Densitometer Aperture Size
vs.
Density Measurements and Dot Area Calculations

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Abstract

During the beginning of the GATF Flexographic Project (1983-1986), a densitometer with a measuring diameter of 3.2 mm was used to measure optical density and percent dot area. Variability in the resulting measurements was unexpectedly high. Tests indicated that measuring techniques were not at fault. Multiple measurements on a single sheet confirmed that there was a reduction of noise in the data when a densitometer with a large measuring area (4.0 mm) was used. Because of the improvement in the quality of the data, the large-spot densitometer was used for density measurements and dot area calculations throughout the project.

Conclusions

Densitometers with larger measuring areas minimize noise in the data. The optimum size for a densitometer would be a measuring diameter of 4.5 mm, a measuring area of about 16 square millimeters.

The optimum viewing area for an electronic planimeter would be about six or seven square millimeters for the two units described in this report. A smaller area is sufficient for the planimeter because it is possible to line up the target dots using the TV screen and reference to a solid patch is not required for making dot area measurements.

When measuring magenta, cyan, and black tints of 25, 50, and 75%, the small-spot densitometer consistently read low on the 50% tints and the medium-spot unit read high on the 50% tints. Of the three units, the large-spot densitom-

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eter generated the smoothest data.

Densitometer reading variations are inversely proportional to the instrument viewing area. The data indicate that screen ruling has no predictable effect.

Introduction

An important measurement associated with print quality is the optical ink film density. In GATF's flexographic studies, this measurement was essential for measuring variations in printed work. The density measurements obtained during the flexographic study were used to evaluate inks, papers, and printing.

Dot area size is of concern in any printing process. Because of problems with tone value changes during prepress and dot gain while printing, it is necessary to monitor the size of the printed dot in order to control production.

Examination of the densitometer readings and the dot area calculations made for the flexo study indicated variations in the data that were higher than expected. It was proposed that these variations were caused by the relatively small viewing area of the densitometer.

Three densitometers were used to test the hypothesis. Included were a densitometer with a measuring diameter of 1.6 mm (which will be referred to as Dens-S), a densitometer with a measuring diameter of 3.2 mm (referred to as Dens-M), and a densitometer with a measuring diameter of 4.0 mm (referred to as Dens-L), with S, M, and L representing small, medium, and large.

In this report the coefficient of variation (CV) is used for making comparisons between sets of data (see Appendix I). The advantage in using CV with such measurements as densities is that we can compare the variations within a set of data for yellow prints (low densities) with those for a set of black readings (high densities). The set with the lowest relative scatter will have the lowest CV.

Densitometers

The initial flexographic commercial runs (1, 2, 3, and 4) were analyzed using Dens-M with an area 3.2 mm in diameter.

For each run, 20 and 40% halftones and solid target areas of the four primary colors (yellow, magenta, cyan, and black) were available for density measurements. Statistics for some of these targets are shown in Table I. These samples were printed on newsprint. The examples used were randomly selected.

Table I. Sample Density Statistics from Four Test Runs
Densitometer Dens-M

Run #	Target	Mean	Range	Std Dev	CV
1	Yellow 20%	.42	.10	.023	5.5
1	Magenta solid	.92	.14	.041	4.5
1	Cyan 40%	.50	.17	.053	10.6
2	Yellow solid	.84	.29	.038	4.6
2	Cyan 40%	.49	.11	.024	4.8
2	Black solid	1.08	.11	.029	2.7
3	Yellow 40%	.24	.12	.027	11.3
3	Magenta 20%	.12	.07	.017	13.8
3	Cyan 20%	.15	.16	.029	18.8
4	Yellow solid	.53	.23	.052	9.8
4	Magenta 40%	.18	.08	.019	10.4
4	Black solid	.84	.26	.059	7.0

Referring to Table I, values for range, standard deviation, and coefficient of variation were higher than expected in many cases. These results, in conjunction with low correlation coefficients obtained by comparing dot area measurements for each color, indicated a problem. For example, a high correlation is expected when a 20% yellow halftone and a 40% yellow halftone in the same job are compared. If the density of one halftone area for a given ink changes, a similar change in other halftone areas for the same ink is expected. For most of the correlations computed, the coefficients were low. In other words, a change in the density of the 20% tint was not necessarily reflected by a similar change in the 40% tint of the same color on the same sheet.

