The Relationship between the Dot Area Monitored and Printing Quality in Offset Lithography

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Keywords: Quality Control, Dot Gain, Solid Ink Density

Abstract: The most popular numerical quality control method used in the press field is to use control strips and measure solid patches by a hand-held densitometer. Scanning densitometers have been developed and being used to save measuring time and to control ink keys recently. However, this method has two problems:

1. Solid Ink Density is not enough to assure the quality of images, which cannot recognize dot gain, doubling, and slur.
2. Control strips do not always represent the image quality, which are easily changed by the 'gap' of the plate cylinder and the amount of dot area on the plate.

To solve the first problem, halftone patches seem to be better than solid patches, because the density of halftone patches are affected by dot gain, doubling, and slur.

Some papers recommend about 3/4 tone to be monitored (Sigg, 1970), and furthermore this 3/4 tone is important to keep print contrast and watch dot gain changing.

The dot area which should be monitored to keep the tone reproduction consistent is called the Special Dot Area (SDA) in this paper and was estimated by the simulation based on tone reproduction curves and the experiments using DDCP.

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The result of this study shows that the SDA which is suitable for the control strip for offset lithography is 65-85%, around 3/4 tone.

Background

The rapid development of technology, especially in computers, changes the process of printing. For example, Desk Top Publishing (DTP) makes some of the prepress process easier and faster, and Computer-to-Plate (CtP) will eliminate some steps in production, such as film outputting and platemaking. Although these new technologies improve the accuracy of making dots on plates, the consistency of color reproduction is still the biggest issue in control over the printing process.

Additionally, the recent increase in direct mailing catalogs makes this problem more significant because the consumer needs the catalog to accurately represent the actual color of the product. Printing companies have to be responsible for the color of photographic reproductions. In order to satisfy the customers' request, it is important not only to reproduce the appropriate color, but also to keep it consistent through the entire printing job.

The most popular numerical quality control method used in the press field is to use control strips and measure solid patches by a hand-held densitometer. However, this method has some disadvantages (Tritton, 1993); Solid Ink Density is not enough to assure the quality of images, which cannot recognize dot gain, doubling, and slur. A control strip needs space on the press sheet and is not always accurate. Each plate cylinder of the sheet-fed press has 'gap', and this causes the inconsistent ink film thickness on a press sheet, and the plate cylinder of the web press also has a small 'gap' on it. Tritton says, "the inking systems are rarely able to achieve a homogeneous ink film from front to back of the sheet." (Tritton, 1993)

Furthermore, the position of the control strip also affects the color consistency on a press sheet. Leines states that the variability in dot gain and solid ink density is changed by the positioning of the control strip, and the trail edge is the most desirable position for the control strip to keep accurate color consistency for web offset printing. (Leines, 1990)

List of Abbreviations

Some abbreviations used in this paper are listed below, and the explanation for each abbreviation is in the Appendices.

ERA: Effective Relative Absorptance (Equal to Tone Value Increase)
TRD: Tone Reproduction Difference
SDA: Special Dot Area
SID: Solid Ink Density

A model for the relationship among SID, Dot Gain, and Tone Reproduction

Figure 1 shows a model of tone reproduction curves. The straight line is assumed to be the aim or original tone reproduction curve, and the curve represents the tone reproduction curve which is distorted by the dot gain during the press run.

When the targeted tone reproduction curve is represented by f (x), and the compensated tone reproduction curve is represented by g (x), the difference between these two curves (Tone Reproduction Difference: TRD) is calculated as follows:

$$TRD = \int_0^1 |f(x) - g(x)| dx \quad (1)$$

with x: Dot area.

