. Inks were selected by GATF for ad-litho strength. No ink quality tests were run. Tack values were known to have been from 11 to 17, conditions not recorded.

Initial and Planned Printing Conditions - The pressman established optimal initial color balance by simultaneous single-color density readings of the three-color gray bar targets of the Figure 1 pictorial format, using an X-Rite Densitometer. The edges and the center column keys were shut nearly to zero because of the format margins. The inking keys were adjusted initially so that the right- and-left-hand large GATF solid and tint target groups were at similar optical densities. No individual inking key nor dampener adjustments were made for the remainder of the test program.

Twenty to fifty printed samples were pulled at this initial condition and at all subsequent printing conditions. Three of each were used for densitometric analysis.

The all-increase or all-decrease feature of the press controls was used to simultaneously and uniformly increase or decrease one or more of the three process color ink input rates at all or at each color's printing couple. The press was operated

FIGURE 1. TEST FORMAT

for ten to thirty minutes at each new ink input condition before pulling samples.

The original experimental design is summarized in Tables I and II. If all possible conditions were run as planned, there

TABLE I. EXPERIMENTAL DESIGN TARGET DENSITY VALUES AND CODE DESIGNATIONS

Printing Condition Code Designation[a]	Optical Density Target Values Magenta	Black	Cyan	Yellow
1 2 1 1	0.76	1.05	0.76	0.66
2 2 2 2	0.97	1.05	0.97	0.78
3 2 3 3	1.18	1.05	1.18	1.08

a. 1 refers to low input rate, 2 to medium, 3 to high.

would be 27 different printing conditions (3 x 3 x 3) and a corresponding number of sample sets. Table II indicates the planned sequence of conditions. With six replicates, the total number of conditions was to be 33.

TABLE II. EXPERIMENTAL CONDITION SEQUENCE PLAN

M	K	C	Y		M	K	C	Y		M	K	C	Y	
2	2	2	2		2	2	2	2	(rep)	2	2	2	2	(rep)
2	2	2	3		2	2	3	1		2	2	1	1	
2	2	2	2	(rep)	2	2	3	2		2	2	1	2	
2	2	2	1		2	2	3	3		2	2	1	3	
					2	2	2	3	(rep)					
3	2	2	1		1	2	2	1		3	2	1	3	
3	2	2	2		1	2	2	2		3	2	1	2	
3	2	2	3		1	2	2	3		3	2	2	1	
					2	2	2	2	(rep)	2	2	2	2	(rep)
3	2	3	3											
3	2	3	2		1	2	1	3						
3	2	3	1		1	2	1	2						
					1	2	1	1						

Actual Printing Conditions - Despite our attempts to control optical densities to predetermined conditions, two confounding factors were encountered, 1) differences in operator side and drive side target values found during subsequent measurements were sufficiently great that the right- and left-hand targets could be considered as two different printing conditions, although the only effect of this factor was to double the number of conditions available for analysis, 2) there was a gradual increase in ink optical density with time at a given condition and consequently the planned replication of settings was not achieved. For instance, no purposeful changes in the black ink input were made but the target optical densities increased from 1.30 to 1.44 during the test.

In view of these confounding factors, the printing conditions were selected and coded for analysis based on solid target optical density ranges that were actually achieved, rather than upon those sought, generally considering sample sets having optical densities within about an 0.05 range as equivalent. Accordingly, twenty experimental ink setting changes became the forty printing conditions enumerated in Table III. Several conditional features may be derived from Table III.

1. Magenta right- and left-hand solid single-color print optical densities differed by 0.04 to 0.10 ODU despite initial attempts by the operator to make them equal.

2. Cyan left and right solid OD values differed by only about 0.02 ODU to 0.05.

3. Yellow solid target print values of the right-hand target were 0.04 to 0.09 higher than the left, an opposite direction to that for magenta.

4. As previously mentioned, black OD values increased during the test by about 0.2 ODU despite no purposeful changes. This is probably a temperature effect.

The experimental single-color optical density ranges for each ink are detailed in Table IV and summarized in Table V. The magenta ink input in optical density terms varied as much as 0.32 optical density units below the highest value of 1.0 ODU; cyan input ranged as much as 0.37 below a high of 0.97 ODU and yellow to about 0.28 below its high of 0.87 ODU.

TABLE III. SOLID TARGET OPTICAL DENSITIES ACHIEVED DURING FIXED KEYS, VARIABLE INK INPUT PRINTING[a]

Sample	Condition Designation[c]				M		K		C		Y	
Code[b]	M	K	C	Y	R	L	R	L	R	L	R	L
NR	2	1	3	3	0.75	-	1.26	-	0.80	-	0.72	-
NL	3	1	3	3	-	0.80	-	1.28	-	0.80	-	0.70
BK1R	2	1	5	4	0.76	-	1.30	-	0.95	-	0.73	-
BK1L	3	1	5	3	-	0.81	-	1.32	-	0.94	-	0.71
BK2R	2	2	3	3	0.77	-	1.34	-	0.71	-	0.71	-
BK2L	3	2	3	3	-	0.81	-	1.37	-	0.71	-	0.69
BK3R	2	2	2	5	0.78	-	1.34	-	0.74	-	0.80	-
BK3L	3	1	2	5	-	0.84	-	1.32	-	0.73	-	0.78
BK4R	2	2	4	6	0.78	-	1.38	-	0.88	-	0.84	-
BK4L	3	2	4	5	-	0.83	-	1.36	-	0.89	-	0.80
BK5L	2	1	3	4	0.77	-	1.28	-	0.80	-	0.75	-
BK5R	3	1	3	3	-	0.84	-	1.29	-	0.82	-	0.71
PU1R	2	1	5	6	0.78	-	1.29	-	0.98	-	0.88	-
PU1L	3	2	5	5	-	0.85	-	1.35	-	1.01	-	0.82
PU2R	4	1	5	6	0.91	-	1.31	-	0.96	-	0.89	-
PU2L	5	1	5	5	-	0.98	-	1.29	-	0.98	-	0.80
PU3R	4	1	3	6	0.90	-	1.29	-	0.81	-	0.88	-
PU3L	5	2	3	5	-	0.99	-	1.35	-	0.82	-	0.81
PU4R	4	2	2	6	0.93	-	1.34	-	0.69	-	0.87	-
PU4L	5	2	2	5	-	1.03	-	1.37	-	0.70	-	0.80
PU5R	4	2	2	4	0.94	-	1.38	-	0.70	-	0.73	-
PU5L	5	3	2	2	-	1.01	-	1.41	-	0.72	-	0.65
BL1R	2	2	3	3	0.76	-	1.36	-	0.81	-	0.70	-
BL1L	2	3	3	2	-	0.82	-	1.41	-	0.81	-	0.66
BL2R	4	3	3	3	0.94	-	1.41	-	0.82	-	0.71	-
BL2L	5	3	3	2	-	1.01	-	1.42	-	0.83	-	0.68
BL3R	4	3	4	3	0.90	-	1.40	-	0.91	-	0.72	-
BL3L	4	3	5	2	-	0.96	-	1.42	-	0.95	-	0.68
BL4R	4	3	4	1	0.92	-	1.44	-	0.93	-	0.59	-
BL4L	5	3	5	1	-	0.99	-	1.46	-	0.97	-	0.56
BL5R	1	3	4	5	0.67	-	1.45	-	0.91	-	0.77	-
BL5L	1	3	5	3	-	0.72	-	1.47	-	0.96	-	0.71
OR1R	2	3	1	5	0.77	-	1.45	-	0.60	-	0.78	-
OR1L	3	3	1	3	-	0.81	-	1.48	-	0.61	-	0.71
OR2R	1	3	2	3	0.66	-	1.44	-	0.69	-	0.72	-
OR2L	1	3	2	2	-	0.69	-	1.46	-	0.72	-	0.66
OR3R	1	3	2	1	0.65	-	1.45	-	0.72	-	0.62	-
OR3L	1	3	2	1	-	0.70	-	1.46	-	0.72	-	0.58
OR4R	2	3	3	3	0.75	-	1.46	-	0.84	-	0.74	-
OR4L	2	3	3	2	-	0.80	-	1.49	-	0.86	-	0.67

a. Net primary color OD, paper value subtracted.
b. In actual sequential order; code refers to sample edge identification mark color and to right or left target measurement.
c. Indicates relative OD level, e.g., 1 to 6, for each of the inks.

TABLE IV. PRINTED OPTICAL DENSITY RANGE VALUES AT VARIOUS INK INPUT CONDITIONS

MAGENTA Input Condition Code[a]	No. of Samples at Condition[b]	Average Solid OD Value[c]	BLACK Input Condition Code[a]	No. of Samples at Condition[b]	Average Solid OD Value[c]
1 X X X	6	0.68 r 0.07	X 1 X X	11	1.30 r 0.06
2 X X X	12	0.77 r 0.07	X 2 X X	11	1.36 r 0.04
3 X X X	8	0.82 r 0.05	X 3 X X	18	1.44 r 0.09
4 X X X	8	0.92 r 0.06			
5 X X X	6	1.00 r 0.05			

CYAN Input Condition Code[a]	No. of Samples at Condition[b]	Average Solid OD Value[c]	YELLOW Input Condition Code[a]	No. of Samples at Condition[b]	Average Solid OD Value[c]
X X 1 X	2	0.60 r 0.01	X X X 1	4	0.59 r 0.06
X X 2 X	12	0.71 r 0.05	X X X 2	6	0.67 r 0.03
X X 3 X	12	0.82 r 0.06	X X X 3	13	0.71 r 0.05
X X 4 X	5	0.90 r 0.05	X X X 4	2	0.73 r 0.04
X X 5 X	9	0.97 r 0.06	X X X 5	9	0.80 r 0.05
			X X X 6	5	0.87 r 0.05

a. Each entry refers to all conditions having indicated input level for the single ink (1 2 3 4 = 1 2 2 4 = 1 2 1 1 etc. = 1 X X X) for magenta.
b. Number of conditions having the indicated ink input level.
c. All values are with paper OD subtracted. The figure after r is the total range of values in the set.

TABLE V. SOLID TARGET OPTICAL DENSITY SUMMARY OF PURPOSEFUL INK INPUT VARIATIONS[a]

	High Average	Low Average	Experimental OD Range
Magenta	1.00	0.68	0.32
Cyan	0.97	0.60	0.37
Yellow	0.87	0.59	0.28

a. Net values with paper OD subtracted from measured values.

