The Relationship Between Paper Properties and the Optical and Mechanical Dot Gain of Prints

John T. Lind* and John MacPhee**

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Abstract: A procedure using relatively inexpensive laboratory equipment is described for measuring the physical areas of halftone dots on lithographic prints. Means for validating such measurements are described and then demonstrated using a series of measurements of a test form that was printed on fifteen different substrates ranging from #1 coated to uncalendered newsprint. The same series of measurements is also used to determine the corresponding mechanical and optical dot gains. Data from a previous paper are recalled to show how these two components of total dot gain are related to paper properties.

Introduction

This paper documents final work on a project started in 1989 (MacPhee and Lind, 1991) that was aimed at determining the effect of paper properties on two characteristics of lithographic prints: density range and dot gain. The purpose of this paper is to present findings on the latter. More specifically, it addresses two related topics: the method used for measuring physical dot area, and the relationship between paper properties and both the optical and mechanical dot gain of corresponding prints. Accordingly, separate sections of the paper are devoted to these two topics. A section on background information has also been included, along with a section containing a discussion and the conclusions.

* Graphic Arts Technical Foundation
** Baldwin Technology Company, Inc. Norwalk, Connecticut

Table I Summary of data on press runs.

Run number	Paper			Number of prints	Ink usage		Solid ink density			Density of paper
	Type	Finish	Grade		Total (grams)	Thickness (grams/m^2)	Measured mean	Std. Dev.	Corrected mean**	
1	Offset	Coated	#1	1000	63.8	1.05	1.37	0.03	1.36	0.04
2	Offset	Coated	#5	1000	64.4	1.06	1.36	0.03	1.33	0.09
3	Offset	Coated	#3	1000	63.5	1.04	1.43	0.03	1.43	0.12
4	Offset	Coated	#5	1000	64.1	1.05	1.38	0.03	1.37	0.12
5	Offset	Coated	#5	1000	62.9	1.03	1.35	0.02	1.36	0.09
6	Offset	Coated	#1	1000	63.8	1.05	1.40	0.04	1.39	0.05
7	Offset	Uncoated	#3	735	48.5	1.08	0.97	0.01	0.93	0.07
8	Offset	Uncoated	Newsprint*	704	42.9	1.10	0.99	0.02	0.94	0.18
9	Offset	Uncoated	Newsprint	938	57.7	1.01	0.99	0.04	1.02	0.20
10	Offset	Coated	#3	1000	62.4	1.02	1.35	0.02	1.38	0.05
11	Offset	Uncoated	#1	1000	61.8	1.02	0.91	0.02	0.93	0.03
12	Offset	Coated	#1	1000	60.7	1.00	1.32	0.02	1.37	0.04
13	TYVEK	—	—	1000	62.4	1.02	0.88	0.03	0.90	0.03
14	Gravure	Coated	#3	1035	63.2	1.00	1.28	0.02	1.33	0.11
15	Offset	Uncoated	#3	1000	64.6	1.06	0.92	0.02	0.90	0.07
16	Offset	Coated	#1	1000	60.7	1.00	1.31	0.02	1.36	0.04
					Mean	1.04				
					Std Dev	0.03				

*Uncalendered

**Corrected to film thickness of 1.04 grams/m^2

Background Information

As reported earlier (MacPhee and Lind, 1992), and summarized in Table I, sixteen sets of test prints were printed on a sheetfed press at a constant ink film thickness of 1.04 microns. Each set was printed on a different paper, except for the last, which was a repeat of the first. Thus, the only variable that changed was the grade and make of paper. Paper grade ranged from number one coated to uncalendered newsprint. The dependence of the density range of these prints (defined as solid ink density to paper at the given ink film thickness) on paper properties was reported in a subsequent paper. There, it was concluded that surface topography is the single most important property affecting density range (MacPhee and Lind, 1994).

The initial measurements of the second print property of interest, dot gain, were of total gain in the 30 and 50 percent dot screens, where total dot gain is defined in equation (1):

$$\left|\begin{array}{l}\text{Total dot gain}\\ \text{film to print}\end{array}\right| = \left|\begin{array}{l}\text{Apparent dot area on}\\ \text{print from Murray-Davies}\end{array}\right| - \left|\begin{array}{l}\text{Physical dot}\\ \text{area on film}\end{array}\right| \qquad (1)$$

Examination of these measurements from the first and last sets, printed on the same paper, disclosed that total dot gain had changed some time between the printing of the first and last sets of paper. Examination of measurements of the line screen slur targets, shown in Figure 1, disclosed that this change was due to a change in line spread in the direction of press travel, i.e., in the perpendicular target. Most likely, this was due to a change in a press variable that was undetected at the time. Because line spread had not changed in the direction perpendicular to paper travel over the course of the tests, i.e., in the parallel targets, it was concluded that the effect of paper properties on dot gain could only be assessed from the gains of the line targets having lines parallel to paper travel.

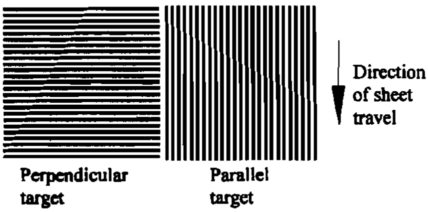


Figure 1 Diagram of the line screen targets at 3.75 times actual size. Line area is 40 percent and ruling is 150 lines per inch.