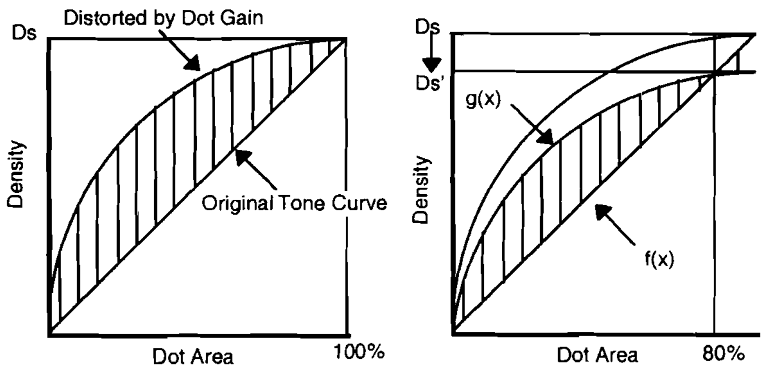

Figure 1. Tone Reproduction Curves and Compensation by SID

To research the Special Dot Area (SDA) which is appropriate to monitor the tone reproduction, the Solid Ink Density for the distorted tone reproduction curve is changed and the TRD is calculated for each Solid Ink Density. When the TRD is minimized, the SDA is found by comparing the two tone reproduction curves; the cross point of two curves.

Darkness was used to evaluate the Tone Reproduction Difference instead of Density because Darkness is more perceptually equal unit.

$$\text{Darkness} = 100 - L^* \qquad (2)$$

Methodology

The test form used in this research consists of the 500 patches of a CMYK overprint chart, which roughly represents all colors reproduced under specific printing conditions, the IT-8.7/3 printer characterization target, and a control strip to check the proofing condition.
The control strip includes Solid, 75%, and 50% halftone patches for each process color and overprint, so the Solid Ink Density (SID), Print Contrast, Dot Gain, Trapping can be evaluated for each proofing sample.

The experiment needed to simulate the actual press run, so the Kodak Approval System was chosen as the model of press machine, and the SID and Dot Gain were changed.

For the experiment to find the SDA, the Magenta Ink was chosen as an experimental object. A sample which had the standard SID and 5% more ΔERA were made. Then two samples whose SID were decreased by 0.1 are made. The other series are for less dot gain. A sample which had the standard SID and 5% less ΔERA was made, and two other samples whose SID were increased by 0.1 were made.

Dot Gain	Sample#2	#3	#4
SID (Status T)	Normal	- 0.1	- 0.2
ΔERA (50%)	+ 5%	+ 5%	+ 5%

Dot Loss	Sample#5	#6	#7
SID (Status T)	Normal	+ 0.1	+ 0.2
ΔERA (50%)	- 5%	- 5%	- 5%

Table 1. Specifications for Test Proofs

ΔERA was changed according to the following model:

$$Y = X + 4 \cdot \Delta_{0.50} \cdot X(1-X) \quad (3)$$

with,

Y : the modified dot area,
X : the original dot area,
$\Delta_{0.50}$: the ΔERA at 50% dot area.

Data Measurement
Spectrophotometer and Measurement condition:
Gretag Spectrolino and Spectroscan
D50, 2 degrees, calibration on the absolute white

Results

Evaluation of Approval Proof
The proofing system used, Kodak Approval, was evaluated whether it supplied good samples or not. The criteria for this evaluation were:
1, Sheet-by-sheet consistency
2, In-sheet consistency
3, Accuracy of response to changing settings.

The standard tone reproduction curve of a printing plant was used as the "Normal Condition" for this research.

In this research, because only the condition of magenta was changed, the data of the other colors, black, cyan, and yellow, can be used to evaluate the consistency of this proofing system.

Table 2 shows the results of the consistency evaluation of SID measured by Status T.

Proofing System Consistency (KCY 1-7)

SID	Ave.	Std.	Max.	Min.
Cyan1	1.34	0.01	1.36	1.32
Cyan2	1.32	0.00	1.33	1.32
Ave.	**1.33**	**0.01**	**1.34**	**1.32**
ΔD	**0.02**	**0.01**	**0.03**	**0.00**
Magenta1	N/A	N/A	N/A	N/A

Magenta2	N/A	N/A	N/A	N/A
Ave.	N/A	N/A	N/A	N/A
ΔD	N/A	N/A	N/A	N/A
Yellow1	0.86	0.00	0.87	0.86
Yellow2	0.85	0.00	0.86	0.85
Ave.	**0.85**	**0.00**	**0.86**	**0.85**
ΔD	**0.01**	**0.00**	**0.02**	**0.01**
Black1	1.77	0.01	1.78	1.76
Black2	1.74	0.01	1.75	1.73
Ave.	**1.76**	**0.01**	**1.76**	**1.75**
ΔD	**0.03**	**0.01**	**0.04**	**0.01**

Table 2. Proofing System Consistency

The control strip in the test chart used in research has two sets of the same combination of color patches. Each set was evaluated individually (sheet-to-sheet consistency), and then the difference between the densities of two patches was also evaluated (in-sheet consistency).