In addition to individual solid ink optical densities, also measured at the left and right GATF Color Reproduction Guide target group of each of the 20 sample sets were:

1. The 75%, 50% and 25% single color tint values.
2. M, C, and Y component values for each of the two-color and three-color overprints.

These data together with the following equations were used to evaluate the indicated print quality factors:

$$\text{Print Contrast, } PC = 100(D_s - D_{75})/D_s \qquad (1)$$

where D_s = solid target optical density
D_{75} = 75% tint optical density of same ink.

Apparent Dot Gain ADG = ADA - FDA (2)
where

$$ADA = 100 \frac{[1 - 10e\ (D_t/n)]}{[1 - 10e\ (D_s/n)]} \qquad (3)$$

from Yule-Nielsen (1), in which
ADA = apparent dot area.
D_t = optical density of tint target, paper-corrected.
D_s = optical density of solid target, paper-corrected.
n = optical correction factor (n = 1 used here).
FDA = film dot area on negative.

Hue Error and Grayness, from Preucil (2),

$$HE = 100\ (M - L)/(H - L) \qquad (4)$$

$$G = 100\ (L/H) \qquad (5)$$

where
H = highest of the three color filter solid patch optical density values, paper-corrected.
L = lowest of the three color filter solid patch optical density values, paper-corrected.
M = intermediate of the three color filter solid patch optical density values, paper-corrected.

Ink Trap, from Preucil (3),

$$T = 100\ (D_2 - D_1)/D_2 \qquad (6)$$

in which D_2 = optical density of second down ink in overprint, paper-corrected.
D_1 = optical density of first down ink in overprint, paper-corrected.

EXPERIMENTAL RESULTS

One way to evaluate a multivariable process such as a printing system is to look for internal consistency of results, in this case to determine whether printed quality of ink delivered by the press to the paper changed in any way other than an amount related to the purposeful volume input changes. Single color optical density ratios of tones to that of solids, as in Table V, reflect that the relative volumes of ink delivered to the paper were remarkably constant for all three colors

TABLE V. OPTICAL DENSITIES OF PRINTED TONE TARGETS RELATIVE TO SOLID VALUES

Ink Color	No. of Conditions	OD Range[a]	Percent Tone OD Values Of Solid OD Values[b] 100	75%	50%	25%
Magenta	40	0.68-1.00	100	73±1	50±1	17±1
Cyan	40	0.60-0.97	100	77±1	54±1	19±1
Yellow	40	0.59-0.87	100	82±1.5	60±1.5	23±1
Black	40	1.30-1.44	100	76±2.5	52±1	17±0.5

a. Measured value less paper OD.
b. The ± variance is the average deviation from the mean ratio of tone to solid OD expressed as percent.

independent of the purposeful ink input variations. These ink input rate differences in turn correspond at least to an estimated two-fold increase in solid ink film thicknesses. Apparent from the Table V data are:

1. Virtual lack of variation in tone optical density relative to solid optical density for any tone value of any of the inks. This demonstrates that the press delivered to the paper volumes of ink directly proportional to the input

rate (key setting) over a significant range of ink input volumes. There may have been a slight increase in tone ratio OD with increase in solid OD for black which involved thicker ink films.

2. The point 1 result is strong verification that in lithography little or no physical dot gain occurs at the printing plate/inking nips. The volume of ink delivered to the paper is essentially proportional to It, where I is ink film thickness available to the plate from the inker and t is the area fraction of image.

3. Assuming correction steps were taken in prepress to reach printed half-tone densities similar to the nominal dot area values of 75%, 50%, and 25% in the film separations, it is apparent that equivalent corrections for the three inks were not used. Except for the 25% tint, yellow varies the most from the nominal film target tone values.

Printed Samples Appearance - Although the printed results have not been visually analyzed and cannot be readily reproduced here, it can be qualitatively stated that none of them were unacceptable based on casual appearance. This reflects the fact that all prints were maintained in register during the test. The only obvious differences in the pictorial four-color printed appearance is hue. They look different but acceptable. Closer examination would be required to verify whether highlight or shadow detail was considered to be lost at any of the experimental conditions. Comparison of individual print condition results against a standard or a proof would allow ranking of acceptable ink input deviation and yet retain that standard of acceptability.

Dot Gain - Single color dot gain values for each of the inks over their respective ranges of densities are given in Tables VI through IX. As expected, dot gain values for all three tones, 75%, 50%, 25%, increased with increase in ink input volume, the latter being represented by optical density of the solid targets. Dot gain values were in the order K>Y>C>M, whereas the dot gain increase with increasing ink input were in the order Y>C>K>M. The dot gain values are in part representative of printing couple conditions and in part the actual ink film thicknesses. Unfortunately, neither are independently known.

TABLE VI. AVERAGE TONE TARGET DOT GAIN VALUES AT VARIOUS SOLID TARGET OPTICAL DENSITIES FOR MAGENTA

Input Conditions[a]	No. of Conditions	Solid Optical Density[b]	Percent Dot Gain for Indicated Tone Value[c] 75%	50%	25%
1 X X X	6	0.68 r 0.07	11	20	8
2 X X X	12	0.77 r 0.07	12	21	8
3 X X X	8	0.82 r 0.05	13	22	8
4 X X X	8	0.92 r 0.06	15	24	8
5 X X X	6	1.00 r 0.05	15	25	9
Overall Range		0.32	4	5	1

a. Controlled magenta variations at various K, C, Y conditions.
b. Value after r indicates range of values in the set.
c. Average variation less than ± 1.

TABLE VII. AVERAGE TONE TARGET DOT GAIN VALUES AT VARIOUS SOLID TARGET OPTICAL DENSITIES FOR BLACK

Input Conditions[a]	No. of Conditions	Solid Optical Density[b]	Percent Dot Gain for Indicated Tone Value[c] 75%	50%	25%
X 1 X X	11	1.30 r 0.06	19	33	17
X 2 X X	11	1.36 r 0.04	20	34	18
X 3 X X	18	1.44 r 0.09	21	35	19
Overall Range		0.14	2	2	2

a. For uncontrolled black shift during printing at various M, C, Y conditions.
b. Value after r indicates range of values for the set.
c. Average variation less than ± 1.0.

TABLE VIII. AVERAGE DOT GAIN VALUES AT VARIOUS SOLID OPTICAL DENSITIES OF CYAN PRINTED TARGETS

Input Condi- tions[a]	No. of Condi- tions	Solid Optical Density[b]	Percent Dot Gain for Indicated Tone Value[c]		
			75%	50%	25%
X X 1 X	2	0.60 r 0.01	12+	20+	7
X X 2 X	12	0.71 r 0.05	14	23	10
X X 3 X	12	0.82 r 0.06	15	25	11
X X 4 X	5	0.90 r 0.05	16	26	12
X X 5 X	9	0.97 r 0.06	17	27	13
Overall Range		0.37	5	7	6

a. Controlled cyan variations using various M, K, Y conditions.
b. Value after r indicates range of values for the set.
c. Average variation less than ± 1.0.

TABLE IX. AVERAGE DOT GAIN VALUES AT VARIOUS SOLID OPTICAL DENSITIES OF YELLOW PRINTED TARGETS

Input Condi- tions[a]	No. of Condi- tions	Solid Optical Density[b]	Percent Dot Gain for Indicated Tone Value[c]		
			75%	50%	25%
X X X 1	4	0.59 r 0.06	14	25	12
X X X 2	6	0.67 r 0.03	16	27	14
X X X 3	13	0.71 r 0.05	16	27	14
X X X 4	2	0.73 r 0.04	17	27	14
X X X 5	9	0.80 r 0.05	18	29	16
X X X 6	5	0.87 r 0.05	19	31	17
Overall Range		0.28	5	6	5

a. Controlled yellow variations using various M, K, C conditions.
b. Value after r indicates range of values for the set.
c. Average variation less than ± 1.0.

The differences among the four inks in the increase of dot gain values with increase in input ink volume over this range of ink inputs are likely related to differing ink rheological properties.

Individual 25%, 50% and 75% dot gain values were plotted versus solid optical densities for all of the printing conditions, Figures 3, 4, 5 and 6. These form a series of three curves for each color, each of which appears to extrapolate to zero dot gain at zero ink input.

When plotted versus tone optical density, the dot gain versus ink input curves for 25% and 50% tones appear closely to form a single curve having no obvious relation to the 75% dot gain values, Figures 7, 8, 9, 10. However, if we take into account that 75% tones are actually 25% dot reversals, it seemed of interest to plot 75% tone dot gains as a function of optical density difference between the 100% solid value and the 75% tone value. Doing so causes all of the target tone dot gain data to fall on the same general curve for each ink, particularly magenta and cyan, Figures 11, 12, 13, 14.

With halftones, the densitometer measures not only optical absorption by the ink but also how many dots (how much ink) are present. This is analogous to UV or infrared absorption measurements of an unknown material dissolved at various concentrations (number of dots) in a solvent. Densitometry measures the volume of ink present in the instrument's field of view.

