The Effect of Certain Process Parameters On Inherent Color Variations on Press

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Abstract: This paper reports on an extension of a previous paper on the subject of color variations on press. There it was explained that inherent type color variations define the lowest level of color variation that can be realized under a given set of press operating conditions. To begin, a more detailed description is given of the procedure used to assess the magnitude of such density variations. Measurements of inherent type variations on two typical offset presses are presented and compared with three similar sets from the previous paper, for the purpose of establishing a benchmark for printing on coated paper. This is followed by presentations of data that show the effect on inherent type variations of an impervious substrate, stochastic versus conventional screening, the absence of water, and the use of a non-paste ink. The conclusions include a definition of the upper bound of inherent type density variations on a lithographic press, the effect of the above process changes on density variations, and an explanation of the factors that determine the shape of the curves of density variations versus screen or dot area.

I Introduction

The differences between extraneous and inherent type color variations on press were set forth in an earlier paper (MacPhee, 2004), wherein inherent type color variations were defined as being produced by causes internal to the process. Thus, such variations are beyond control of the operator and constitute the lower limit that the process operator can hope to realize. Inherent type variations are assessed through analysis of a set of 50 consecutive sheets printed on coated paper following the procedure described in Appendix A. Extraneous or externally caused variations are unpredictable, occur less frequently, and are superimposed on variations of the inherent type.

Figure 1 shows the inherent density variations at the center of the patch in a tone scale that contained various colors, printed on coated paper by a typical offset

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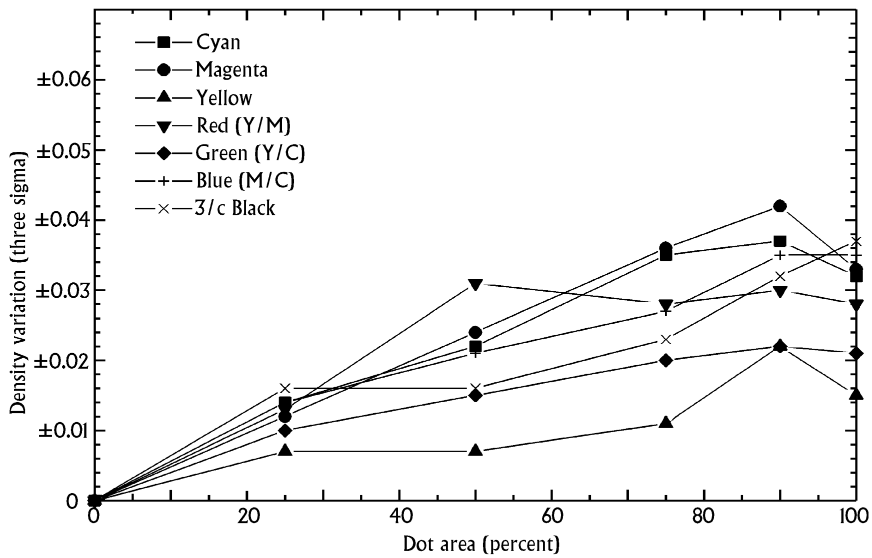

Figure 1 Measured three sigma density variations on a typical lithographic sheetfed press printing on coated paper.

lithographic press, plotted as a function of screen area. The three sigma values plotted are equal to three times the standard deviation of each set of 50 measurements and represent a probability of greater than 0.99 that the variations do not exceed this value. From this data it can be seen that, as screen area is reduced from 100 percent, the magnitudes of the density variations either rise to a peak in the shadows before decreasing monotonically to zero, or else simply decrease monotonically.

The trend disclosed by this data raised three questions, as follows:

1. What is the expected upper bound of inherent type density variations for the lithographic printing process?

2. Is it possible to reduce the magnitude of this upper bound by changing one or more process parameters?

3. What is the cause of the inherent type density variations plotted in Figure 1, and what is the explanation for the shape of these plots?