Various plots of these gains disclosed no trend vis-à-vis paper grade or paper properties. Therefore it was decided to separate the total gains in these targets into their two components: mechanical gain due to physical enlargement of the dot, and optical gain, the apparent increase in dot area due to optical effects. The rationale for this was that the two components might be governed by different properties of paper and/or press. These components of gain are defined by equations (2) and (3) wherein the terms line and dot are used interchangeably:

$$\left|\begin{matrix}\text{Mechanical dot}\\ \text{gain on press}\end{matrix}\right| = \left|\begin{matrix}\text{Physical dot}\\ \text{area on print}\end{matrix}\right| - \left|\begin{matrix}\text{Physical dot}\\ \text{area on film}\end{matrix}\right| \qquad (2)$$

$$\left|\begin{matrix}\text{Optical dot}\\ \text{gain on press}\end{matrix}\right| = \left|\begin{matrix}\text{Apparent dot}\\ \text{area on print}\end{matrix}\right| - \left|\begin{matrix}\text{Physical dot}\\ \text{area on print}\end{matrix}\right| \qquad (3)$$

From these equations it can be seen that to obtain a reliable assessment of both components, it is necessary to find a way to accurately measure the physical areas of the printed dots or lines. The initial approach taken was to make enlarged photographs of both slur targets and use a planimeter to measure the physical area of the lines. As a check of the method, the resultant optical gains of the perpendicular line targets were plotted versus the optical gain of the parallel targets. This was done on the assumption that the optical gains of a given set of parallel and perpendicular targets would be equal. Thus, the method of measurement could be judged reliable if these points lay on a straight line having a slope of one. When this did not prove out, as shown in Figure 2, the planimeter method was judged to be unreliable and alternate methods were explored. This led to the development of the method reported herein.

Methods Used to Measure Dot Area

The printed samples were those listed in Table III, where each paper was printed with magenta ink at a film thickness of 1.04 microns. The measurements reported on here were made on the UGRA line screen targets marked 0 degrees and 90 degrees. The 0 degree target lines were perpendicular to the direction of sheet travel, while the 90 degree target lines were parallel to the direction of sheet travel, as shown in figure 1. Hereafter, these are referred to as the parallel and perpendicular targets. Both line screen targets have a nominal image area coverage of 40 percent, and it is not unusual for the printed perpendicular target to be slightly darker, due to greater slurring or line spread in the direction of press travel.

Apparent Dot Area. The apparent dot areas of the line targets were obtained by measuring densities with an X-Rite 418 densitometer, with status T response, and then using the Murray-Davies equation (Murray, 1936) to calculate apparent area as given in equation (1).

Physical Dot Area on Film. The physical dot area on the film can be obtained by taking photomicrographs of the targets on the film and using a digital planimeter to measure area. In this method, the line targets were imaged on a SONY video printer paper at 100X or 200X. The photomicrographs were fastened to a digital tablet made by Jandel Scientific, and the line edges were traced with a digital pointer to calculate image area coverage. Prior experience had shown that this

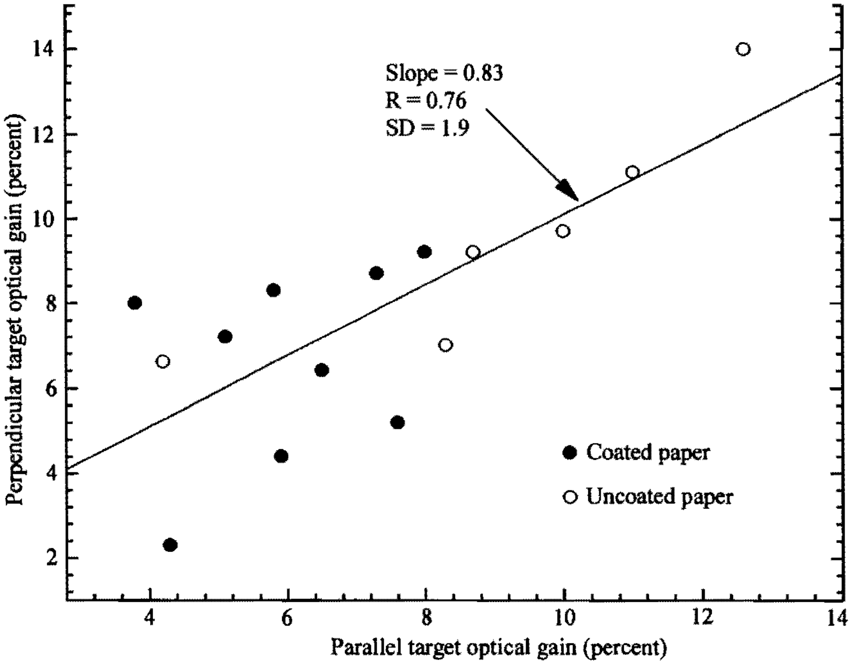


Figure 2 Plot of optical gains determined from print areas measured with planimeter.

technique works extremely well for film and plates where the edges of the dots or lines are sharp and thus well defined. For this study, the nominal area of 40 percent was used because previous measurements has also shown that the area is very close to this value.

Physical Dot Area on Print. Initial assessments of physical dot areas on the prints were made using photomicrographs and the digital planimeter described above. As noted in the previous section, and shown in Figure 2, this method was found to be unreliable. The reason for this is that, on paper prints, the edges of dots and lines in photomicrographs are very irregular and therefore difficult to trace, especially on uncoated papers and newsprint.

It was then decided to investigate image analysis systems. These systems are composed of various combinations of cameras, software, video cameras, digital cameras, and microscopes. A survey of available suppliers showed that they were not well suited to provide dot area coverage information. Most of the systems were designed to count dirt particles in recycled paper. Closer study suggested that the components of an image analysis system already existed at GATF: an Olympus BH-2 microscope, a Kodak DC420 digital camera, and Adobe PhotoShop software. The concept was demonstrated about 30 minutes after the components were assembled by G. Bassinger and J.T. Lind of GATF in 1997.

The first step in this procedure is to determine the best exposure with the digital camera. This depends on whether it is film and transmitted light or a yellow shade of newsprint with magenta ink and reflected light. The exposure is increased until visual contrast on the monitor is optimized. For ink on paper with the illumination system at GATF, the exposure is two seconds with dark field illumination. The image is captured at 50X and imported into Adobe PhotoShop as an RGB file.