<u>Two Color Trap</u> - There is a basic problem in the graphic arts field in that trap is not singularly defined. The term "trap" can mean any of several things:

1. Amount of a solid ink film that can be printed in the same location as a first down solid ink film.

2. Amount of tone ink that can be printed in the same location as a previously printed solid ink film.

3. Amount of solid or tone ink that can be printed in the same location as a previously printed tone.

Obviously, each of these will produce different values since

FIGURE 3
TONE DOT GAIN AS A FUNCTION OF SOLID
OPTICAL DENSITY FOR MAGENTA

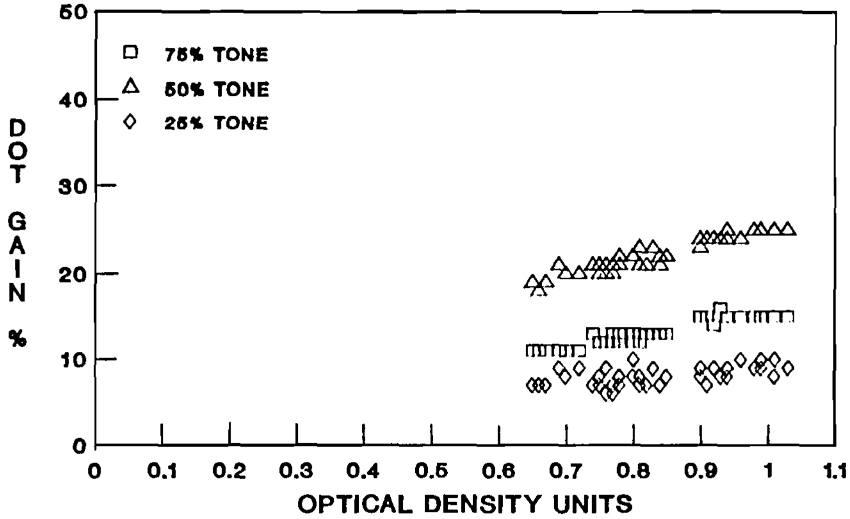


FIGURE 4
TONE DOT GAIN AS A FUNCTION OF SOLID
OPTICAL DENSITY FOR BLACK

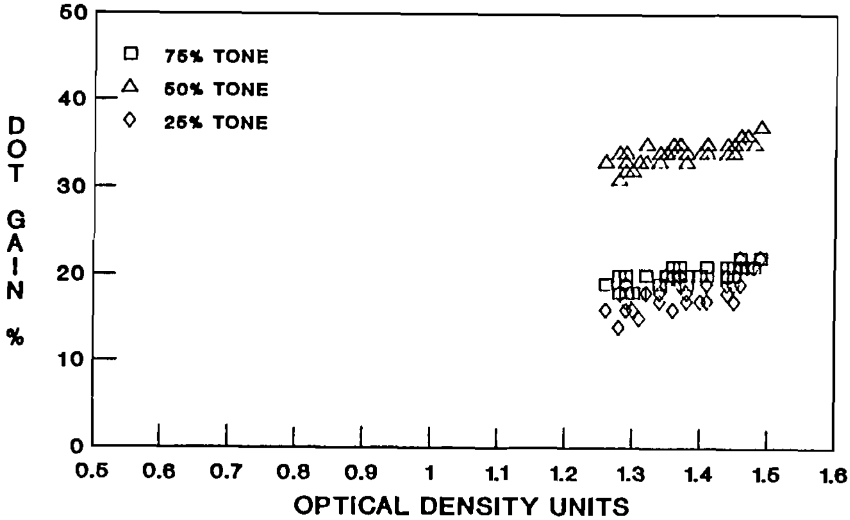


FIGURE 5
TONE DOT GAIN AS A FUNCTION OF SOLID OPTICAL DENSITY FOR CYAN

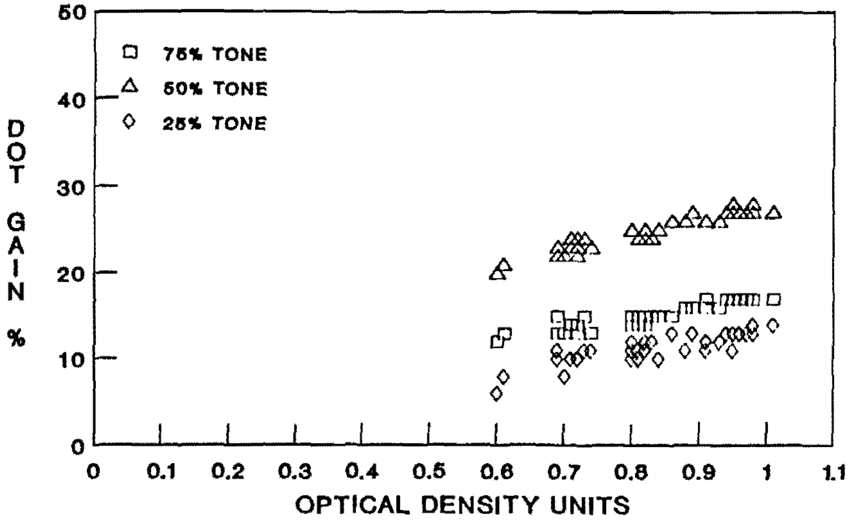


FIGURE 6
TONE DOT GAIN AS A FUNCTION OF SOLID OPTICAL DENSITY FOR YELLOW

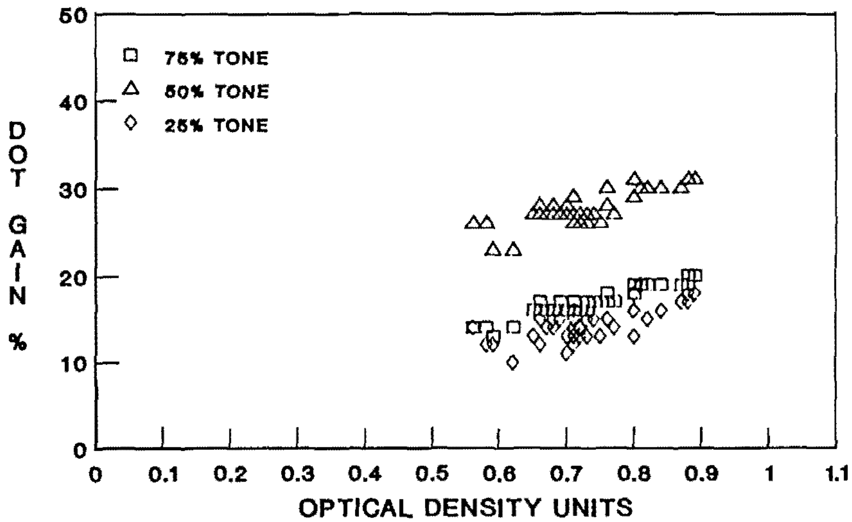


FIGURE 7
TONE DOT GAIN VERSUS TONE
OPTICAL DENSITY FOR MAGENTA

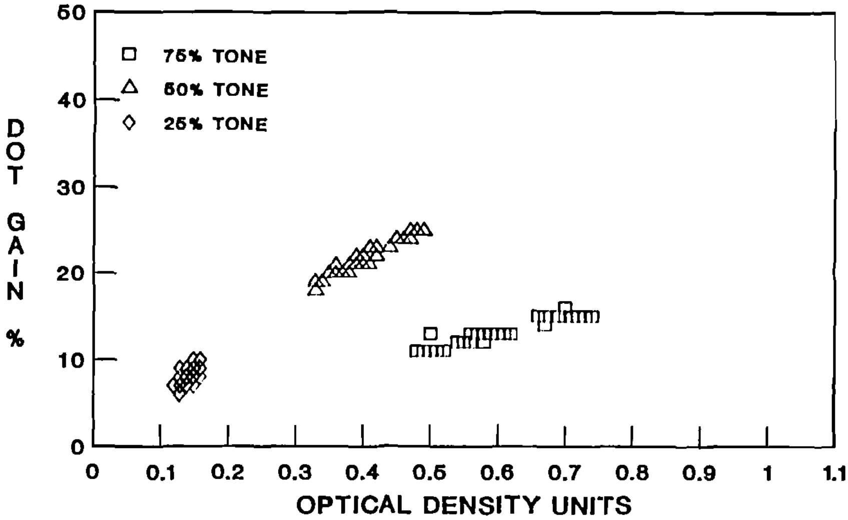


FIGURE 8
TONE DOT GAIN VERSUS TONE
OPTICAL DENSITY FOR BLACK

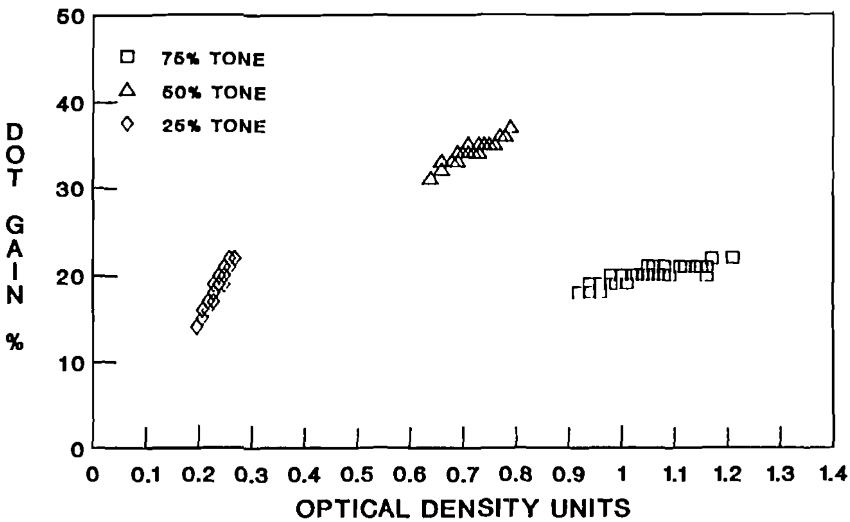


FIGURE 9
TONE DOT GAIN VERSUS TONE
OPTICAL DENSITY FOR CYAN

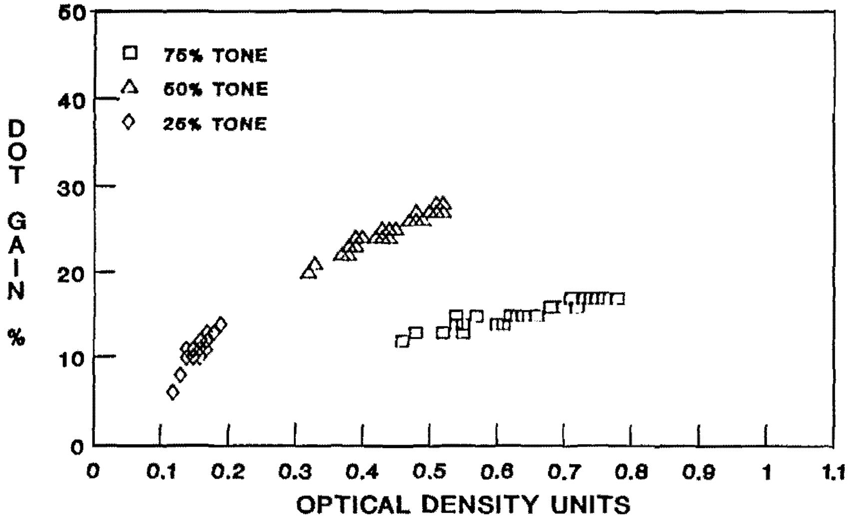


FIGURE 10
TONE DOT GAIN VERSUS TONE
OPTICAL DENSITY FOR YELLOW

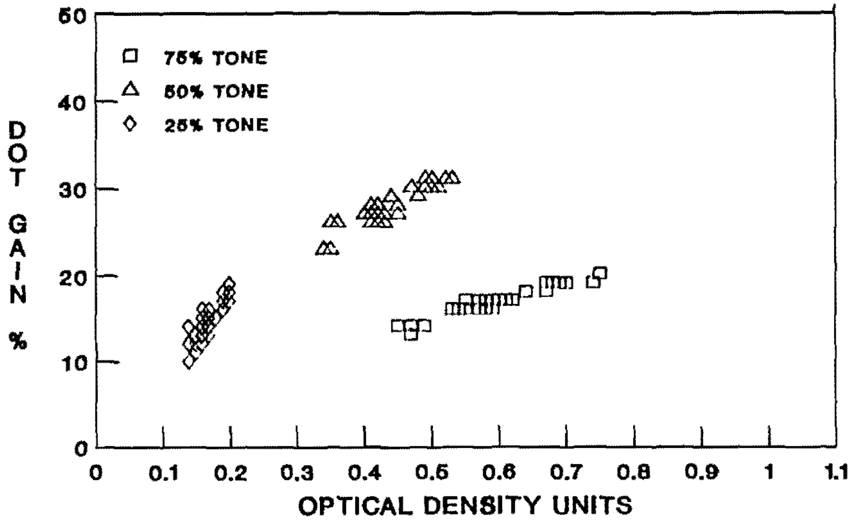


FIGURE 11
TONE DOT GAIN VERSUS TONE OPTICAL DENSITY
FOR MAGENTA WITH 75% TONE CORRECTED

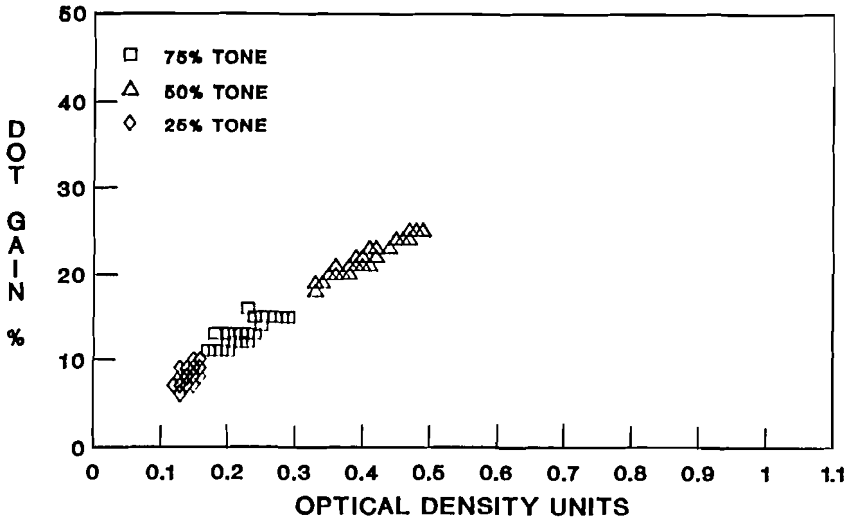


FIGURE 12
TONE DOT GAIN VERSUS TONE OPTICAL DENSITY
FOR BLACK WITH 75% TONE CORRECTED

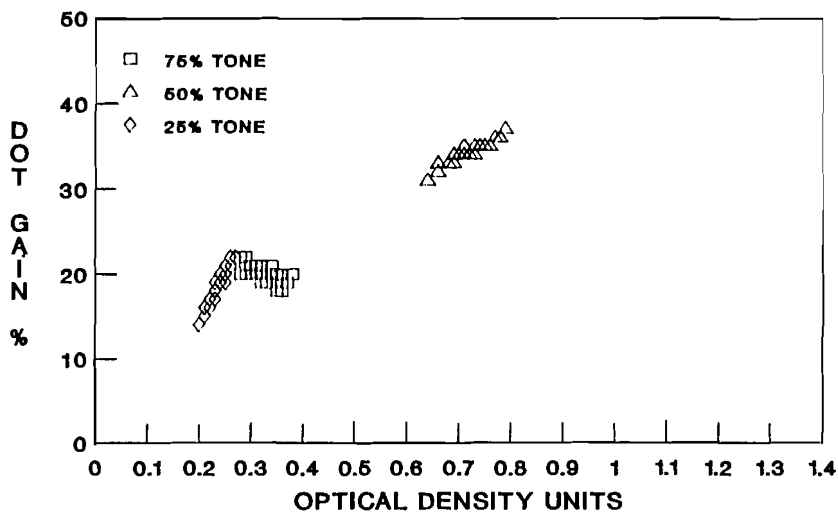


FIGURE 13

TONE DOT GAIN VERSUS TONE OPTICAL DENSITY
FOR CYAN WITH 75% TONE CORRECTED

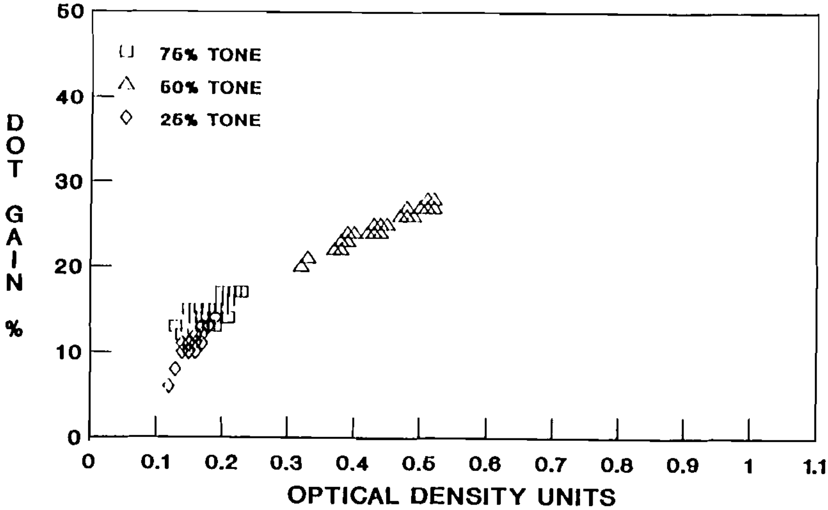
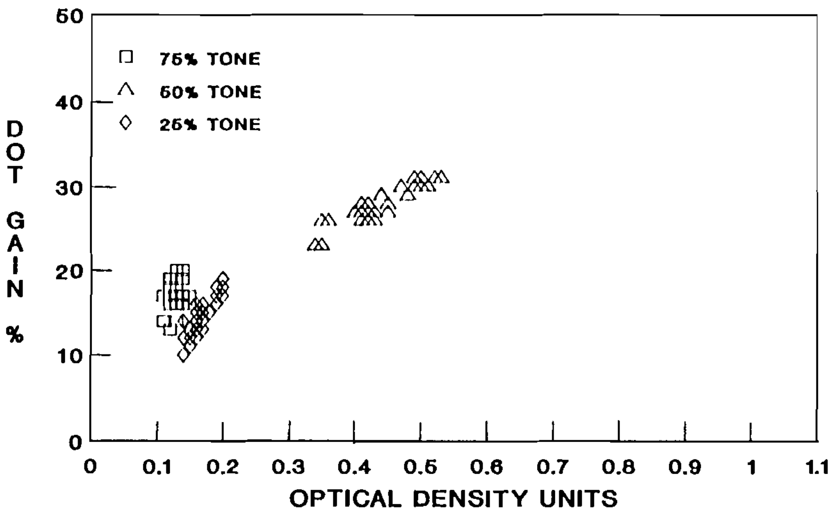


FIGURE 14

TONE DOT GAIN VERSUS TONE OPTICAL DENSITY
FOR YELLOW WITH 75% TONE CORRECTED



the term trap refers either to printing of ink onto an overall ink film or printing of ink onto a substrate partially covered with an ink film.

For this analysis, Preucil's practical definition, Equation (6) was used. It provides a relative value of how much of the second ink was printed over the first, independent of whether either ink is a solid film or a tone. In practice, this allows making corrections without knowing exactly what the word trap means.