The objective of this paper is to describe work that was undertaken with the aim of providing answers to the above three questions.

The first of the two sections that comprise the main body of this paper presents the results of new measurements of color variations made both to increase the store of benchmarks and to gauge the effect of changing different process parameters. The second of the two main sections presents an analysis of operator induced density changes and some additional observations that provide further insight. The last section of the paper contains the conclusions reached.

II. New Measurements

This section presents the results of six different sets of measurements of color variations, two of which constitute additional benchmarks, while the remaining four provide a measure of the effects of substrate, type of screening, water, and type of ink.

A. Additional Benchmarks.

The two sets of measurements shown in Figures 1 and 2 are of prints from representative sheetfed presses. Together with those in Figures 4 (b), 5 (b), and 6 (b) in the 2004 paper, they are considered to represent the best that can be achieved with the lithographic printing process, and were used to establish the upper and lower bounds of the envelope defined by the dotted lines in Figure 2. As such, this envelope will be used to judge whether or not four different parameters have any effect on color variations.

B. Effect of Substrate.

Paper substrates were suspect because it was speculated that their heterogeneity (fibers and fillers) and and/or non-uniformities in their permeability could produce color variations. In order to explore this, a set of sheets printed on plastic was obtained and measured. Plastic was chosen because, compared to paper, it is both impermeable and homogeneous. Although the volume of data that could be obtained was limited by the lack of a tone scale on this set of sheets, the results shown in Figure 3 indicated that the substrate is not a factor.

C. Effect of Screening.

Early on in the investigation, it was thought most probable that variations in ink film thickness played a big role in causing color variations. To check on this, it was decided to measure sheets printed using stochastic screened plates, based on printers' claims that color is relatively insensitive to changes in ink key settings when running such plates. However, the results of the measurements, given in Figure 4 show that, if anything, stochastic screening produces color variations on the high side in the screened regions, compared to the benchmarks. This would seem to rule out ink film thickness variations as the source of color variations in *screened areas*.

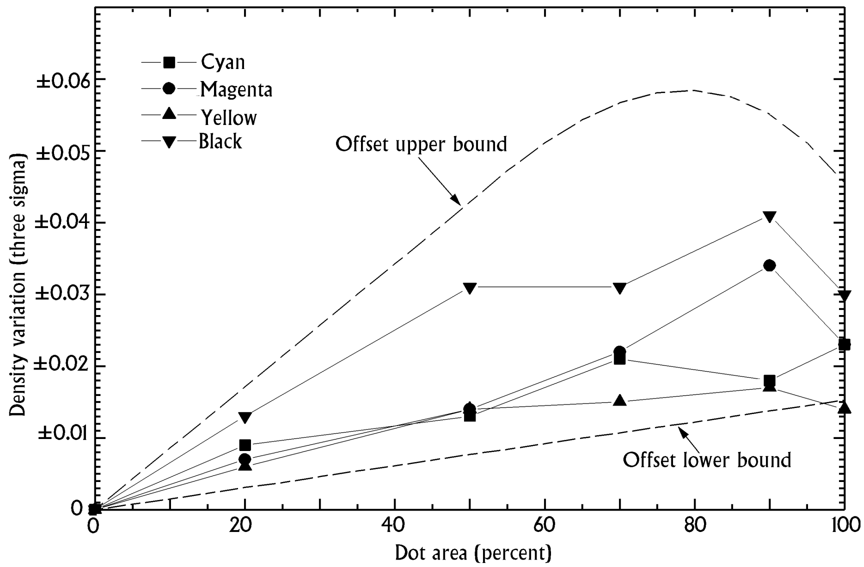

Figure 2 Measurement of inherent type density variations printed on 50 consecutive sheets by a typical six color sheetfed lithographic press. Upper and lower bounds are defined in text.