The cursor tools in Adobe PhotoShop are used to determine the tilt of the image, and the image is rotated by the exact amount indicated by the software to make the image exactly horizontal or perpendicular. Once the image is aligned, the file is converted to a gray scale image, discarding the color information. Another tool is used to create a square or rectangular box around as many dot or line centers as possible. This area, inside the box, is used to count the number of pixels at each level of brightness. The image histogram is chosen and displayed on the screen, appearing as in Figure 3, along with the following values:

Mean	the average brightness value
Std Dev	represents how widely the values vary
Median	the middle brightness value
Pixels	the total number of pixels in the displayed image

When the cursor is placed anywhere along the horizontal axis of the histogram, the following variables are displayed:

Level	brightness level at that location
Count	number of pixels at that brightness level
Percentile	percentage of total pixels below that level

Thus, to find dot area, all that is necessary is to find the dividing line between the two distributions, light and dark, of the pixels—since the percentile at that point is equal to the dark or dot area. This is the saddle or minimum point between the two peaks.

Several methods were explored for picking the saddle point for ink and paper histograms. The technique adopted was founded on the fact that the two peaks in the histogram are always more sharply defined than the saddle point between them. Thus, the cursor is used to find the level corresponding to each peak and the saddle level is then defined as the average of the two. When the cursor is placed at this average or midpoint level, the corresponding *percentile* displayed on the screen yields dot area.

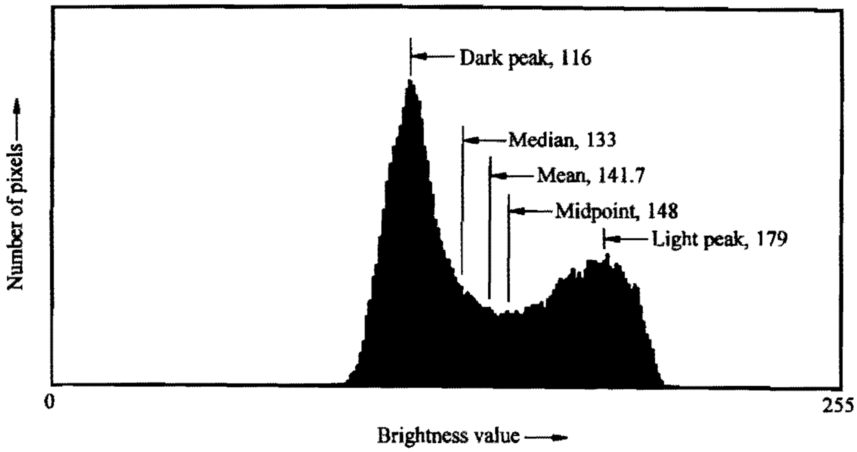
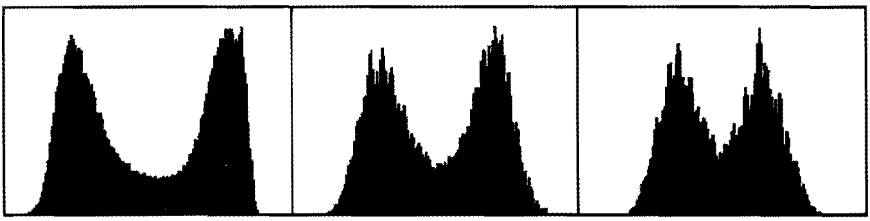


Figure 3 Typical histogram of perpendicular target printed on #1 coated stock. Values displayed are for sample 16-500.

The character of the histogram varies somewhat with the type of paper used for the print, as shown in Figure 4. For a very smooth paper, as in Figure 4(a), the histogram changes more or less monotonically, resulting in a smooth shape. As paper roughness increases, as in Figures 4(b) and (c), the changes become noisier, resulting in a jagged shape.



(a) Number 1 coated. (b) Number 1 uncoated. (c) Uncalendered newsprint.

Figure 4 Effect of paper grade on character of histogram.

The histogram character is also generally found to be different for the parallel compared to the perpendicular targets. As shown in Figure 4(a), the two peaks in the Sample 16 parallel target are approximately symmetrical. In contrast, in the corresponding perpendicular target histogram, shown in Figure 3, the light (right-hand) peak is truncated drastically. This difference, while not always present, seems to reflect the greater degree of line slur in the perpendicular targets, which was worst in Sample 16, as to be described shortly.

It should also be noted that the dark peak decreases in size, relative to the light peak, as dot area decreases below the midtone, while the converse occurs as dot area increases. This increases the error in this method when measuring very large and very small dots.

Verification. As a check on the above methods for obtaining dot areas, the corresponding optical dot gains of the perpendicular targets were calculated and then plotted against those of the parallel targets as in Figure 5. Recalling that R^2 is the probability that the total variations in the Y values are attributable to differences in the X values, it can be seen that this second method has a probability of 0.84 that the variations in optical dot gain of the perpendicular targets are attributable to those of the parallel targets, rather than chance—and much higher than the corresponding probability of 0.58 for the data in Figure 2 for the planimeter method. This provides confidence that the above methods can be used to separate total dot gain into its two components.