In evaluating overprint information the previous single color dot gain results should be considered: 1) volume of ink delivered to the paper is accurately proportional to the relative volume of ink input (Table V), and 2) the tone dot size is a monotonic function of the volume of ink delivered, as measured by optical density, taking into account that tones greater than 50% are actually reversals (Figures 11, 12, 13, 14).

The two color trap values measured in this study are given in Tables X, XI and XII, for the three process colors, corresponding to 100% over 100% solid ink conditions and 75% over 75%, 50/50 and 25/25 tone overprint conditions. With these appropriately screen-separated and angled targets, true ink-on-ink overprinting occurs primarily only for the first two of these conditions; 75/75 overprinting involves about 50% ink-on-ink overlap; 50/50 overprinting of two colors involves only about 5% ink-on-ink overlap; 25/25 overprinting none.

Cyan over Magenta - Review of the Table X data allows the following qualitative conclusions:

1. The relative amount of cyan ink that could be printed over a magenta printed area increased in the order 100/100 < 75/75 < 50/50; the 25/25 values were similar to the 75/75 values.

2. Statement 1 applied for all optical density values (relative input volumes) of magenta from 0.68 to 1.00 ODU and of cyan from 0.60 to 0.97 ODU.

TABLE X. PERCENT PREUCIL TRAP OF CYAN OVER MAGENTA AT VARIOUS INK INPUT CONDITIONS AS A FUNCTION OF PERCENT COVERAGE

M K C Y Input Condition[a]	No. of Conditions R	No. of Conditions L	PERCENT COVERAGES 100%/100% R	100%/100% L	75%/75% R	75%/75% L	50%/50% R	50%/50% L	25%/25% R	25%/25% L
1 X 1 X	-	-	-	-	-	-	-	-	-	-
1 X 2 X	2	2	93	89	101	93	104	93	100	85
1 X 3 X	-	-	-	-	-	-	-	-	-	-
1 X 4 X	1	-	100	-	104	-	104	-	94	-
1 X 5 X	-	1	-	90	-	92	-	95	-	89
2 X 1 X	1	-	93	-	100	-	102	-	-	111
2 X 2 X	-	-	-	-	-	-	-	-	-	-
2 X 3 X	4	2	95^{b}	87	101^{c}	91	104^{d}	95	101^{e}	90
2 X 4 X	1	-	99	-	106	-	107	-	102	-
2 X 5 X	2	-	99	-	106	-	106	-	99	-
3 X 1 X	-	1	-	86	-	89	-	96	-	90
3 X 2 X	-	1	-	85	-	89	-	95	-	87
3 X 3 X	-	3	-	86^{f}	-	92^{g}	-	95^{h}	-	90^{i}
3 X 4 X	-	1	-	86	-	91	-	93	-	87
3 X 5 X	-	2	-	87	-	93	-	97	-	93
4 X 1 X	-	-	-	-	-	-	-	-	-	-
4 X 2 X	2	-	89	-	98	-	101	-	95	-
4 X 3 X	2	-	90	-	100	-	101	-	97	-
4 X 4 X	2	-	95	-	102	-	106	-	102	-
4 X 5 X	1	1	97	86	105	92	106	95	100	91
5 X 1 X	-	-	-	-	-	-	-	-	-	-
5 X 2 X	-	2	-	79	-	88	-	92	-	85
5 X 3 X	-	2	-	82	-	90	-	94	-	86
5 X 4 X	-	-	-	-	-	-	-	-	-	-
5 X 5 X	-	2	-	85	-	92	-	95	-	91

a. Increasing value of notation corresponds to increasing input ink volume as measured by printed solid optical density.
b. Average deviation from mean of b ±3, c. ±2, d. ±1, e. ±3, f. ±1, g. ±1, h. ±2, i. ±2.