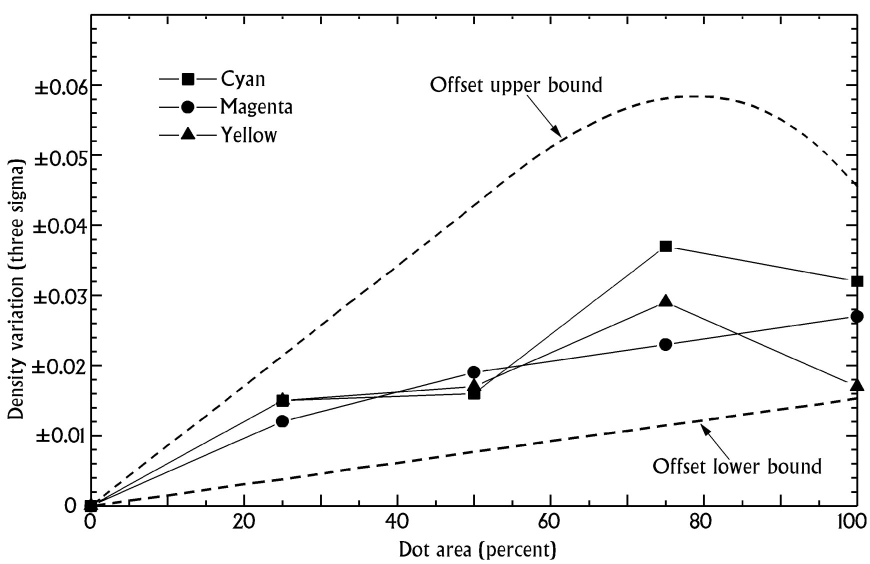

Figure 3 Measurement of inherent type density variations printed on 50 consecutive sheets that occurred when printing on a plastic substrate.

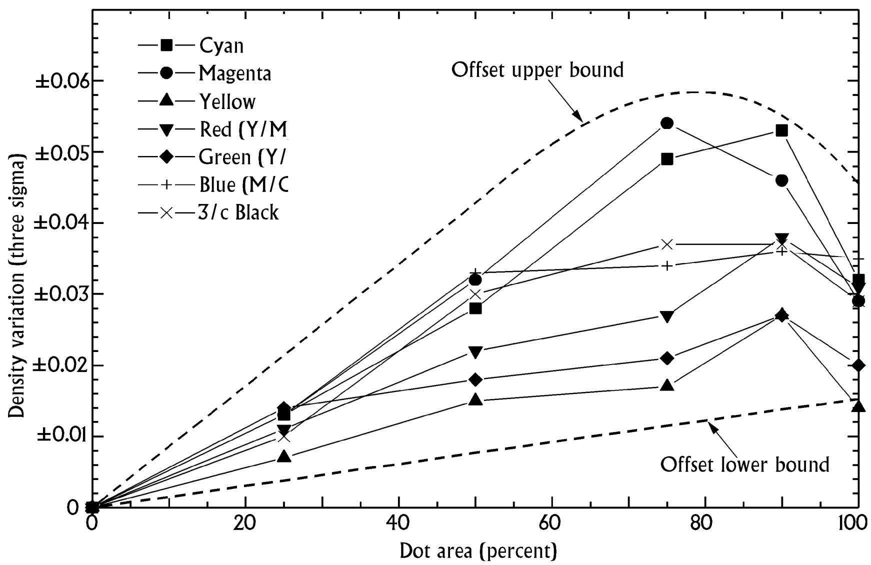

Figure 4 Measurement of inherent type density variations printed on 50 consecutive sheets that show the effect of using stochastically screened plates.