At this point, it was decided to investigate the measuring technique. Twenty-five consecutive signatures from a flexographic press test were measured with densitometer Dens-M on solid and 25%, 50%, and 75% halftone targets. Targets with both 65- and 85-line screen rulings in all four colors were measured. Table II illustrates the inconsistent results that were obtained. The ranges and coefficients of variation again were higher than expected. Further investigation was indicated.

Table II. Examples of Density Statistics--Test 1A
25 consecutive signatures (65- and 85-line screen rulings)

	Densitometer Dens-M				
Sheet ID*	Target	Mean	Range	Std Dev	CV
1C6	Yellow 25%	.13	.03	.011	8.7
1C6	Magenta 25%	.10	.03	.008	8.1
1C6	Cyan 25%	.11	.04	.010	10.0
1C8	Cyan 25%	.10	.10	.018	18.1
1G8	Yellow 50%	.43	.05	.013	3.0
1G8	Black 75%	.51	.14	.037	7.3
1G8	Black 25%	.12	.05	.014	12.2
2G6	Cyan 75%	.50	.14	.037	7.4
2G8	Magenta 50%	.23	.03	.009	3.9

* Impression (1 or 2); center or gear; 65 or 85 lpi

The coefficient of variation data from two flexo runs (3 and 4) were available, and again, Dens-M was used to measure densities. Table III shows typical values obtained from these readings.

Table III. Examples of Density Statistics--Two Flexo Runs

		Densitometer Dens-M			
Run #	Target	Mean	Range	Std Dev	CV
3	Yellow 40%	.20	.09	.022	11.4
3	Cyan 20%	.11	.13	.024	21.6
3	Magenta 20%	.09	.06	.016	16.8
3	Black solid	.88	.17	.051	5.8
4	Yellow 20%	.11	.06	.014	13.0
4	Magenta solid	.45	.16	.039	8.8
4	Cyan 40%	.24	.06	.012	4.8
4	Magenta 40%	.20	.05	.011	5.5

Again, the results were disappointing. Poor correlation between halftones of the same color again indicated that measurement variations were greater than expected.

Flexography uses a very low printing pressure (plate/paper squeeze). Coupled with the roughness of the newsprint surface, this makes it difficult to achieve a uniform print. The substrate's roughness prevents the ink from completely covering the paper's surface. These variations are especially apparent when examining solids. Another factor which was thought to contribute to measurement variations was coarse screen ruling. Because the densitometer is measuring a small area, relatively few dots are included in the aperture. As it turned out, screen ruling had no effect.

Having recognized the problems and probable causes, tests were then conducted to determine the best instrumentation to be used for density measurements. At this time the study was expanded to include dot area measurements. It was proposed that a larger measuring area would help to minimize the problems illustrated in Tables I, II, and III.

To determine the effects of measuring area on variations and ranges, three densitometers with different viewing areas were evaluated. The measuring area diameters of the three densitometers were: Dens-S, 1.6 mm; Dens-M, 3.2 mm; and Dens-L, 4.0 mm.

The next step consisted of evaluating a single newsprint test sheet. The sheet, printed during the flexo test program and designated XYZ, was measured by each of the three densitometers. Each of the instruments was calibrated according to manufacturer's instructions. Ten separate readings were taken with each instrument on a 65-line GATF Color Reproduction Guide. The targets were 25, 50, and 75% halftones and solids for each color. Table IV shows the averages (coefficients of variation and ranges) for sheet XYZ along with the corresponding instrument measuring areas.

Table IV. Density Range and Coefficient of Variation by Target Size--Test Sheet XYZ

Instrument	Viewing Area Dia. (mm)	Viewing Area (mm^2)	Avg CV	Avg Range
Dens-S	1.6	2.0	5.5	5.3
Dens-M	3.2	8.0	3.6	3.1
Dens-L	4.0	12.6	1.8	1.1

Figure 1 plots the average coefficients of variation and the average ranges for each densitometer as listed in Table IV. On the left, the CV data is plotted against the measuring area. This graph clearly indicates that variations decrease as the measuring area increases. Extrapolation of the curve down to the right indicates that a measuring area of 16 mm^2 (4.5 mm in diameter) would be optimum.