TABLE XI. PERCENT PREUCIL TRAP OF YELLOW OVER MAGENTA AT VARIOUS INK INPUT CONDITIONS AS A FUNCTION OF PERCENT COVERAGE

M K C Y Input Condition[a]	No. of Conditions R	No. of Conditions L	PERCENT COVERAGES 100%/100% R	100%/100% L	75%/75% R	75%/75% L	50%/50% R	50%/50% L	25%/25% R	25%/25% L
1 X X 1	1	1	82	80	86	86	90	86	85	83
1 X X 2	-	1	-	85	-	88	-	87	-	82
1 X X 3	1	-	85	-	88	-	89	-	73	-
1 X X 4	-	-	-	-	-	-	-	-	-	-
1 X X 5	1	-	83	90	92	-	91	-	85	-
2 X X 1	-	-	-	-	-	-	-	-	-	-
2 X X 2	-	2	-	81	-	85	-	87	-	84
2 X X 3	4	-	83^{b}	-	86^{c}	-	89^{d}	-	84^{e}	-
2 X X 4	2	-	82	-	86	-	90	-	84	-
2 X X 5	2	-	85	-	88	-	90	-	85	-
2 X X 6	2	-	87	-	90	-	91	-	85	-
3 X X 1	-	-	-	-	-	-	-	-	-	-
3 X X 2	-	-	-	-	-	-	-	-	-	-
3 X X 3	-	5	-	82^{f}	-	87^{g}	-	89^{h}	-	85^{i}
3 X X 4	-	-	-	-	-	-	-	-	-	-
3 X X 5	-	3	-	86^{j}	-	89^{k}	-	91^{l}	-	85^{m}
3 X X 6	-	-	-	-	-	-	-	-	-	-
4 X X 1	1	-	74	-	81	-	88	-	79	-
4 X X 2	-	1	-	82	-	78	-	84	-	85
4 X X 3	2	-	83	-	84	-	88	-	83	-
4 X X 4	1	-	80	-	83	-	85	-	85	-
4 X X 5	-	-	-	-	-	-	-	-	-	-
4 X X 6	3	-	85^{n}	-	91^{o}	-	93^{p}	-	87^{q}	
5 X X 1	-	1	-	71	-	78	-	84	-	73
5 X X 2	-	2	-	78	-	83	-	86	-	84
5 X X 3	-	-	-	-	-	-	-	-	-	-
5 X X 4	-	-	-	-	-	-	-	-	-	-
5 X X 5	-	3	-	82	-	87	-	89	-	83
5 X X 6	-	-	-	-	-	-	-	-	-	-

a. Increasing value of notation corresponds to increasing input ink volume as measured by printed solid optical density.
b. Average deviations from the mean are b. ±2, c. ±2, d. ±1, e. ±1, f. ±1, g. ±0, h. ±1, i. ±3, j. ±0, k. ±1, l. ±2, m. ±3, n. ±0, o. ±1, p. ±1, q. ±4.

3. The relative amount of cyan ink that could be printed over a magenta printed area decreased with increase in the magenta optical density (ink volume) from about 100% at 0.68 ODU to about 85% at 1.00 ODU.

4. The relative amount of cyan ink that could be printed over a magenta printed area increased with increase in the cyan optical density (relative ink input volume), from about 4 to 8 percentage points.

5. The effects of ink volume on apparent trap values, Points 3 and 4, were greater for the right-hand targets than for left-hand targets at similar optical densities (ink volumes). This appears to be a press-related factor.

Yellow over Magenta - The Table XI results are similar to the cyan over magenta results.

1. The relative amount of yellow ink that could be printed over the first-down magenta increased in the order 100/100 < 75/75 < 50/50, with 25/25 values being less than the 50/50 values. This result is qualitatively similar to that for cyan over magenta.

2. Statement 1 applies for all optical density values (relative ink volumes) of magenta from 0.68 to 1.00 ODU and of yellow from 0.59 to 0.87 ODU.

3. The relative amount of yellow ink that could be printed over a magenta printed area decreased with increase in the magenta optical density (relative ink volume), for example, from about 86% at 0.68 magenta OD to about 78% at 1.00 magenta OD.

4. The relative amount of yellow ink that could be printed over a magenta printed area increased with increase in the yellow optical densty (relative ink volume), from about 2 to 10% percentage points.

5. There is no obvious difference in side-to-side press performance based on right- and left-hand target values.

This result differs from the cyan over magenta result.

Yellow over Cyan - The Table XII results, summarized below indicate:

1. The relative amount of yellow ink that could be printed in the same region as the previously-printed cyan increased in the order 100/100 < 75/75 < 50/50, with 25/25 tone overprints generally having values less than any of the others. This result is also qualitatively similar to that for the other two overprints.

TABLE XII. PERCENT PREUCIL TRAP OF YELLOW OVER CYAN AT VARIOUS INK INPUT CONDITIONS AS A FUNCTION OF PERCENT COVERAGE

M K C Y Input Condition[a]	No. of Conditions R	No. of Conditions L	PERCENT COVERAGES 100%/100% R	100%/100% L	75%/75% R	75%/75% L	50%/50% R	50%/50% L	25%/25% R	25%/25% L
X X 1 1	-	-	-	-	-	-	-	-	-	-
X X 1 2	-	-	-	-	-	-	-	-	-	-
X X 1 3	-	-	-	-	-	-	-	-	-	-
X X 1 4	-	-	-	-	-	-	-	-	-	-
X X 1 5	1	-	96	-	99	-	102	-	86	-
X X 2 1	1	1	88	90	95	96	101	101	94	90
X X 2 2	-	2	-	95	-	100	-	103	-	86
X X 2 3	1	-	92	-	97	-	102	-	88	-
X X 2 4	1	-	89	-	95	-	97	-	92	-
X X 2 5	-	2	-	101	-	107	-	108	-	91
X X 2 6	1	-	99	-	103	-	107	-	95	-
X X 3 1	-	-	-	-	-	-	-	-	-	-
X X 3 2	-	3	-	90[b]	-	96[c]	-	101[d]	-	91[e]
X X 3 3	5	3	91[f]	95[g]	96[h]	102[i]	101[j]	104[k]	87[l]	89[m]
X X 3 4	1	-	91	-	96	-	104	-	88	-
X X 3 5	-	1	-	98	-	103	-	107	-	93
X X 3 6	-	1	-	93	-	103	-	105	-	87
X X 4 1	1	-	80	-	89	-	97	-	86	-
X X 4 2	-	-	-	-	-	-	-	-	-	-
X X 4 3	1	-	90	-	96	-	100	-	88	-
X X 4 4	-	-	-	-	-	-	-	-	-	-
X X 4 5	1	1	89	95	97	102	101	103	88	87
X X 4 6	1	-	93	-	99	-	103	-	91	
X X 5 1	-	1	-	78	-	88	-	94	-	80
X X 5 2	-	1	-	85	-	95	-	99	-	90
X X 5 3	-	1	-	89	-	97	-	101	-	88
X X 5 4	1	-	87	-	92	-	98	-	74	-
X X 5 5	-	1	-	95	-	104	-	110	-	89
X X 5 6	2	-	90	-	98	-	102	-	92	-
5 X X 6	-	-	-	-	-	-	-	-	-	-

a. Increasing value of notation corresponds to increasing input ink volume as measured by printed solid optical density.

b. Average deviations from the mean are b. ±1, c. ±1, d. ±1, e. ±2, f. ±1, g. ±2, h. ±2, i. 1, j. ±1, k. ±2, l. ±4, m. ±4.

2. Statement 1 applies for all optical density values(relative ink volumes) of yellow from 0.59 to 0.87 and of cyan from 0.60 to 0.97.

3. The relative amount of solid yellow ink that could be printed over a solid cyan printed area decreased slightly with increase in cyan optical density (relative ink input volume), from about 96% at 0.60 cyan OD to 90% at 0.97 cyan OD. No consistent effect of yellow ink volume was apparent for 75/75, 50/50 or 25/25 overprints. This result differs from the other two overprint results.

4. The relative amount of yellow ink that could be printed over a cyan printed area increased with increase in yellow optical density (relative ink volume) typically by about 4 to 10 percentage points as the yellow OD increased from 0.59 to 0.87.

5. No left-to right-hand overprint differences were apparent.

Three Color Overprints - To evaluate three color trap a suggestion by S-M Chou (4) was adopted, namely that Preucil's equation could be used but in this case becomes yellow trapping over blue overprints:

$$T = 100\,(D_y^o - D_y^b)\,/D_y \qquad (7)$$

in which D_y^o = yellow optical density of the three-color target, paper corrected,

D_y^b = yellow optical density of the two-color blue target, paper corrected,

D_y = single color target yellow optical density, paper corrected.

Results for the forty MKCY press conditions are given in Table XIII. These data indicate:

1. The relative amount of last down yellow that could be printed in the same region as previously printed cyan plus magenta increased in the order 100/(100+100)< 75/(75+75) < 50/(50+50), with 25/(25+25) values similar to 75/(75+75) values. This result is qualitatively the same as all of the two-color trap results despite the intervening cyan ink.