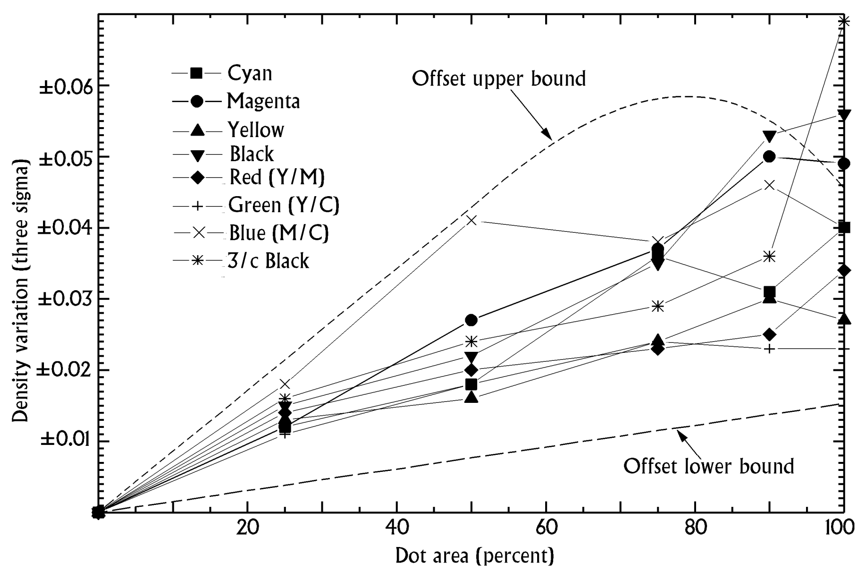

Figure 5 Measurement of inherent type density variations printed on 50 consecutive sheets that show the effect of waterless plates.

F. Effect of Water

Another prime candidate for the source of color variations was water. Accordingly, a set of waterless prints was obtained and measured, as shown in Figure 5. As can be observed, two of the solid targets in the tone scale had variations beyond the upper bound, while those in the screened targets were on the high side. Thus, getting rid of water is not a panacea when it comes to color variations.

E. Effect of Ink.

The last process parameter to be addressed was ink and, in particular, the pasty nature of lithographic ink. It was thought that the orange peel-like surface, produced on paste ink when transferred by film splitting, could play a role in producing color variations. Because, in contrast, the gravure process uses a watery ink, it was thought useful to obtain and measure a set of gravure prints. The results, shown in Figure 6, were again negative in that the color variations were comparable to the lithographic benchmarks.

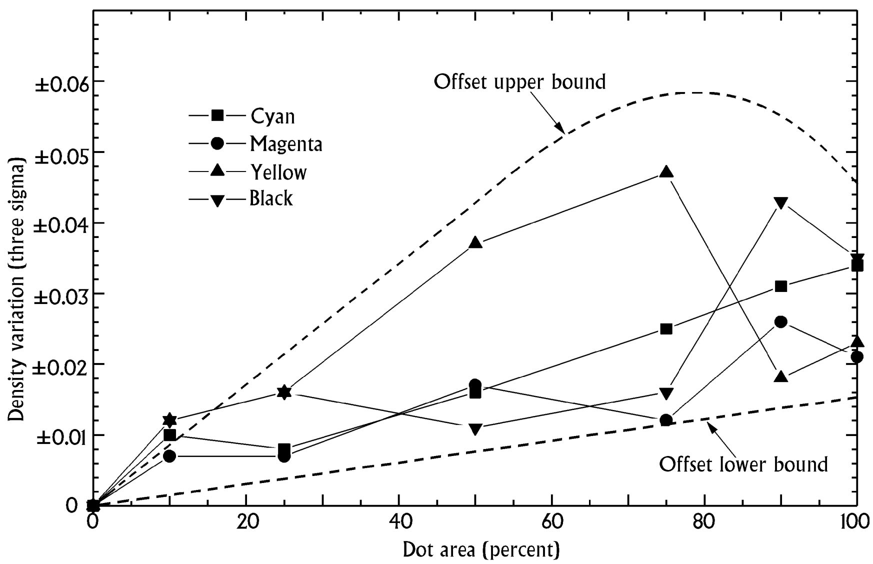

Figure 6 Measurement of inherent type density variations printed on 50 consecutive sheets that show the effect of printing with the gravure process.