Estimated Error in Dot Gain. From equation (3) it can be seen that the total error in optical dot gain obtained using this method is the sum of the errors in the measurements of the apparent dot area of the print and the physical dot area of the print. The major error in the apparent or total dot area is judged to be due to

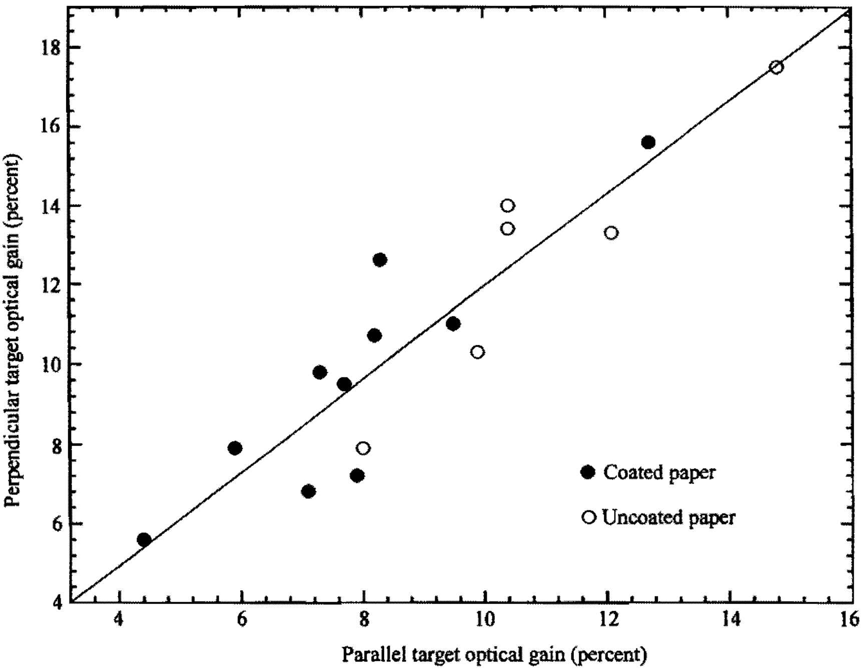


Figure 5 Plot of optical gains determined from print areas measured with Adobe PhotoShop. Displayed best linear fit has slope of 1.17. Corresponding R is 0.91 and standard deviation is 1.4, a big improvement over the plot in Figure 2 for the planimeter method.

measuring the screen densities with a densitometer to only two places. For the range of screen densities on these sheets, this rounding off can result in an error as large as 0.5 to 0.7 percent in area. Errors in measuring physical dot area can occur as a result of the following three judgments that must be made by the person making the measurement:

Error 1. The camera exposure used in capturing the image is selected based on the operator's judgment of what constitutes optimum visual contrast. (This is true in most, if not all, image analysis systems.)

Error 2. The selection of the area of the image to be analyzed in Adobe PhotoShop is based on the operator's judgment on where the centerline of a dot or line is located.

Error 3. The location of the saddle point of the histogram is based on the operator's judgment of where the two peaks in the histogram are located on the brightness level scale.

For the prints obtained in these tests, *Error 1* was judged to be very small relative to the other two. The magnitude of *Error 2* will depend on the number of dots or lines in the image—the larger the number the smaller the error. For the measurements reported on here, an image containing 12 lines was used. It is estimated that the midpoint of each boundary line, (left-hand side and right-hand side) could be found to within one pixel, yielding a resultant potential error in area of 0.2 percent.

The sensitivity of *Error 3* was explored by recording the deviations in area for each ± 2, and ± 4 brightness level deviation from the level of each selected saddle point. Data for three different papers is plotted in Figure 6. It is estimated that each peak could be located with an error not exceeding one level. From Figure 6 it can be seen that the corresponding potential error is a low of 0.7 percent for the best case, and 1.5 percent, or double, for the worst.

The total estimated error in the measured values of optical dot gain thus ranges from 1.4 to 2.4 percent as shown in Table II. This is consistent with the variance of the optical gain data with the best-fit straight line in Figure 5, and the variance of the mechanical gains presented in the next section.

Results

The measured areas and calculated gains of both the parallel and perpendicular targets are listed in Table III. The mechanical dot gains of both targets are displayed in Figure 7. This display indicates two things:

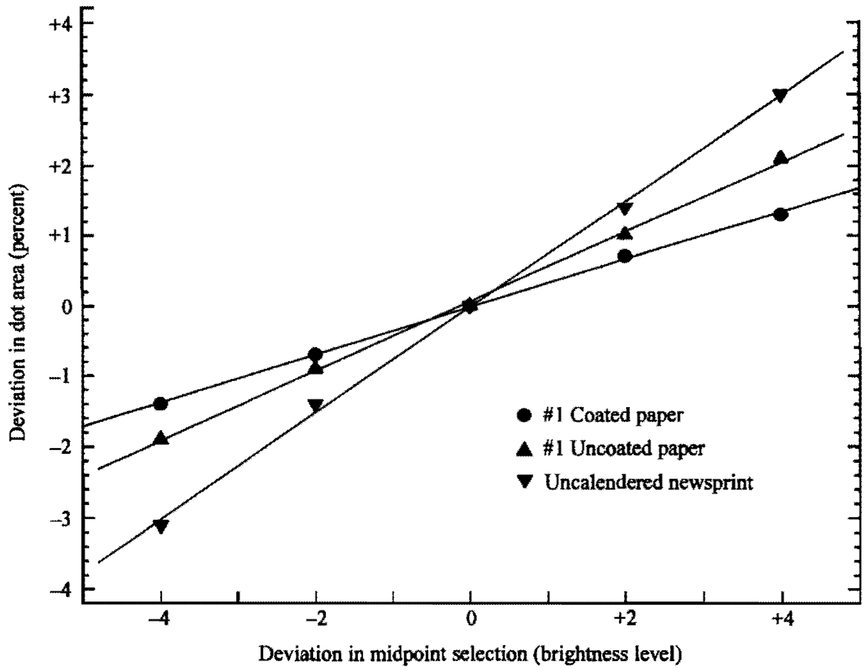


Figure 6 Sensitivity of dot area in Adobe PhotoShop to selection of midpoint or saddle location.

Table II Summary of estimated errors in measuring optical dot gain.