The difference in the densities of these two patches was named ΔD (e.g. ΔD = Cyan1 - Cyan2). The SID for all colors were very consistent for both sheet-to-sheet and in-sheet consistency. Both Contrast and ΔERA were very consistent as well. However, the Contrast values of this proofing system were a little lower, and, conversely, the ΔERA values were a little higher than the SWOP Recommendation.

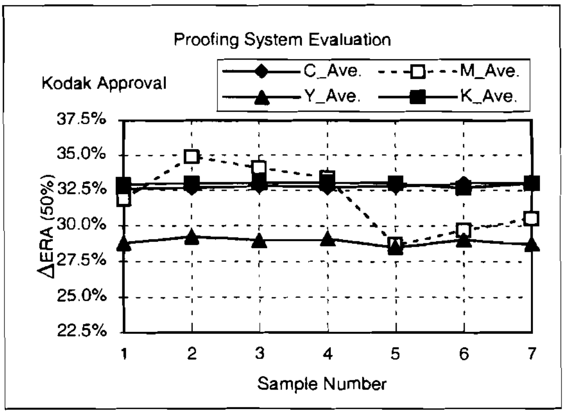

Figure 2. SID for each sample

Figure 2 shows how ΔERA was actually changed by the settings shown in table 1. It is clear that this proofing system is very consistent and the conditions changed almost as expected.

From these analyses, it was concluded that the samples obtained from this proofing system were good enough to be used in this research.

SDA (Special Dot Area) Simulation

Figures 3 to 6 show the relationship between TRD (Tone Reproduction Difference) and SID. The horizontal axis is the Dot Area at the cross point of the normal and the compensated curves, and the vertical axis is the TRD. Solid lines are the TRD, and Dotted lines are the SID.

Figure 3 shows the simulation result for +5% ΔERA. As SID is decreasing from 1.35, the TRD is also decreasing to 1.27 of the SID. The TRD is 2.40, and the Dot Area at the cross point is 80% at this point.

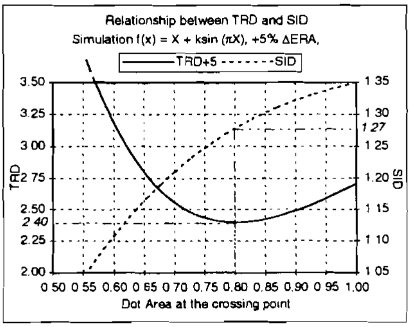

Figure 3. Simulation of the TRD

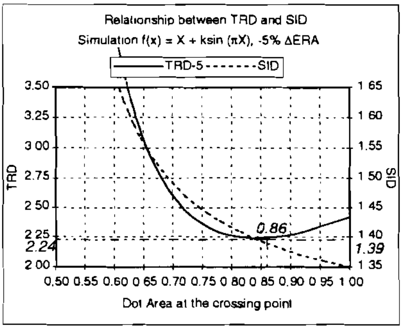

Figure 4. Simulation of the TRD

Figure 4 shows the simulation result for -5% ΔERA. As SID is increasing from 1.35, the TRD is decreasing to 1.39 of the SID. The TRD is 2.24, and the Dot Area at the cross point is 86% at this point.

Figure 5 shows the simulation result for +10% ΔERA. As SID is decreasing from 1.35, the TRD is also decreasing to 1.16 of the SID. The TRD is 4.87, and the Dot Area at the cross point is 76% at this point.

Figure 6 shows the simulation result for -10% ΔERA. As SID is increasing from 1.35, the TRD is decreasing to 1.43 of the SID. The TRD is 4.31, and the Dot Area at the cross point is 85% at this point.