III. Some Fundamental Considerations

A. Analysis of Operator Induced Density Changes.

When considering the question of what causes density variations, the first answer that comes to mind is random variations in printed ink film thickness, which can occur for a variety of reasons. This answer is suggested by the known fact that a pressman can induce a color variation by adjusting the ink keys, i.e., that a change in printed ink film thickness changes the density in both solid and screened areas of a print (at least when printing conventional or AM screens). To quantify this, density data on AM screened press sheets having a range in solid density of 0.80 to 1.80 were analyzed to create curve (a) in Figure 7, which is a plot of the density change versus screen area induced by a change of 0.03 in solid density. This curve mimics the curves in Figures 1 - 6 that do not exhibit peaks. It also shows that changes in solid printed ink density, induced by ink key adjustments do not in general produce changes in screen densities that are larger than the corresponding change in solid density. i.e., do not produce peaks on the curve of density change versus dot area.

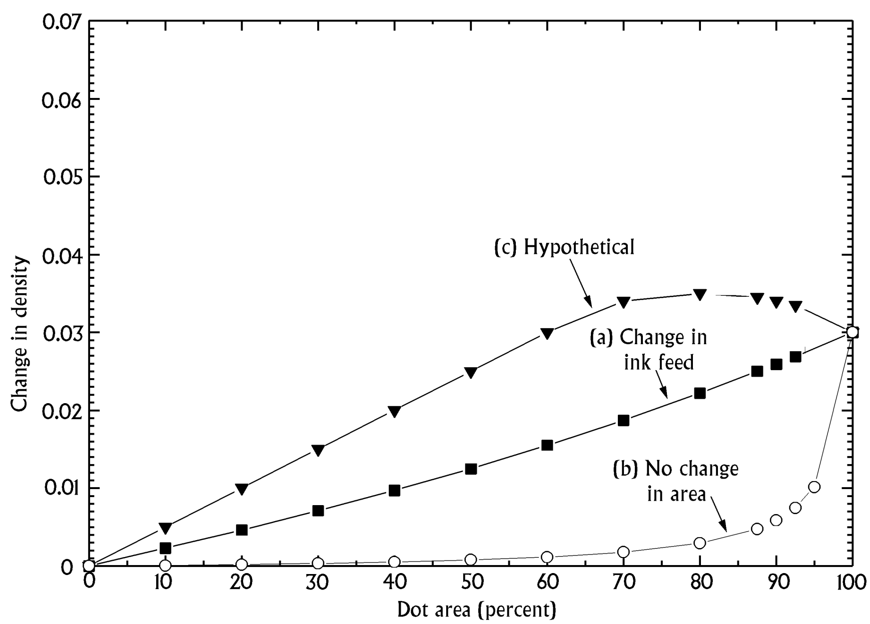

Figure 7 Curve (a) shows changes in print density that occur when ink feed rate is adjusted by press operator to increase solid density by 0.03 density units. See text for description of curves (b) and (c).

Curve (b) in Figure 7 was constructed to discover what the corresponding changes in density would have been produced if no changes in dot area had occurred. This was accomplished by differentiating equation (1), the Murray-Davies equation, with respect to solid density, and using the result (equation (2)) to calculate tint density as a function of screen or dot area. A comparison of Curves (a) and (b) shows that the contribution of dot area change, induced by the change in ink film thickness is indeed great.

$$D_t = -\log_{10}\left[1 - a\left(1 - 10^{-D_s}\right)\right] \qquad (1)$$

where:

a = area of dots in screened region
D_s = density of solid
D_t = density of screened region

$$dD_t = \frac{\left(a * 10^{-D_s}\right)}{\left[1 - a\left(1 - 10^{-D_s}\right)\right]} * dD_s \qquad (2)$$

Curve (c) in Figure 7 is a hypothetical one constructed to mimic the curves of density variations versus dot area that do exhibit a peak in the shadows. Given the above considerations, it should be obvious that, compared to Curve (a), the peak in Curve (c) is due to a change in the areas of the shadows where the peak occurs, that is about twice as large as the area change of Curve (a) relative to (b).