Source of error	Estimated error	
	Low	High
Measurement of screen density to two places.	0.5%	0.7%
Selection of centerline of dots or lines.	0.2%	0.2%
Selection of midpoint or saddle location.	0.7%	1.5%
Total estimated error	1.4%	2.4%

- Mechanical dot gain of the parallel targets was a constant 9.5 percent with a standard deviation of 1.5 percent. Thus, mechanical dot gain is not a function of the paper on which it was printed. (Of this gain, 3—4 percent can be attributed to the gain from film to plate. Thus, mechanical gain from plate to print was 5.5—6.5 percent.)
- Except for Run 16, the mechanical dot gain of the perpendicular targets was also constant, 14.3 percent, with a standard deviation also of 1.5 percent. Thus, the difference between the gains on Runs 1 and 16, referred to earlier, resulted from some change in press condition that occurred after Run 15 and prior to Run 16. This change caused an increase in dot slur in the direction of press travel.

Table III Summary of measured dot areas and corresponding mechanical and optical dot gains, all in percent.

Sample number	Paper grade	Targets parallel to travel					Targets perpendicular to travel				
		Total area	Physical area	Total gain	Mech. gain	Optical gain	Total area	Physical area	Total gain	Mech. gain	Optical gain
1	#1 Ctd	55.7	47.8	15.7	7.8	7.9	59.9	52.7	19.9	12.7	7.2
6-600	#1 Ctd	57.7	50.6	17.7	10.6	7.1	62.8	56.0	22.8	16.0	6.8
12-1000	#1 Ctd	53.7	49.3	13.7	9.3	4.4	59.3	53.7	19.3	13.7	5.6
16-500	#1 Ctd	55.9	50.0	15.9	10.0	5.9	68.6	60.7	28.6	20.7	7.9
3-400	#3 Ctd	61.0	48.3	21.0	8.3	12.7	69.2	53.6	29.2	13.6	15.6
10-250	#3 Ctd	59.0	50.8	19.0	10.8	8.2	66.7	56.0	26.7	16.0	10.7
14-400	#3 Ctd	55.5	47.2	15.5	7.2	8.3	66.0	53.4	26.0	13.4	12.6
2-400	#5 Ctd	58.9	49.4	18.9	9.4	9.5	63.8	52.8	23.8	12.8	11.0
4-1000	#5 Ctd	58.7	51.4	18.7	11.4	7.3	65.8	56.0	25.8	16.0	9.8
5-1000	#5 Ctd	58.5	50.8	18.5	10.8	7.7	65.5	56.0	25.5	16.0	9.5
13-550	Tyv	61.3	46.5	21.3	6.5	14.8	70.4	52.9	30.4	12.9	17.5
11-120	#1 Unctd	60.0	49.6	20.0	9.6	10.4	68.4	54.4	28.4	14.4	14.0
7-400	#1 Unctd	60.9	51.0	20.9	11.0	9.9	65.6	55.3	25.6	15.3	10.3
15-500	#3 Unctd	56.3	48.3	16.3	8.3	8.0	62.8	54.9	22.8	14.9	7.9
9-450	Newsprint	61.8	51.4	21.8	11.4	10.4	69.4	56.0	29.4	16.0	13.4
8-700	Newsprint*	60.9	48.8	20.9	8.8	12.1	64.8	51.5	24.8	11.5	13.3
				Mean	9.5					14.3	
				Std Dev	1.5					1.5	

*Uncalendered

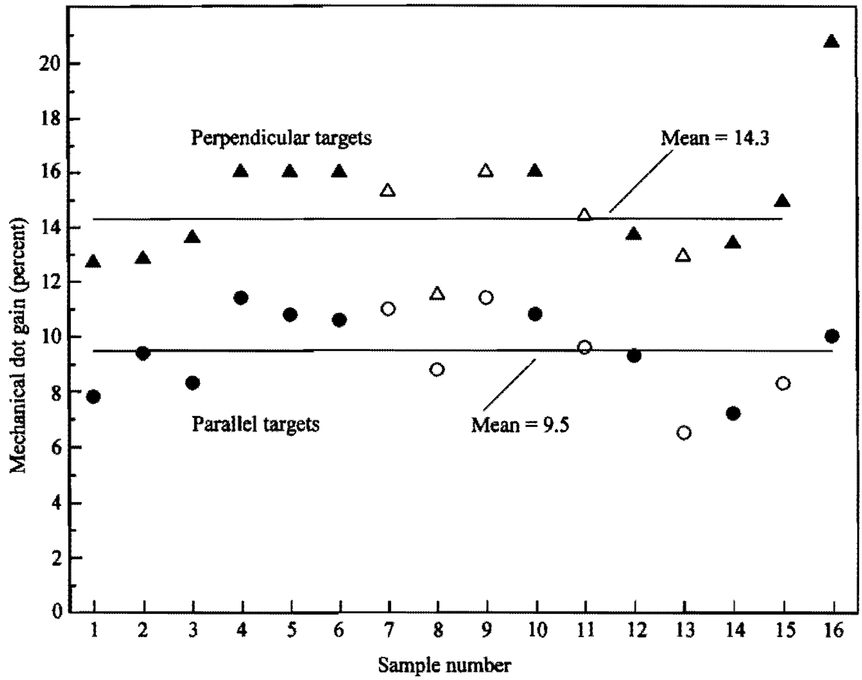


Figure 7 Mechanical gains of parallel and perpendicular targets. Solid points are data for coated papers; open points are for uncoated papers.

The optical dot gains of the parallel targets are displayed in Figure 8 as a function of paper grade. There is a trend for the poorer grades to have higher mean values, except for those of the #3 coated papers, which are almost as high as those of the uncoated papers. Only one value of optical gain could be found in the literature—15 percent for newsprint (Malmqvist, Verikas, Bergman, 1999)—which compares with the values of 10.4 percent and 12.1 percent in Figure 8.