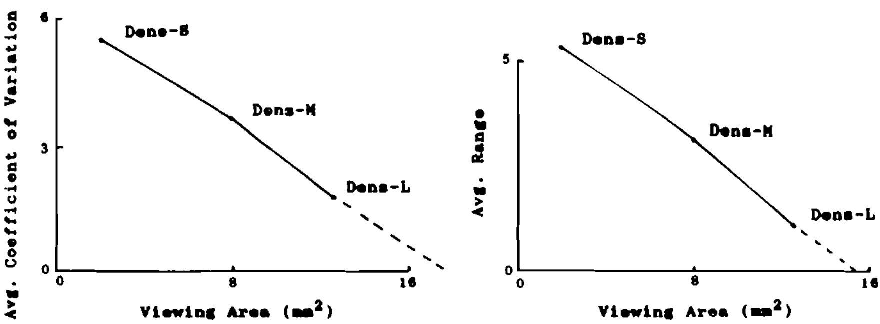


Figure 1. Density Scatter as a Function of Measuring Area

As seen on the right side of Figure 1, the range of density readings also decreases as measuring area increases. This graph also indicates an ideal measuring area of about 16 square millimeters.

Based upon these results, densitometer Dens-L was selected for density measurements in the flexography study.

Table V compares the coefficients of variation for density readings made by densitometers having viewing diameters of 3.2 mm and 4.0 mm. Data from flexo runs 3 and 4 are included. Because of the nature of the work, not all of the target areas were available for measurement on both runs. The notation "N/A" indicates that particular target area was not available. The data are averaged by color (vertically), by dot area (horizontally), and as a complete set (lower right corner). In almost all cases the larger aperture densitometer has lower values, indicating more consistent results.

These results from production jobs illustrate the improved consistency obtained by using a densitometer with a larger viewing area.

Table V. Coefficients of Variation--Density Readings

Test 3

3.2 mm Aperture (Dens-M) Dot Area	Y	M	C	K	Avg
20%	N/A	17	22	N/A	19
40%	11	9	12	N/A	11
Solid	8	7	10	6	8
Avg	10	11	14	6	11

4.0 mm Aperture (Dens-L) Dot Area	Y	M	C	K	Avg
20%	N/A	12	17	N/A	15
40%	9	9	10	N/A	9
Solid	9	5	9	5	7
Avg	9	9	12	5	10

Test 4

3.2 mm Aperture (Dens-M) Dot Area	Y	M	C	K	Avg
20%	13	12	10	N/A	12
40%	10	6	5	N/A	7
Solid	9	9	4	7	7
Avg	11	9	7	7	9

4.0 mm Aperture (Dens-L) Dot Area	Y	M	C	K	Avg
20%	9	11	12	N/A	11
40%	7	7	6	N/A	7
Solid	7	8	4	6	7
Avg	8	9	8	6	8

Dot Area

Having precise measurements of dot area, along with density measurements, is necessary to characterize the way that inks transfer from plate to substrate. The Murray-Davies equation was used to calculate dot area:

$$\text{Percent Dot Area} = 100(1-10^{(-D_t)})/(1-10^{(-D_s)})$$

Where: D_t = Density of the tint area
D_s = Density of the solid area

D_t and D_s are measured relative to the paper

The instruments evaluated were four densitometers and two electronic planimeters. The densitometers were one Dens-S, two Dens-M, and a Dens-L.

Planimeters

The planimeter makes a direct measurement of printed area. We worked with two. The first, with a viewing area of 1.7 x 1.1 mm (1.9 mm^2) is referred to as Plan-X. The second with viewing areas of 1.6 x 1.2 mm (1.9 mm^2) and 2.4 x 1.9 mm (4.6 mm^2) is referred to as either Plan-S or Plan-L. Both units use a nine inch CRT to display the area being analyzed. An advantage over the densitometer is that dot area calculations are made without reference to the density of a "solid" target area. The main disadvantages of these units are their relative immobility, the time required to make readings, and the subjective setting of Plan-X.