B. Further Insight Into the Character of Density Variations.

A review of the offset data plotted in the Figures 4(b), 5(b), and 6(b) of the previous paper, and Figures 1 to 5 of this paper provided additional insight into density variations with respect to color, screen area, and location on the sheet. These insights proved helpful in arriving at the conclusions set forth in Section IV.

1. The Factor of Color. Considering only the single film colors, cyan, magenta, yellow and black, a very definite trend is evident in the densities of the solid patches of the tone scales: yellow always has the smallest variation and black, when measured, always has the largest variation. However, no trend is evident in the screened patches with respect to color.

2. The Factor of Screen Area. The eight figures of density variations cited above comprise a total of 39 plots of single film color variations. Two thirds of these plots rise to a peak at a screen area of between 50 and 90 percent. No trends are evident, so all that can be said is that the shape of the curve of density variation versus screen area is not consistent, although more often than not it does exhibit a peak.

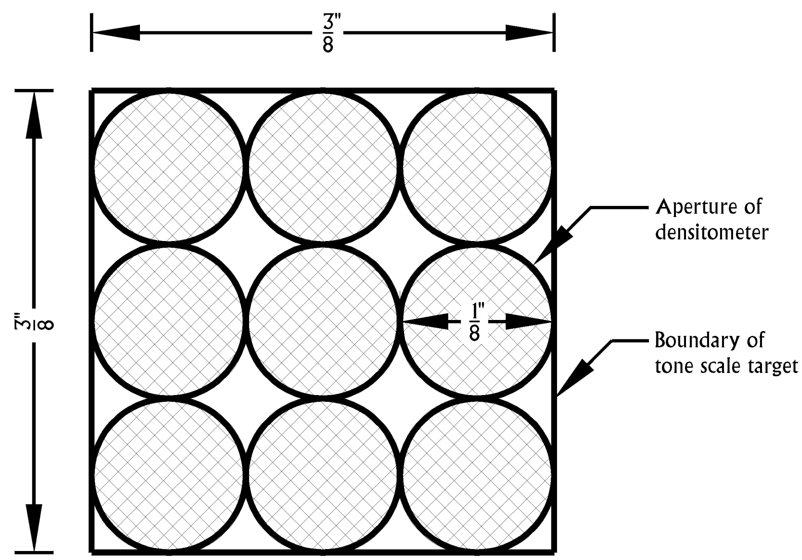

Figure 8 Diagram of the locations of the nine density measurements made in each tone scale target on Sheet 1.

3. Location as a Factor. The final set of data presented here comprises density measurements of the tone scale on Sheet 1 of the benchmark set of sheets plotted in Figure 2. In this case, the size of the tone scale made it possible to measure density in nine non-overlapping locations on each tone scale target, as described by the diagram in Figure 8. The range of each such set of nine measurements was then plotted versus screen area to produce Figure 9. This figure is remarkable for its similarity to Figure 2 that contains plots of the density variations exhibited by a family of 50 consecutive sheets. Further evidence of the alikeness of the two sets of data is their good correlation demonstrated when the range data of the single sheet is plotted versus the three sigma data of the family of 50, as shown in Figure 10. This striking similarity suggests that the variations displayed from sheet to sheet on the consecutive sheets and from location to location on the single sheet were produced by the same cause, whatever that is.