To explore the dependency of optical gain, the optical dot gains of the parallel targets were plotted versus three types of properties of the papers measured previously—optical, absorbent, and topographical (MacPhee and Lind, 1994). Plots of optical dot gain versus scattering power and absorbing power, two optical properties of paper, showed almost zero correlation. However, as shown in Figure 9, there is quite a relatively good correlation with the diffusing *power* of light in paper where diffusing *power* is taken to be proportional to the square root of the reciprocal of the product of the scattering and absorbing powers. This is based on an analogy with neutron diffusion in a lightly absorbing medium (Glasstone and Edlund, 1952), where diffusion *length* is proportional to the

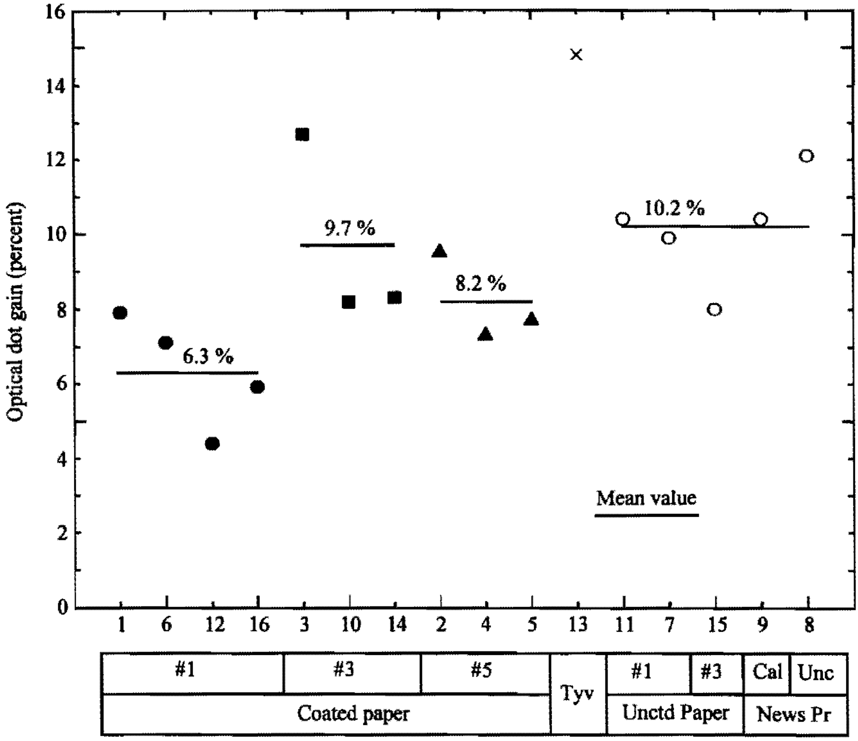


Figure 8 Optical gains of parallel targets versus paper grade.

square root of the reciprocal of the product of the scattering and absorbing *coefficients*. In this context it should be noted that for paper scattering *power* is equal to the product of the scattering *coefficient* and basis weight. Also of significance is that there was very little correlation between optical dot gain and diffusion *length* in paper.

In Figures 9, 10, and 11, data points for coated papers are represented by solid dots while open dots represent data points for uncoated papers. Also shown are the best linear fits and the corresponding correlation coefficients (R) and standard deviations (SD).

Figure 10 shows a plot of optical gain versus K/N density, an indicator of paper absorbency. The degree of correlation shown by this plot is typical of the plots versus paper properties that are a measure of absorbency. Figure 11 is typical of the plots of measurements that reflect the topographical properties of the papers—in this case, roughness as measured with a stylus-type profilometer.

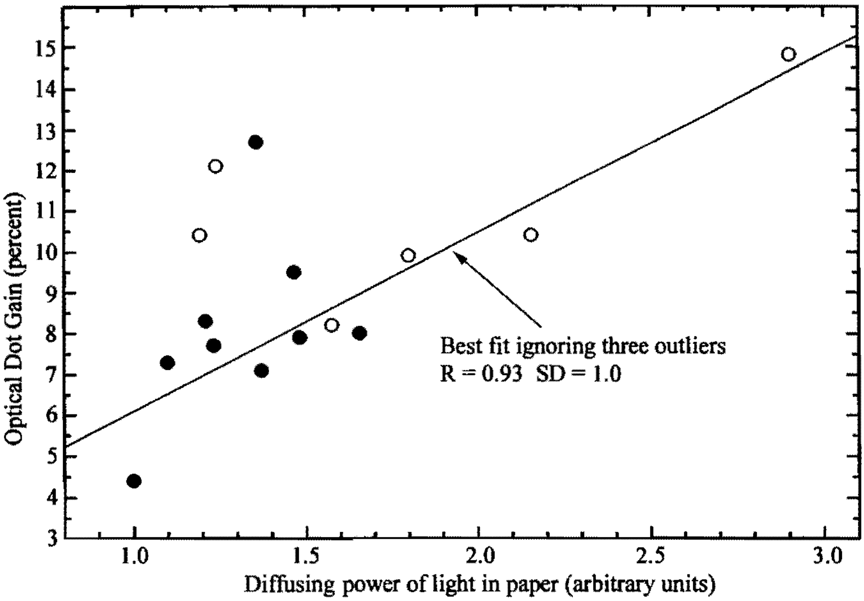


Figure 9 Optical dot gain of parallel targets versus diffusing power of light in paper. Best fit of all data has R of 0.63 and SD of 2.1.