TABLE XIII. PERCENT PREUCIL TRAP OF YELLOW OVER FIRST-DOWN CYAN PLUS MAGENTA AT VARIOUS INK INPUT CONDITIONS AS A FUNCTION OF PERCENT COVERAGE

M K C Y Input Condition[a]	No. of Conditions R	No. of Conditions L	PERCENT COVERAGES 100%/100% R	100%/100% L	75%/75% R	75%/75% L	50%/50% R	50%/50% L	25%/25% R	25%/25% L
1 X 2 1	1	1	74	65	79	69	88	76	79	81
1 X 2 2	-	1	-	70	-	78	-	72	-	84
1 X 2 3	1	-	80	-	82	-	88	-	78	-
2 X 1 5	1	-	81	-	89	-	92	-	77	-
X X 1 5	1	-	96	-	99	-	102	-	86	-
3 X 1 3	-	1	-	65	-	70	-	76	-	67
2 X 2 5	1	-	81	-	88	-	86	-	88	-
2 X 3 2	-	2	-	63	-	70	-	78	-	67
2 X 3 3	4	-	77[b]	-	80[c]	-	89[d]	-	81[e]	-
2 X 3 4	1	-	78	-	87	-	93	-	82	-
3 X 2 5	-	1	-	68	-	71	-	80	-	75
1 X 4 5	1	-	78	-	87	-	93	-	82	-
1 X 5 3	-	1	-	64	-	69	-	78	-	74
3 X 3 3	-	3	-	63[b]	-	67[c]	-	77[d]	-	75[e]
4 X 2 4	1	-	76	-	81	-	87	-	81	-
4 X 2 6	1	-	82	-	91	-	91	-	87	-
2 X 4 6	1	-	86	-	91	-	89	-	63	-
5 X 2 2	-	1	-	62	-	68	-	76	-	76
4 3 X X	1	-	77	-	82	-	85	-	-	-
2 X 5 4	1	-	70	-	70	-	84	-	76	-
3 X 4 5	-	1	-	66	-	68	-	75	-	68
5 X 2 5	-	1	-	68	-	72	-	79	-	75
4 X 3 6	1	-	78	-	86	-	90	-	82	-
2 X 5 6	1	-	79	-	84	-	90	-	80	-
4 X 4 1	1	-	68	-	73	-	82	-	79	-
5 X 3 2	-	1	-	60	-	66	-	78	-	66
4 X 4 3	1	-	75	-	88	-	85	-	81	-
3 X 5 3	-	1	-	59	-	65	-	72	-	68
5 X 3 5	-	1	-	65	-	68	-	79	-	63
3 X 5 5	-	1	-	63	-	69	-	78	-	71
4 X 5 2	-	1	-	59	-	67	-	75	-	70
4 X 5 6	1	-	79	-	84	-	90	-	80	-
5 X 5 1	-	1	-	49	-	55	-	68	-	61
5 X 5 5	-	1	-	62	-	68	-	82	-	74

a. Increasing value of notation corresponds to increasing input ink volume as measured by printed solid optical density.
b. Average deviations from the average are, for b. ±0, c. ±1, d. ±1, e. ±1.

2. Statement 1 applies for all optical density values of 0.68 to 1.00 for magenta, 0.60 to 0.97 for cyan and 0.59 to 0.87 for yellow, therefore for all input ink volumes.

Perusal of Table XIII yields no obvious trends relative to ink volume input variations. However, trends become apparent when these data are rearranged to compare either constant yellow ink input conditions at variable first-down blue conditions or constant first-down blue conditions at variable yellow ink input conditions. To make this comparison the Table V result was employed, which allows using printed solid single ink optical densities as indicative of the relative volumes of ink that were delivered to the regions being measured. Thus Tables XIV through XVII could be constructed which show ink volume effects on third down color trapping. Since optical densities are inconvenient to convey in tables of this type, the optical density numerical group designations of Table III were used to illustrate the trends. These Tables clearly show that for third down ink trapping:

1. The greater the total of the first down inks (magenta plus cyan), the smaller was the percentage of the incoming yellow ink volume that could be transferred to that already printed region. This trend held over the entire range of first down blue volumes corresponding to (M + C) total optical densities from about 1.4 to 2.0. This trend was consistent at all combinations of image coverage, 100/200, 75/150, 50/100 and 25/50.

2. The greater the volume of the last down yellow ink, the greater percentage of that incoming ink volume was transferred to the previously printed blue (magenta plus cyan) region. Again, this trend was consistent over all image coverage conditions and over all ink volume values corresponding to yellow optical densities from 0.59 to 0.87 and printed blue volumes corresponding to optical densities from about 1.4 to 2.0.

Review of Tables X through XII will reveal that these relative ink volume trapping results are also consistent with the two color trapping results. This is an expected result when trapping is considered simply as ink film splitting at the substrate. Intuitively, if the first down ink volume is high, the fraction of incoming ink that can be transferred will be less than that for lower first-down ink volumes. And, the greater the incoming ink volume, the greater fraction of it will be forcibly transferred to the first down ink. In its simplest form, this corresponds to film splitting dictated by:

$$\frac{a + b}{2} = K \qquad (8)$$

where a and b are the incoming and already-printed ink volumes,

TABLE XIV. TRAP VALUES AS A FUNCTION OF RELATIVE INK VOLUMES FOR 100% YELLOW OVER 100%-MAGENTA-PLUS-100% CYAN

CONSTANT YELLOW INPUTS

No. of Conditions R	No. of Conditions L	Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1	1	1/(2+1)	74	65
1	-	1/(4+4)	68	-
-	1	1/(5+5)	-	49
-	1	2/(1+1)	-	70
-	2	2/(2+3)	-	63
-	1	2/(5+2)	-	62
-	1	2/(5+3)	-	60
-	1	2/(4+5)	-	59
1	-	3/(1+2)	80	-
-	1	3/(3+1)	-	65
4	-	3/(2+3)	77[c]	-
-	1	3/(1+5)	-	64
-	3	3/(3+3)	-	63[d]
1	-	3/(4+3)	77	-
1	-	3/(4+4)	75	-
-	1	3/(3+5)	-	59
1	-	4/(2+3)	78	-
1	-	4/(4+2)	76	-
1	-	4/(2+5)	70	-
1	-	5/(2+1)	81	-
1	-	5/(2+2)	81	-
1	-	5/(1+4)	78	-
-	1	5/(3+2)	-	68
-	1	5/(3+4)	-	66
-	1	5/(2+5)	-	68
-	1	5/(3+5)	-	63
-	1	5/(5+3)	-	65
-	1	5/(5+5)	-	62
1	-	6/(2+4)	86	-
1	-	6/(4+3)	78	-
1	-	6/(2+5)	79	-
1	-	6/(4+5)	79	-

CONSTANT (M + C) INPUTS

Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1/(2+1)	74	65
2/(1+2)	-	70
3/(1+2)	80	-
5/(2+1)	81	-
3/(3+1)	-	65
5/(2+2)	81	-
2/(2+3)	-	63
3/(2+3)	77[b]	-
4/(2+3)	78	-
5/(1+4)	78	-
5/(3+2)	-	68
3/(1+5)	-	64
3/(3+3)	-	63[e]
4/(4+2)	76	-
6/(2+4)	86	-
2/(5+2)	-	62
3/(4+3)	77	-
4/(5+2)	70	-
5/(3+4)	-	66
5/(2+5)	-	68
6/(4+3)	78	-
6/(2+5)	79	-
1/(4+4)	68	-
2/(5+3)	-	60
3/(4+4)	75	-
3/93+5)	-	59
5/(3+5)	-	63
5/(5+5)	-	62
2/(4+5)	-	59
6/(4+5)	79	-
1/(5+5)	-	49
5/(5+5)	-	62

a. Increasing notation number corresponds to increasing printed ink volume. Notation 1/(4+4) refers, for example, to yellow ink film input volume condition 1 (lowest) printed over a first down blue ink volume of 8, namely volume of 4 for magenta and 4 for cyan, all volumes measured as optical densities of the corresponding solid single prints.

Average deviations from the mean are, for b. ±1, c. ±0, d. ±0.

TABLE XV. TRAP VALUES AS A FUNCTION OF RELATIVE INK VOLUMES FOR 75%YELLOW TONE OVER 75%-MAGENTA-PLUS-75% CYAN TONES

CONSTANT YELLOW INPUTS

No. of Conditions R	No. of Conditions L	Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1	1	1/(2+1)	79	69
1	-	1/(4+4)	73	-
-	1	1/(5+5)	-	55
-	1	2/(1+2)	-	78
-	2	2/(2+3)	-	70
-	1	2/(5+2)	-	68
-	1	2/(5+3)	-	66
-	1	2/(4+5)	-	67
1	-	3/(1+2)	82	-
-	1	3/(3+1)	-	70
4	-	3/(2+3)	80[c]	-
-	1	3/(1+5)	-	69
-	3	3/(3+3)	-	67[d]
1	-	3/(4+3)	82	-
1	-	3/(4+4)	88	-
-	1	3/(3+5)	-	65
1	-	4/(2+3)	87	-
1	-	4/(4+2)	81	-
1	-	4/(2+5)	70	-
1	-	5/(2+1)	89	-
1	-	5/(2+2)	88	-
1	-	5/(1+4)	87	-
-	1	5/(3+2)	-	71
-	1	5/(3+4)	68	-
-	1	5/(5+2)	-	72
-	1	5/(5+3)	-	68
-	1	5/(3+5)	-	69
-	1	5/(5+5)	-	68
1	-	6/(2+4)	91	-
1	-	6/(4+2)	91	-
1	-	6/(4+3)	86	-
1	-	6/(2+5)	84	-
1	-	6/(4+5)	84	-

CONSTANT (M + C) INPUTS

Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1/(2+1)	79	69
2/(1+2)	-	78
3/(1+2)	82	-
5/(2+1)	89	-
3/(3+1)	-	70
5/(2+2)	88	-
2/(2+3)	-	70
3/(2+3)	80[b]	-
4/(2+3)	87	-
5/(1+4)	87	-
5/(3+2)	-	71
3/(1+5)	-	69
3/(3+3)	-	67[e]
4/(4+2)	81	-
6/(2+4)	91	
2/(5+2)	-	68
3/(4+3)	82	-
4/(2+5)	70	-
5/(3+4)	68	-
6/(4+3)	86	-
6/(2+5)	84	-
	-	
1/(4+4)	73	-
2/(5+3)	-	66
3/(4+4)	88	-
3/93+5)	-	65
5/(3+5)	-	69
5/(5+3)	-	68
2/(4+5)	-	67
6/(4+5)	84	-
1/(5+5)	-	55
5/(5+5)	-	68

a. Increasing notation number corresponds to increasing printed ink volume. Notation 1/(4+4) refers to yellow ink film input volume condition 1 (lowest) printed over a first down blue ink volume of 8, namely a volume of 4 for magenta and 4 for cyan, all volumes measured as optical densities of the corresponding solid single prints.
Average deviations from the mean, for b. ±1, c. ±1, d. ±1, e. ±1.