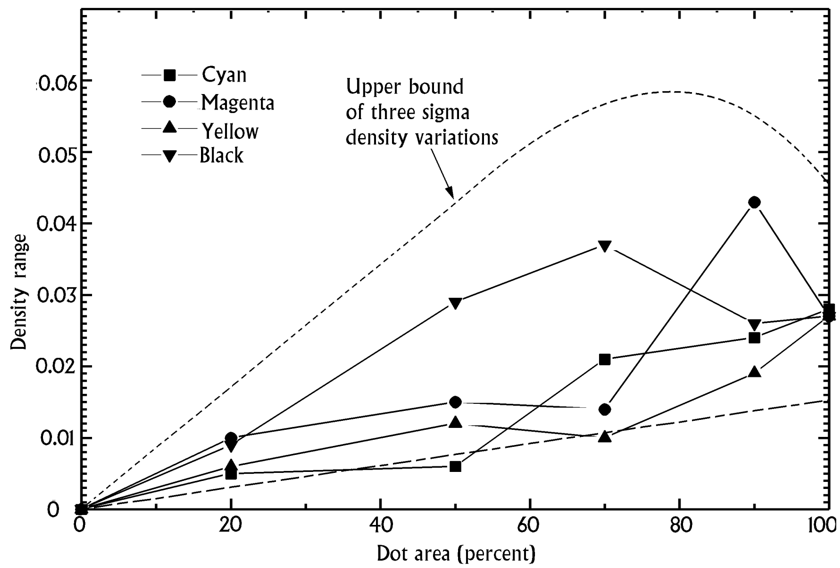

Figure 9 Range of density measurements in each tone scale target of Sheet 1. For comparison with plot of measurements of the three sigma variations for 50 consecutive sheets, see Figure 2.

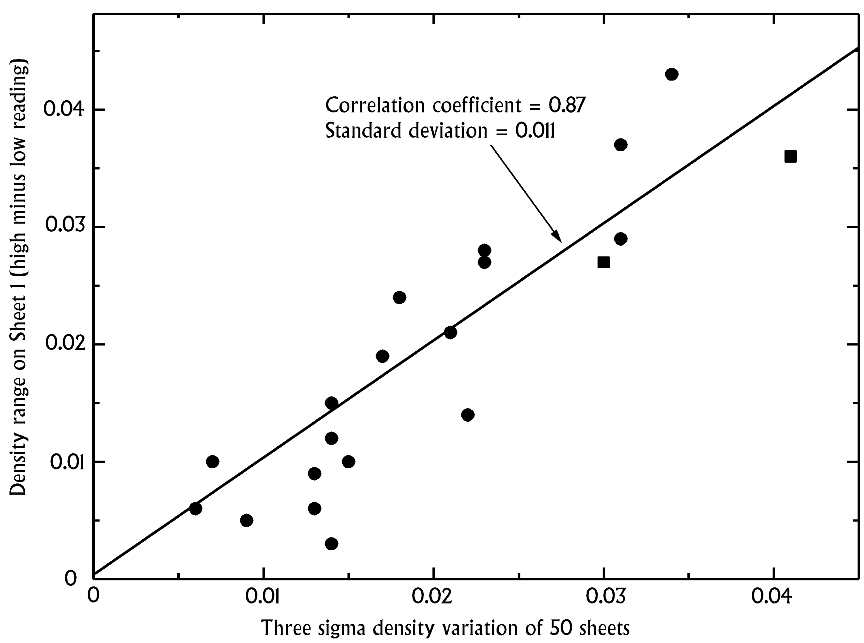

Figure 10 Correlation between density range on Sheet 1 and three sigma variations on 50 consecutive sheets.

IV Summary and Conclusions

This section provides answers to the following three questions that were set forth at the beginning of this paper.

1. What is the expected upper bound of inherent type density variations for the lithographic printing process?

Based on the two sets of benchmark measurements presented here, and the three sets contained in the 2004 paper, it is reasonable to conclude that the magnitude of inherent type density variations expected to occur in the lithographic printing process, using coated paper, are within the three sigma limits set forth in Table I and plotted as the upper bounds in Figures 2 - 6. However, it must be emphasized that in practice the only way to achieve these limits is to inspect every printed sheet and reject all those that have variations produced by external causes. This is because it is probably not economically feasible to completely eliminate all externally caused color variations.

Table I Recommended upper bound of expected three sigma density variations.