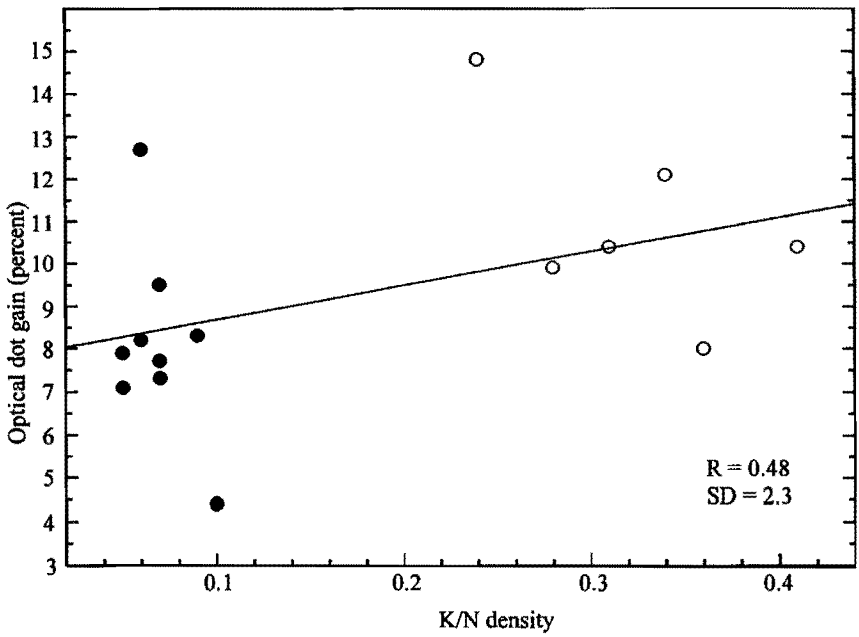


Figure 10 Optical dot gain of parallel targets versus K/N density.

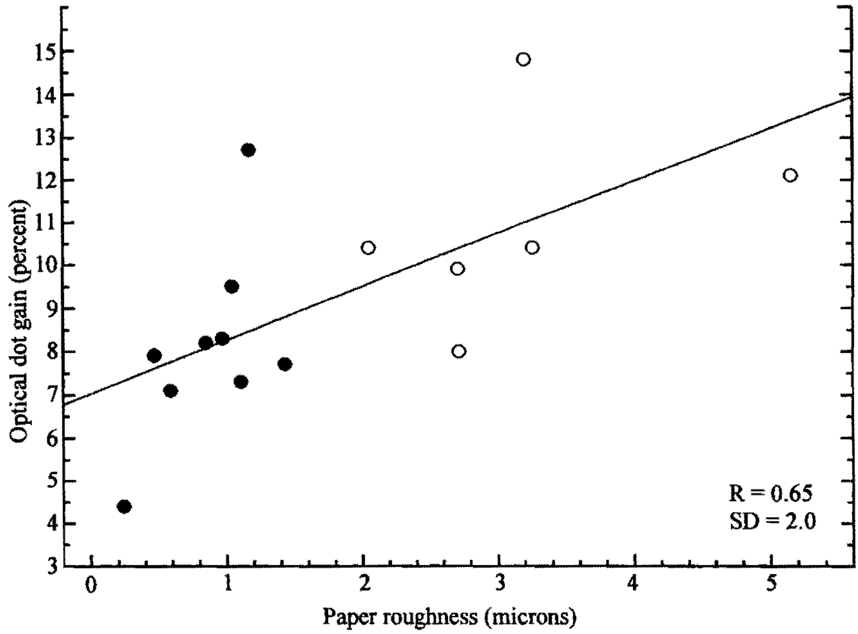


Figure 11 Optical gain of parallel targets versus roughness measured with stylus-type profilometer.

Table IV Data on correlation of optical gain of parallel targets with various paper properties, from plots as in Figures 9—11. Values of R^2 and standard deviation are for best linear fits of all data in the plots. Note that for diffusing power of light R^2 for all data is 0.40 but if the three outliers in Figure 9 are ignored, R^2 rises to 0.87.

Paper Property		R^2	Std. dev.
Type	Name		
Optical	Scattering power	0.01	2.7
	Absorbing power	0.005	2.7
	Diffusion length of light in paper	0.02	2.7
	Diffusing power of light in paper	0.40	1.0
Absorbent	K/N density	0.23	2.3
	Parker porosity	0.21	2.4
Topographical	Roughness, stylus-type profilometer	0.42	2.0
	Max BRDF to BRDF at 45 degrees	0.40	2.1
	Gloss at 60 degrees	0.30	2.2

Table IV summarizes the data on the correlations of optical gain with nine different paper properties. The tabulation indicates that there is essentially zero correlation between optical dot gain and the scattering and absorbing powers of the papers and with diffusion *length*. Conversely, it can be seen that the probabilities that the total variations in the optical gains are attributable to differences in the topographical properties and the diffusing *power* of light are about twice as high as they are for the properties related to paper absorbency.

Discussion and Conclusions

The implications of the correlations summarized in Table IV are that optical dot gain is related to both the diffusing power of light and the surface roughness of the paper. The former has some physical basis and is consistent with the traditional explanation that optical dot gain is due to light scattering within the paper. The latter, however, was surprising to the authors in that there is no physical reason to explain it. Thus, to determine if the correlation with roughness was more than just a quirk, an additional experiment was carried out whereby dot gains were measured on two printed stocks that differed only in surface finish.

The first stock was gloss finish 10 point PVC (polyvinyl chloride) used to print credit cards, having a surface roughness of 0.72 and 0.75 microns, as measured in the machine and cross-machine directions, with s stylus-type profilometer. The second stock was identical except it has a matte finish, and surface roughness of 2.88 and 4.36 microns. (These correspond to the roughnesses of the #1 coated and newsprint sheets.) During a test run on the gloss stock, several sheets of the matte stock were added to the feed pile. Thus, sheets of the two stocks were obtained, printed under identical conditions. (The screens were made up of round dots.) Dot area measurements of both 150 lines/inch and 300 lines/inch screens with nominal areas of about 40 percent were made in accordance with the methods described herein. The results, listed in Table V and displayed in Figure 12, exhibit two trends, one expected and one unexpected:

- For both screen rulings, optical gain is higher on the rougher sheet, an expected result, given Figure 11.

- For both screen rulings, mechanical gain on the rougher sheet was higher (2.9 and 2.8 percent respectively) than the mechanical gain on the smoother sheet, an unexpected result, given Figure 7.

It is possible that the differences in mechanical dot gain (between gloss and matte finishes) are due to errors in measurement, although this is not likely in view of the measurement variances given in Table V. However, if this were the case, then the differences in optical gains on the prints on the gloss and matte finish stocks would be even greater than indicated in Figure 12. In either case,

Table V Results from test prints on 10 point PVC (credit card) stock. Dot areas on film were 41.0 percent for 150 lines/inch ruling and 38.6 percent for 300 line/inch ruling.