TABLE XVI. TRAP VALUES AS A FUNCTION OF RELATIVE INK VOLUMES FOR 50% YELLOW TONE OVER 50% MAGENTA-PLUS-50% CYAN TONES

CONSTANT YELLOW INPUTS

No. of Conditions R	No. of Conditions L	Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1	1	1/(2+1)	88	76
1	-	1/(4+4)	82	-
-	1	1/(5+5)	-	68
-	1	2/(1+2)	-	72
-	2	2/(2+3)	-	78
-	1	2/(5+2)	-	76
-	1	2/(5+3)	-	78
-	1	2/(4+5)	-	75
1	-	3/(1+2)	88	-
-	1	3/(3+1)	-	76
4	-	3/(2+3)	89[c]	-
-	1	3/(1+5)	-	78
-	3	3/(3+3)	-	77[d]
1	-	3/(4+3)	85	-
1	-	3/(4+4)	85	-
-	1	3/(3+5)	-	72
1	-	4/(2+3)	93	-
1	-	4/(4+2)	87	-
1	-	4/(2+5)	84	-
1	-	5/(2+1)	92	-
1	-	5/(2+2)	86	-
1	-	5/(1+4)	93	-
-	1	5/(3+2)	-	80
-	1	5/(3+4)	75	-
-	1	5/(5+2)	-	79
-	1	5/(5+3)	-	79
-	1	5/(3+5)	-	78
-	1	5/(5+5)	-	82
1	-	6/(2+4)	89	-
1	-	6/(4+2)	91	-
1	-	6/(4+3)	90	-
1	-	6/(2+5)	90	-
1	-	6/(4+5)	90	-

CONSTANT (M + C) INPUTS

Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1/(2+1)	88	76
2/(1+2)	-	72
3/(1+4)	88	-
5/(2+1)	92	-
3/(3+1)	88	-
5/(2+2)	86	-
2/(2+3)	-	78
3/(2+3)	89[b]	-
4/(2+3)	93	-
5/(1+4)	93	-
5/(3+2)	-	80
3/(1+5)	-	78
3/(3+3)	-	77[e]
4/(4+2)	87	
6/(2+4)	89	-
2/(5+2)	-	76
3/(4+3)	85	-
4/(2+5)	84	-
5/(3+4)	75	-
6/(4+3)	90	-
6/(2+5)	90	-
1/(4+4)	82	-
2/(5+3)	-	78
3/(4+4)	85	-
3/(3+5)	-	72
5/(3+5)	-	78
5/(5+3)	-	79
2/(4+5)	-	75
6/(4+5)	90	-
1/(5+5)	-	68
5/(5+5)	-	82

a. Increasing notation number corresponds to increasing printed ink volume. Notation 1/(4+4) refers to yellow ink film input volume condition 1 (lowest) printed over a first down blue ink volume of 8, namely a volume of 4 for magenta and 4 for cyan, all volumes measured as optical densities of the corresponding solid single prints.

Average deviations from the mean, for b. ±4, c. ±4, d. ±1, e. ±1.

TABLE XVII. TRAP VALUES AS A FUNCTION OF RELATIVE INK VOLUMES FOR 25% YELLOW TONE OVER 25% MAGENTA-PLUS-25% CYAN TONES

CONSTANT YELLOW INPUTS

No. of Conditions R	No. of Conditions L	Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1	1	1/(2+1)	79	81
1	-	1/(4+4)	79	-
-	1	1/(5+5)	-	61
-	1	2/(1+2)	-	84
-	2	2/(2+3)	-	76
-	1	2/(5+2)	-	76
-	1	2/(5+3)	-	66
-	1	2/(4+5)	-	70
1	-	3/(1+2)	78	-
-	1	3/(3+1)	-	67
4	-	3/(2+3)	81[c]	-
-	1	3/(1+5)	-	69
-	3	3/(3+3)	-	75[d]
1	-	3/(4+3)	79	-
1	-	3/(4+4)	81	-
-	1	3/(3+5)	-	68
1	-	4/(2+3)	82	-
1	-	4/(4+2)	81	-
1	-	4/(2+5)	76	-
1	-	5/(2+1)	77	-
1	-	5/(2+2)	88	-
1	-	5/(1+4)	82	-
-	1	5/(3+2)	-	75
-	1	5/(3+4)	68	-
-	1	5/(5+2)	-	75
-	1	5/(5+3)	-	63
-	1	5/(3+5)	-	71
-	1	5/(5+5)	-	74
1	-	6/(2+4)	63	-
1	-	6/(4+2)	87	-
1	-	6/(4+3)	82	-
1	-	6/(2+5)	80	-
1	-	6/(4+5)	80	-

CONSTANT (M + C) INPUTS

Y/(M+C) Input Condition[a]	Trap Value R	Trap Value L
1/(2+1)	79	81
2/(1+2)	-	84
3/(1+2)	78	-
5/(2+1)	77	-
3/(3+1)	-	67
5/(2+2)	88	-
2/(2+3)	-	76
3/(2+3)	81[b]	-
4/(2+3)	82	-
5/(1+4)	82	-
5/(3+2)	-	75
3/(1+5)	-	69
3/(3+3)	-	75[e]
4/(4+2)	81	
6/(4+2)	87	-
2/(5+2)	-	76
3/(4+3)	79	-
4/(2+5)	76	-
5/(3+4)	68	-
6/(4+3)	82	-
6/(2+5)	80	-
1/(4+4)	79	-
2/(5+3)	-	66
3/(4+4)	81	-
3/(3+5)	-	68
5/(3+5)	-	71
5/(5+3)	-	63
2/(4+5)	-	70
6/(4+5)	80	-
1/(5+5)	-	61
5/(5+5)	-	74

a. Increasing notation number corresponds to increasing printed ink volume. Notation 1/(4+4) refers to yellow ink film input volume condition 1 (lowest) printed over a first down blue ink volume of 8, namely a volume of 4 for magenta and 4 for cyan, all volumes measured as optical densities of the corresponding solid single prints.
Average deviations from the mean, for b. ±1, c. ±1, d. ±1, e. ±1.

K is a constant for the press' physical condition,
2 is a film split factor which in this simplest case corresponds to 50/50 film split at the blanket/paper nip exit.

PRINT CONTRAST, GRAYNESS, HUE ERROR

Values were calculated according to Equations (1), (4) and (5) for all 40 of the printing conditions.

Single Color Values - Magenta, cyan, and yellow values are given in Table XVIII. With the possible exception of yellow, there are no significant changes in single color print contrast, grayness or hue error values within the optical density ranges included in this study. The inference is that two-and three-color values will not be confounded by any single ink experimental volume input changes.

TABLE XVIII. PRINT CONTRAST, GRAYNESS, HUE ERROR FOR VARIOUS SINGLE INK INPUT VOLUME CONDITIONS

MKCY Input Conditions[a]	Average Optical Density[b]	No. of Conditions	Print Contrast	Grayness	Hue Value	Error Direction
1XXX	0.68	6	22+	10	44	Red
2XXX	0.77	12	23	10	45	Red
3XXX	0.82	8	23+	10	45	Red
4XXX	0.92	8	23	10+	45	Red
5XXX	1.00	6	25	10	45	Red
XX1X	0.60	2	21	9	22	Blue
XX2X	0.71	10	21	9	24	Blue
XX3X	0.82	14	21	9	23+	Blue
XX4X	0.90	5	21	9	23	Blue
XX5X	0.97	9	21	9	22+	Blue
XXX1	0.59	4	14	4	3	Red
XXX2	0.67	6	14	4	3	Red
XXX3	0.71	13	15	4	3	Red
XXX4	0.73	3	15	3	3	Red
XXX5	0.80	8	13	3	3	Red
XXX6	0.87	5	13	2	3	Red

a. Increasing notation value corresponds to increasing input ink film volume as measured by solid optical density.
b. Measured value minus paper value.

Two-Color Values - Hue error and grayness values for the three two-color overprints under all 40 printing conditions are shown in Tables XIX, XX, and XXI. These data illustrate several interesting results:

1. Grayness values of two color prints as calculated here, equation 5, are completely insensitive to variations in volume of either ink. Obviously, two color grayness represents a useless control parameter.

2. Hue error values and directions change with increasing quantities of second down ink in the qualitative manner expected. Obviously, these values can be used effectively for print quality control.

3. Hue error is affected by cross-press differences. The right- and left-hand target values for similar ink film input conditions are significantly different. In keyless inking this could mean press roller and cylinder interrelationships may be more important than with conventional keyed inking. With the appropriate real-time tools, these cross-press differences could have been corrected by inking key adjustments.

4. With an appropriate panel of observers, these hue error factors could probably be sensibly related to pictorial appearance differences. However, this would better be done with three color overprint values.

Three-Color Values - Grayness and hue error values for all 40 conditions are listed in Table XXII. These results show:

1. Contrary to calculated two-color greyness values and as expected, three-color values vary as the amounts of the three inks are changed. Of course, the gray value is not a singular indication of quality. For instance, conditions 1X21, 2X54, 4X41, 4X43, and 5X51 all have a gray value of 76 to 78. These do not correspond to equivalent ratios of ink inputs nor to equivalent optical densities with or without paper density included.

2. Hue error values and direction are in accord with expectations for the various ink volume quantities represented.

TABLE XIX. GRAYNESS AND HUE ERROR FOR CYAN ON MAGENTA OVERPRINTS AT VARIOUS INK VOLUME INPUT CONDITIONS

MKCY Input Volume Condition[a]	No. of Conditions		Grayness		HUE ERROR Value		HUE ERROR Direction	
	R	⊥	R	⊥	R	⊥	R	⊥
1X2X	2	2	47	47	4	22	M	M
1X4X	1	-	37	-	28	-	C	-
1X5X	-	1	-	43	-	13	-	C
2X1X	1	-	47	-	48	-	M	-
2X3X	4	2	46[b]	47	10[c]	24	C/M	M
2X4X	1	-	45	-	7	-	C	-
2X5X	2	-	41	-	19	-	C	-
3X1X	-	1	-	49	-	62	-	M
3X2X	-	1	-	48	-	49	-	M
3X3X	-	3	-	48[d]	-	36[e]	-	M
3X4X	-	1	-	48	-	21	-	M
3X5X	-	2	-	47	-	6	-	M
4X2X	2	-	48	-	57	-	M	-
4X3X	2	-	47	-	36	-	M	-
4X4X	2	-	47	-	10	-	M	-
4X5X	1	1	48	47	4	30	M	M
5X2X	-	2	-	48	-	76	-	M
5X3X	-	2	-	48	-	56	-	M
5X5X	-	2	-	47	-	32	-	M

a. Increasing notation value corresponds to increasing input ink volume as measured by solid optical density.
Average deviations from the mean, for b. ±1, c. ±8, d. ±0, e. ±9.