Plan-X is manually adjusted to set the area that the unit considers as printed. The discrimination between printed and non-printed areas is not easily defined because of the gradual transition between printed and non-printed areas. A judgment as to where the edge of the dot actually occurs must be made by the operator. This determination is aided by the use of the "index" switch. In the index mode, the TV monitor displays the area being detected as printed by the instrument. By flipping back and forth between "index" and "view" the operator can see any difference in the size of the dot as determined by the operator and that which is seen by the machine. The detected area is adjusted until the two images are in agreement. The percent dot area can then be read.

The other planimeter (Plan-S/Plan-L) is equipped with an automatic indexing mode. In this mode, the planimeter automatically decides the area of the target being detected. The selections it makes agree well with test procedures developed to determine physical dot areas.

With the planimeters there is less variation associated with a small viewing area. By using the TV image, samples can be placed in the same position under the viewing head.

Planimeters vs. Densitometers

A study of the instruments used for dot area measurements was conducted to determine their reliability for the flexo project. The same test sheet (XYZ) used for the density analysis was used for dot area measurements. The target was a 65-line GATF Color Reproduction Guide. As with the density readings, ten readings of each test area were made with each instrument. The mean, standard deviation, coefficient of variation, and range were calculated for each group of ten readings. Measurements were made on yellow, magenta, cyan, and black targets with nominal dot areas of 25, 50, and 75%.

Table VI. Dot Area Data

Aperture vs Coefficient of Variation and Range

Instrument	Reading Area Dia. (mm)	Reading Area (mm^2)	Average CV	Average Range
Dens-S	1.6 dia.	2.0	4.7	9.4
Dens-M	3.2 dia.	8.0	2.8	4.1
Dens-L	4.0 dia.	12.6	1.3	1.7
Plan-X	1.7 x 1.1	1.9	3.4	4.4
Plan-S	1.6 x 1.2	1.9	3.4	3.6
Plan-L	2.4 x 1.9	4.6	1.7	1.5

Table VI lists the reading areas of the various instruments along with the coefficients of variation and ranges (averages from twelve sets of ten readings each). Data from Table VI is plotted in Figure 2.

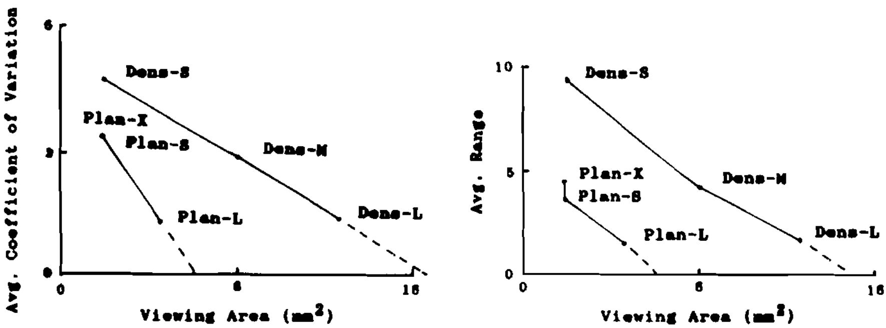
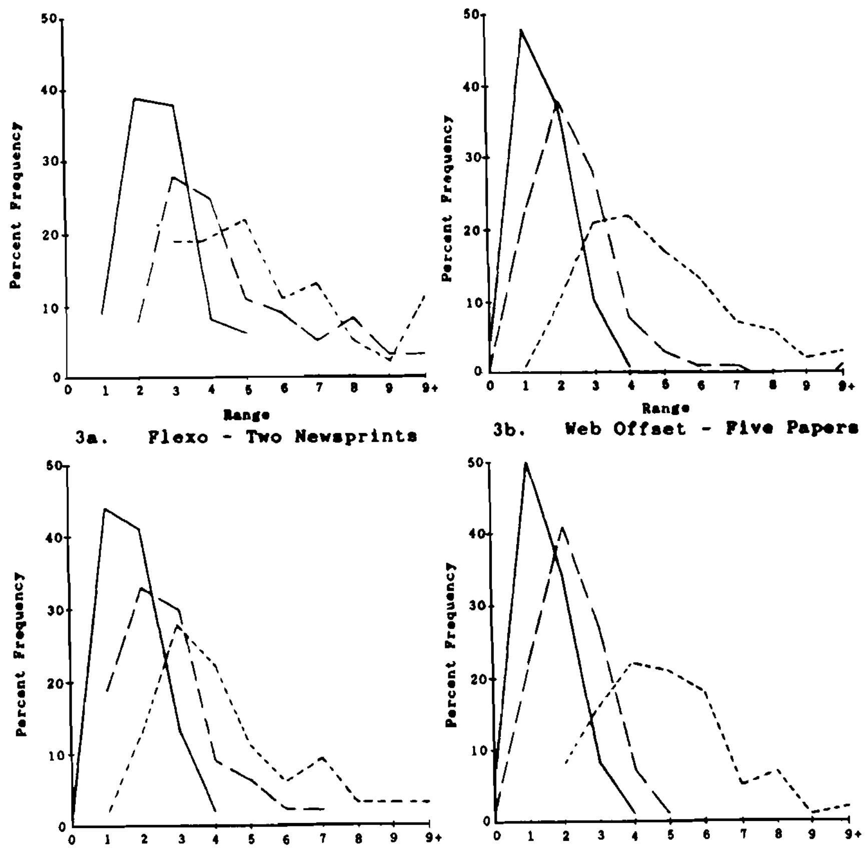