Ruling (lpi)	Finish	Density readings			Dot areas (%)		Dot gains (%)	
		Solid	Base	Tint	MD*	Phs**	Mech	Opt
150	Gloss	1.529	0.082	0.459	60.2	49.1***	8.1	11.1
	Matte	1.550	0.082	0.501	64.1	52.0***	11.0	12.1
300	Gloss	1.612	0.084	0.593	71.1	53.4	14.8	17.7
	Matte	1.569	0.087	0.694	77.9	56.2	17.6	21.7

* Dot area calculated from Murray-Davies equation.

** Physical dot area measured using Adobe PhotoShop method.

*** Average of ten measurements. SD = 0.6 percent for gloss and 0.5 for matte.

this data supports the findings given in Figure 11 regarding optical gain. Therefore, it is believed that the following conclusions can be drawn, which are very significant to both printers and paper makers:

1. The method described in this paper for measuring the physical area of halftone dots printed on paper can be used in conjunction with density readings and the Murray-Davies equation to determine the mechanical and optical components of midtone dot gain to an estimated accuracy of 1.4—2.4 percent in area depending on paper roughness. Estimated accuracy can be improved to 0.9—1.9 percent by measuring the densities—especially those of the tints—to the third place. The method can also be used for measuring dot area on plates where even greater accuracy can be achieved. (Although the method was used to measure line screens, it should work for round dots and stochastic screens as well because the ratio of area to perimeter is about the same as for dots.)

2. Mechanical dot gain from plate to print is independent of paper properties, for a given set of ink properties, a given printed ink film thickness, and a given set of press conditions. Conversely, it is known from previous studies that changing either printed ink film thickness, ink properties, or cylinder packing can change dot gain (MacPhee and Lind, 1990) and it is taken for granted that such changes in dot gain occur only in its mechanical component. These collective findings are consistent with an earlier study by others (Takahashi, Fujita, and Sakata, 1986-7) in which it was found that dot spreading occurs primarily during transfer of the image from plate to blanket, where, of course, the paper is not involved. Mechanical dot gain can also result from slurring caused by differential cylinder or paper movement during image transfer, but here again, this is independent of paper properties. Thus, broadly speaking, mechanical dot gain is press and ink related, not paper related.

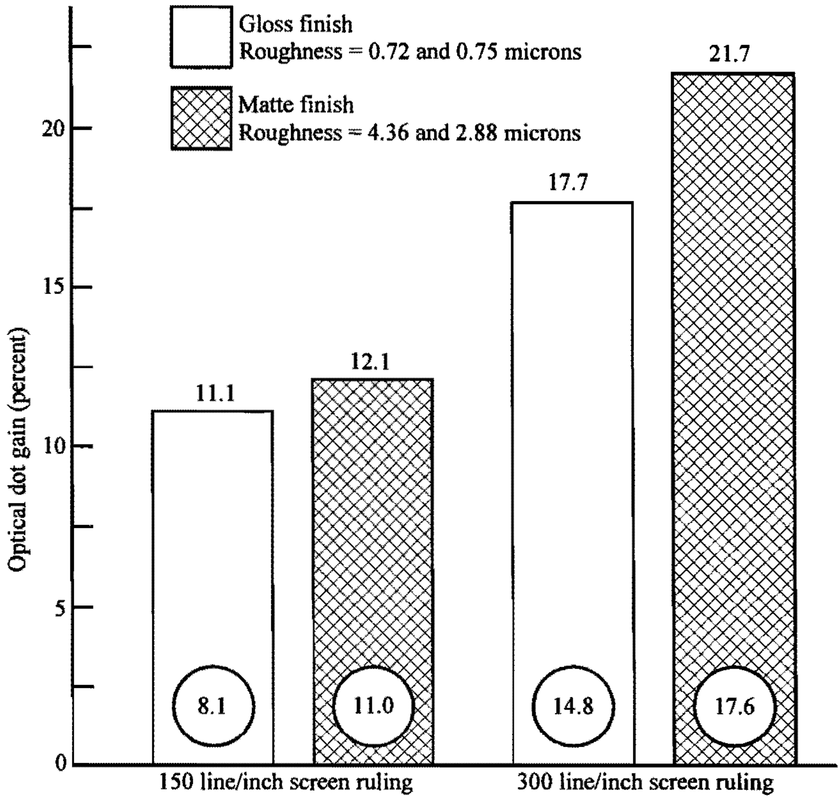


Figure 12 Optical dot gains of round dots printed on 10 point credit card stock. Only difference in prints is surface roughness of stocks and screen ruling. Numbers in circles are mechanical dot gains, film to print. See Table V for dot areas on film.

3. In contrast, it can be concluded that optical gain is paper related, but not press or ink related. Furthermore, this work indicates that it is very probable that optical gain is related to the diffusing power of light in paper, a value that is dependent on two optical properties of paper in combination: scattering power and absorbing power. This is consistent with the conventional wisdom that explains optical gain as being the result of light diffusing away from where it entered an unprinted area to a point under a dot where it emerges. This work also indicates that it is very probable that optical gain is related to the topographical properties of papers, with rougher papers producing higher levels of optical gain. This appears to be consistent with the conventional wisdom that the wire side (and hence the rougher side) of paper prints with higher dot gain. However, the authors cannot suggest any mechanism that would explain the

dependence of optical dot gain on the topographical properties of paper. Given the range of roughness of the PVC, the limited measurements on PVC suggest that roughness has a weaker effect on optical dot gain compared to that of the diffusing power of light.

4. The measurements reported on here suggest that there may be considerable variation in optical gain within a given grade of paper. It would be interesting to see if this is true by repeating the experiment for, say, a dozen different papers of the same grade and basis weight.

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