TABLE XX. GRAYNESS AND HUE ERROR FOR YELLOW ON MAGENTA OVERPRINTS AT VARIOUS INK VOLUME INPUT CONDITIONS.

MXCY Input Volume Condition[a]	No. of Conditions		Grayness		HUE ERROR Value		HUE ERROR Direction	
	R	⊥	R	⊥	R	⊥	R	⊥
1XX1	1	1	10	11	16	11	Y	Y
1XX2	-	1	-	9	-	21	-	Y
1XX3	1	-	8	-	26	-	Y	-
1XX5	1	-	8	-	29	-	Y	-
2XX2	-	2	-	10	-	13	-	Y
2XX3	4	-	9[b]	-	18[c]	-	Y	-
2XX4	2	-	8	-	22	-	Y	-
2XX5	2	-	8	-	22	-	Y	-
2XX6	2	-	8	-	27	-	Y	-
3XX3	-	5	-	9[d]	-	15[e]	-	Y
3XX5	-	3	-	8[f]	-	22[g]	-	Y
4XX1	1	-	11	-	6	-	M	-
4XX2	-	1	-	11	-	2	-	Y
4XX3	2	-	9	-	8	-	Y	-
4XX4	1	-	10	-	6	-	Y	-
4XX6	3	-	8[h]	-	21[i]	-	Y	-
5XX1	-	1	-	12	-	12	-	M
5XX2	-	2	-	10	-	2	-	Y/M
5XX5	-	3	-	9	-	11	-	Y

a. Increasing notation value corresponds to increasing input ink volume as measured by solid optical density.
Average deviations from the mean are, for b. ±0, c. ±2, d. ±1, e. ±1, f. ±0, g. ±2, h. ±0, i. ±0.

TABLE XXI. GRAYNESS AND HUE ERROR FOR YELLOW ON CYAN OVERPRINTS AT VARIOUS INK VOLUME INPUT CONDITIONS.

MKCY Input Volume Condition[a]	No. of Conditions		Grayness		HUE ERROR Value		HUE ERROR Direction	
	R	⊥	R	⊥	R	⊥	R	⊥
XX15	1	-	29	-	38	-	Y	-
XX21	1	1	36	35	17	32	C	C
XX22	-	2	-	36	-	6	-	C
XX23	1	-	34	-	12	-	Y	-
XX24	1	-	34	-	8	-	Y	-
XX25	-	2	-	31	-	25	-	Y
XX26	1	-	28	-	38	-	-	Y
XX32	-	3	-	35[b]	-	26[c]	-	C
XX33	5	3	36[d]	36[e]	8[f]	10[g]	-	C
XX34	4	-	36	-	-	-	C	-
XX35	-	1	-	34	-	9	-	Y
XX36	-	1	-	14	-	77	-	Y
XX41	1	-	34	-	53	-	C	-
XX43	1	-	34	-	23	-	C	-
XX45	1	1	34	35	18	5	C	-
XX46	1	-	35	-	4	-	Y	-
XX51	-	1	-	33	-	66	-	C
XX52	-	1	-	34	-	43	-	C
XX53	-	1	-	34	-	34	-	C
XX54	1	-	35	-	27	-	C	-
XX55	-	1	-	35	-	21	-	C
XX56	2	-	35	-	3	-	C	-

a. Increasing notation value corresponds to increasing input ink volume as measured by solid optical density.
Average deviations from the mean are, for b. ±0, c. ±2, d. ±0, e. ±0, f. ±2, g. ±5.

TABLE XXII. GRAYNESS AND HUE ERROR FOR THREE COLOR OVERPRINT TARGETS AT VARIOUS INK VOLUME INPUT CONDITIONS.

MKCY Input Volume Condition[a]	No. of Conditions		Grayness		HUE ERROR Value		HUE ERROR Direction	
	R	⊥	R	⊥	R	⊥	R	⊥
1X21	1	1	76	86	32	57	Y(Red)	Mag(Red)
1X22	-	1	-	84	-	5	-	Mag(Red)
1X23	1	-	67	-	51	-	Y(Red)	-
1X45	1	-	80	-	77	-	Y(Red)	
1X53	-	1	-	95	-	18	-	Cyan(Blue)
2X15	1	-	52	-	34	-	Y(Red)	-
2X25	1	-	57	-	40	-	Y(Red)	-
2X32	-	2	-	85	-	48	-	M(Red)
2X33	4	-	70[b]	-	30[c]	-	Y(Red)	-
2X34	1	-	72	-	37	-	Y(Red)	-
2X46	1	-	63	-	48	-	Y(Red)	-
2X54	1	-	78	-	39	-	Y(Red)	-
2X56	1	-	71	-	62	-	Y(Red)	-
3X13	-	1	-	67	-	2	-	M(Red)
3X25	-	1	-	72	-	14	-	Y(Red)
3X33	-	3	-	81[d]	-	19[e]	-	M(Red)
3X45	-	1	-	85	-	16	-	Y(Red)
3X53	-	1	-	93	-	61	-	M(Blue)
3X55	-	1	-	94	-	11	-	Y(Red)
4X24	1	-	59	-	2	-	Y(Red)	-
4X26	1	-	50	-	28	-	Y(Red)	-
4X33	1	-	66	-	2	-	Y(Red)	-
4X36	1	-	59	-	36	-	Y(Red)	-
4X41	1	-	77	-	59	-	M(Red)	-
4X43	1	-	76	-	3	-	M(Red)	-
4X52	-	1	-	82	-	88	-	M(Red)
4X56	1	-	67	-	38	-	Y(Red)	-
5X22	-	1	-	62	-	33	-	M(Red)
5X25	-	1	-	61	-	1	-	M(Red)
5X32	-	1	-	70	-	46	-	M(Red)
5X35	-	1	-	70	-	8	-	M(Red)
5X51	-	1	-	75	-	64	-	M(Blue)
5X55	-	1	-	82	-	20	-	M(Red)

a. Increasing notation value corresponds to increasing input ink volume as measured by solid optical density.
Average deviations form the mean are, for b. ±5, c. ±6, d. ±4, e. ±3.

3. The highest gray values, 93 to 95, are for cyan high compared with yellow and magenta, conditions 1X53, 3X53, and 3X55, whereas the least hue error is for equal or low values of cyan relative to each of the other two inks, 3X13, conditions 4X24, 4X33, 4X43, and 5X25, Table XXIII.

TABLE XXIII. INK INPUT CONDITIONS CORRESPONDING TO LEAST HUE ERROR

Hue Error R	Hue Error L	Ink Condition R	Ink Condition L
-	2	-	3X13
2	-	4X24	-
2	-	4X33	-
3	-	4X43	-
-	1	-	5X25

4. None of the right-hand targets achieved the highest gray values although both target positions achieved lowest hue error values. The latter were, of course, achieved at qualitatively differing ink input values.

These three-color cross-press results infer that an excellent compromise of greyness and hue error values can be achieved by what can be termed shade control of keyless inking. That is, a means for overall cross-press or page-wide ink-input variation should allow quality equivalent to keyed inking systems. With the potential for simplified real-time color measurement control using keyless input rather than keyed, the overall result is expected to be more consistent and more uniform color quality throughout a press run whether or not shade control is available.

Multiple Grayness Values - It seemed incongruent that in Table XXII grayness value is not uniquely defined by three ink densities. For instance, conditions 1X21, 2X54, 4X41 and 4X43 all had a 77±1 grayness value. As the single color ink input optical density values in Table XXIV illustrate, these four conditions correspond to quite different single color ink input rates. However, treating these values as ink volumes (according to the Table V results) and correcting them for the appropriate condition's Preucel apparent trap values in Tables X and XIII, produces values representing the relative ink volumes that were actually printed, shown in Table XXV. Calculation of the relative individual printed ink volumes as (single color density/total of three color densities) gives the Table XXVI values. These data illustrate that equal grayness value is achieved at similar volume proportions of the single color inks, not necessarily at equal single color optical density (ink input) values.

TABLE XXIV. PRINTING CONDITIONS HAVING PREUCIL GRAYNESS VALUE OF 77±1.

MKCY Volume Input Condition	Relative Single-Color Ink Input Volumes[a] M	C	Y
1X21	0.65	0.72	0.62
2X54	0.76	0.95	0.73
4X41	0.92	0.93	0.59
4X43	0.90	0.91	0.72

a. OD values of major color component as single color print, from Table III.

TABLE XXV. CORRECTED THREE-COLOR PRINTED INK VOLUMES OF TABLE XXIV

MKCY Volume Input	Relative Single-Color Ink Input Volumes[a]			Corrected Printed Ink Volumes		
Condition	M	C	Y	M	C	Y[b]
1X21	0.65	0.72	0.62	0.65	0.71	0.46
2X54	0.76	0.95	0.73	0.76	0.94	0.51
4X41	0.92	0.93	0.59	0.92	0.88	0.40
4X43	0.90	0.91	0.72	0.90	0.86	0.43

a. From Table XXIII.
b. Single color OD multiplied by Preucil trap value (as a fraction) using condition value for cyan from Table X and for yellow from Table XIII.

TABLE XXVI. CORRELATION OF GRAYNESS VALUES WITH RELATIVE PRINTED INK VOLUMES

MKCY Volume Input Condition	Corrected Single-Color OD Values[a]			Relative Total Ink Volume[b]	Relative Volume Fractions of Printed Inks[c]		
	M	C	Y		M	C	Y
1X21	0.65	0.71	0.46	1.82	0.36	0.39	0.25
2X54	0.76	0.94	0.51	2.21	0.34	0.42	0.23
4X41	0.92	0.88	0.40	2.20	0.42	0.44	0.24
4X43	0.90	0.86	0.43	2.29	0.39	0.38	0.23
				Averages	0.38 ±0.03	0.41 ±0.02	0.24 ±0.01

a. From Table XXV.
b. Total of M+C+Y density values.
c. Ratio of corrected OD values to relative total ink volume.

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