Figure 2. Dot Area Averages and Ranges as a Function of Measuring Area

There is a reduction in the scatter of the data as the reading area increases. This is true for both the densitometers and the planimeters with the best overall performance coming from Dens-L, the device with the largest aperture. Extrapolation of the curves down to the right indicates that the optimum aperture size for the densitometers should be about 16 mm^2 (approximately 4.5 mm in diameter). Similarly, a planimeter would ideally read an area of about 6 or 7 mm^2.

Density Ranges: Flexo and Web Offset

For the following comparisons, data from both flexo and heatset web offset runs were generated. Both the flexo and



3a. Flexo - Two Newsprints

3b. Web Offset - Five Papers

3c. Web Offset - Two Newsprints

3d. Web Offset - Three Higher Quality Papers

Viewing Diameter: 1.6mm - - - - 3.2mm — — 4.0mm ———

Figure 3. Frequency Distribution of Density Ranges Flexo and Web Offset

web offset targets were printed on the same two newsprints. In addition, high-quality uncoated, coated, and gloss coated papers were measured for the web offset. To generate the data for each paper, 32 readings on each of 32 targets were made. The targets were the 25, 50, and 75% tints and solids of the four primary inks and each set included both 65- and 85-line screen rulings.

For each of the 32 readings on each individual target, a range figure was obtained by subtracting the lowest density value from the highest density value. Figure 3 plots the ranges (horizontal axis) against the frequency of occurrence. Figure 3a plots the data for flexo, and Figures 3b, 3c, and 3d for heatset web offset.

Ideally, all of the range values would be zero. Therefore, as a plot extends to the right of the graph, the data are more scattered. As can be seen in the four plots, the data for the densitometer with the largest measuring area (solid line) always shows less scatter and the data for the densitometer with the smallest area (short dashes) always has the most scatter.

Accepting the premise that a density difference of 0.03 density units represents the minimum visually discernible difference, all range values under 0.04 are considered acceptable and all ranges greater than 0.05 are considered unacceptable. Range figures of 0.04 and 0.05 are treated as questionable. These classifications are arbitrary.

Referring to Figure 3, the 4.0 mm densitometer generated only acceptable readings. No readings had a range greater than 0.05 and, only for the flexo data did a few 0.05 values occur. It can also be seen that in every case, the 1.6 mm densitometer has more unacceptable values than does the 3.2 mm densitometer.

Figures 3c and 3d separate the web offset data into newsprint and other types of paper. This allows direct comparison between flexo (3a) and web offset (3c) on newsprint. For all densitometers, there are fewer unacceptable readings for the web offset data.

Figure 4 contains the plots of the percentage distribution of acceptable, questionable, and unacceptable range values derived from the data plotted in Figure 3. In the bar graphs the clear block at the top indicates the percentage of acceptable values (groups with ranges less than 0.04), the shaded block the percentage of questionable values, and the black block the percentage of unacceptable values (groups with ranges greater than 0.05).