Dot area (percent)	0	10	20	30	40	50
Three sigma upper bound	0.000	0.009	0.017	0.026	0.034	0.034
Dot area (percent)	60	70	80	90	100	
Three sigma upper bound	0.051	0.057	0.058	0.055	0.055	

2. Is it possible to reduce the magnitude of these density variations by changing one or more process parameters?

The concise answer to this question is that there is small likelihood that the limits defined above can be lowered by changing process parameters. However, printing on uncoated paper may increase the limits.

3. What is the cause of the inherent type density variations plotted in Figures 1 to 5, and what is the explanation for the shape of these plots?

It has been demonstrated that the typical curve of density variation versus dot area can be generated by a change in the density of the printed ink film and a concurrent change in dot area. For the combination of such changes that are induced by an operator's adjustment of ink feedrate, it has also been demonstrated that the resulting density variation is greatest in the solid area and decreases monotonically toward zero as dot area decreases. Thus, the occurrence of a peak in most density variation curves can only be explained by an additional change in dot area in the region of the peak. Therefore, the most likely explanation for the shape of the two curves is that there are two mechanisms involved. The first mechanism is most likely a variation in printed ink film thickness that generates a change in solid density, and that is known to also produce a concurrent change in dot area. (The phenomenon that accounts for the concurrent change in dot area has never been satisfactorily explained.) The second mechanism is thought to be an independent change in dot area in the region of the peak produced by a phenomenon like slurring.

V References

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VI Acknowledgements

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Appendix A Outline of the Procedure For Analyzing Density Measurements of 50 Consecutive Prints

Step 1. Measure density, to three places, of each target in a given color in the tone scale.

Step 2. Calculate the average value and standard deviation, SDc, of each set of density measurements.

Step 3. Plot density of each set of data versus sheet number, determine best linear fit to the data, and record slope of best linear fit.

Step 4. Is drift, or change in best straight line fit from sheet #1 to sheet #50 (50 times the slope), significantly greater than the corresponding calculated standard deviation?

> If YES, proceed to Step 5.
> If NO, proceed to Step 7.

Step 5. If necessary, remove drift in measured density data using the following equation to correct the measured densities in the given set:

(Corrected density) = (meas. Dens.)*(1-(Slope)*(sheet#-25.5)

In using this equation be sure to enter the sign of the slope. In many cases the standard deviation of the corrected set will be less than, and the average will be the same as, the corresponding values for the uncorrected set.

Step 6. Use the standard deviation of the corrected data as SDc in steps that follow.

Step 7 Divide each data set into a minimum of four (and preferably more) groups that constitute a binomial frequency distribution and then plot. Helpful hint: Set group width equal to calculated standard deviation and select the midpoint equal to the average. Arriving at the best binomial distribution is sometimes an exercise in trial and error but becomes easier with experience.

Step 8. Obtain the best fit of a Gaussian curve to the appropriate binomial frequency distribution, i.e., to either the uncorrected or corrected data set and note SDf, the standard deviation (one half the width of the curve peak at half its height, times 0.849), and average value (density at curve peak center) of the best fit curve. As a check for errors, make sure the average value is approximately the same as obtained in Step #2.

Step 9. Determine if the following criteria are satisfied:

(i) The difference between the standard deviation of the measurements, SDc, and that of the Gaussian curve, SDf, must not exceed the greater of either 15% of the SD or 0.002 density units. (This condition eliminates the need to define an outlier.)

(ii) There must be no double peaks in the distribution. (This determination is subjective in that there can be a double peak even if there is no difference in the two standard deviations.)

Helpful hint:

Noncompliance with these criteria can also indicate that the best binomial distribution has not been constructed. Therefore when a distribution is judged not normal, it will be worthwhile to review the construction of the frequency distribution.

Step 10. If the criteria in Step 9 are satisfied, then the magnitude of the inherent type variations can be taken to be equal to 3 times SDc.