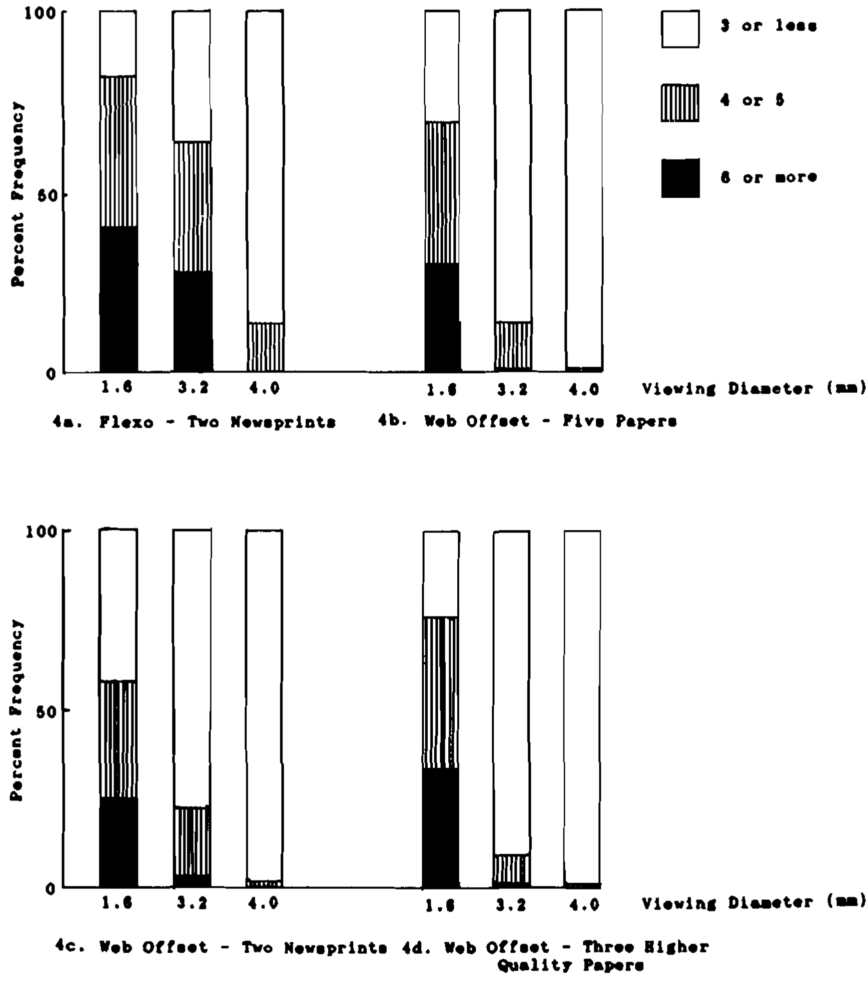


Figure 4. Distribution of Ranges--Three Densitometers

Screen Ruling

Analysis of the data from the flexo project has shown that for the small-spot densitometer, there appeared to be more scatter in the data at 65 lines per inch than at 85 lines per inch. To test the effect of screen ruling on data scatter a heatset web offset target sheet which included a multiple dot area/screen ruling target (ByChrome) was measured. The target included tint values of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 95% for each screen ruling of 65, 85, 100, 110, 120, 133, and 150 lines per inch.

Targets printed in each of the four process colors were measured. The 20, 50, and 70% tints were read for each of the seven screen rulings. Each target area was measured ten times with densitometers having 1.6 and 3.2 mm viewing areas (Dens-S and Dens-M). The measure of data scatter used was the coefficient of variation (see Appendix A).

It was expected that the scatter of density readings would decrease as the screen ruling increased. To test this hypothesis, the coefficients of variation (CV) for each group of ten readings (four colors, three tint values, seven screen rulings) were linearly correlated against the screen rulings (65, 85, 110, 120, 133, and 150 lpi). The correlations were expected to be negative, that is, less scatter with the higher screen rulings.

Table VII lists the coefficients of variation (x100) for each group of ten readings for densitometer Dens-S. Table VIII lists the same data for densitometer Dens-M. The CVs

Table VII. Densitometer Dens-S

	Dot Area	Screen Ruling 65	85	100	110	120	133	150	Corr. Coef.
Yellow	20	117	94	55	122	39	77	131	-.02
	50	67	30	44	131	59	47	84	0.22
	70	54	64	87	44	17	30	24	-.65
Magenta	20	94	130	41	65	116	73	76	-.27
	50	57	86	25	85	100	66	111	0.50
	70	67	107	134	30	60	70	71	-.25
Cyan	20	133	103	93	91	72	190	157	0.37
	50	177	82	47	45	34	52	83	-.60
	70	30	43	39	51	28	33	36	-.06
Black	20	227	163	110	150	135	53	79	-.88
	50	95	82	67	46	38	21	14	-.99
	70	109	49	42	18	65	168	57	0.09

are for each of the four process colors at the three tint values measured.

The rightmost column in each table lists the correlation coefficient of the seven CVs and the various screen rulings. Correlations on the order of -0.95 or better were expected. However, the data follow no pattern. The correlation coefficients for Dens-S range from -0.99 to +0.50 and those for Dens-M from -0.73 to +0.81. No relationship between screen ruling and scatter in densitometer readings was found.

Table VIII. Densitometer Dens-M

	Dot Area	Screen Ruling 65	85	100	110	120	133	150	Corr. Coef.
Yellow	20	28	30	16	51	33	32	33	0.25
	50	44	34	22	9	13	20	41	-.27
	70	17	23	37	24	20	16	13	-.35
Magenta	20	48	42	17	39	51	17	31	-.41
	50	21	23	14	22	26	45	21	0.39
	70	15	68	34	30	12	41	35	-.01
Cyan	20	41	45	34	77	74	99	81	0.81
	50	39	37	45	55	22	37	36	-.20
	70	20	18	11	8	8	20	17	-.15
Black	20	77	61	79	82	39	28	49	-.65
	50	52	59	78	29	24	8	19	-.73
	70	29	15	8	10	15	15	8	-.67

Summary

As a result of the study of reflection densitometers for the GATF Flexography Project, it was found that densitometers with relatively large viewing areas had less noise in their readings.

The optimum measuring area for a reflection densitometer was projected to be 4.5 mm in diameter (16 mm^2). The optimum measuring area for an electronic planimeter was projected to be about 6 or 7 mm^2.

Appendix I: Coefficient of Variation

This report uses the coefficient of variation instead of the standard deviation when making comparisons between different groups of similar data. This is done because standard deviation does not reflect the relative differences between sets of data as does the coefficient of variation. The coefficient of variation is 100 times the std. dev./mean.

This example uses three groups of data which are identical except for their relative size. Group 1 is made up of ten numbers between 10 and 17. Group 2 is the Group 1 multiplied by three and Group 3 is Group 1 multiplied by six.

Table I

Group 1:	16,	11,	15,	11,	15,	12,	14,	12,	13,	12
Group 2:	48,	33,	45,	33,	45,	36,	42,	36,	39,	36
Group 3:	96,	66,	90,	66,	90,	72,	84,	72,	78,	72

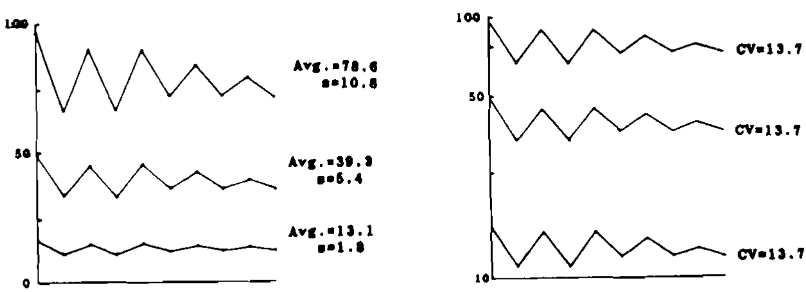


Figure 1. Linear and Semilog Plots of Table I

The data in Table I are plotted in Figure 1. On the left, the vertical axis is linear. It is very difficult to see that there is any similarity in the relative spread of the three plots, although it is exactly the same. Beside the plot are listed the average and std. dev. for each set of data. Even with this information it is very difficult to see that the three sets have the same relative spread.

On the right side of Figure 1 the same data are plotted, but this time the vertical axis is logarithmic. It is quite apparent that the three sets of data are very similar.

On the right of the semi-log plot are listed the coefficients of variation. They are all 13.7, indicating that the relative variation of the three sets of data are the same. In essence, the coefficient of variation lets us compare different sets of data as if they were on a logarithmic scale. This is very convenient when looking for the relative spread of a data set.