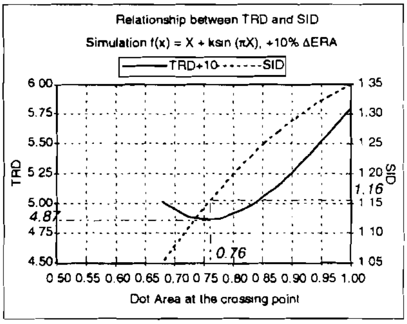

Figure 5. Simulation of the TRD

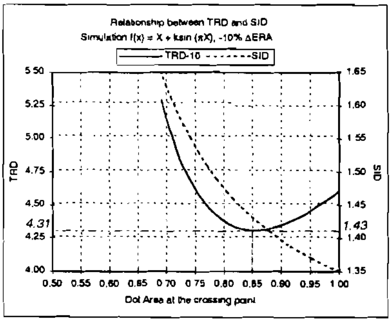

Figure 6. Simulation of the TRD

Figure 7 shows the relationship between the Dot area at the crossing point and the TRD, and table 3 summarizes the results of this simulation.

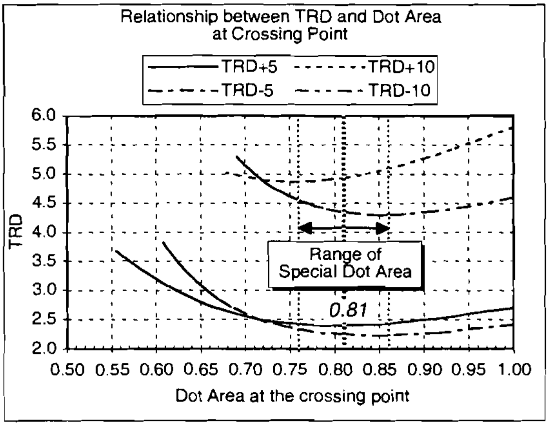

Figure 7. Simulation of the TRD

Because we cannot always foresee whether dot gain or loss will occur relative to the conditions prevailing at the time the first "OK" sheet was obtained, so it was concluded that an SDA of 81%, midway between 76 and 86 percent, may be used.

Condition	Normal	+5% ERA	+10% ERA
ΔERA	+22%	+27%	+32%
SID	1.35	1.27	1.15
SDA		80%	76%
TRD		2.40	4.87

Condition	Normal	-5% ERA	-10% ERA
ΔERA	+22%	+17%	+12%
SID	1.35	1.39	1.43
SDA		86%	85%
TRD		2.24	4.31

Table 3. Summary of the simulation

SDA Experiments

The criterion for evaluating the effectiveness of the SDA is:

When the densities at the SDA are same for two printing samples, the color of the images in these two samples are also same.

To evaluate the result of this experiment, 119 colors were selected from the IT-8.7/3 chart. All colors had certain amounts of magenta ink.

–Dot Gain Experiment–

Figures 8 and 9 show the result of +5% ΔERA experiment. "Normal" means the normal condition. Dn/+5% means the normal SID but +5% ΔERA. Dn-0.1/+5% and Dn-0.2/+5% mean the SID is decreased by 0.1 or 0.2, respectively, and ΔERA is increased by 5 percent.

The tone reproduction curve of the normal condition is within the curves of the Dn/+5% and Dn-0.2/+5%. So these samples seem to be good enough to analyze the SDA. In figure 11, the line of Dn-0.1/+5% crosses the solid line, which represents the normal tone reproduction, at the 70%. And table 4 shows that the -0.1 SID sample has the smallest TRD. So it was predicted the color differences of each of the selected 119 colors may be smaller than those of the other conditions.

+5%	Normal	SID-0.0	SID-0.1	SID-0.2
ΔERA	+22%	+27%		
SID	1.16	1.17	1.10	1.02
Crossing Point		100%	70%	45%
TRD		1.68	0.77	0.82

Table 4. TRD Comparison for +5% ΔERA

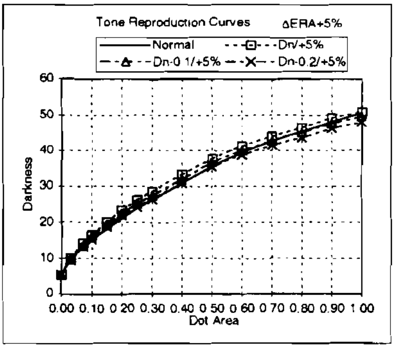

Figure 8. Tone Reproduction Curves

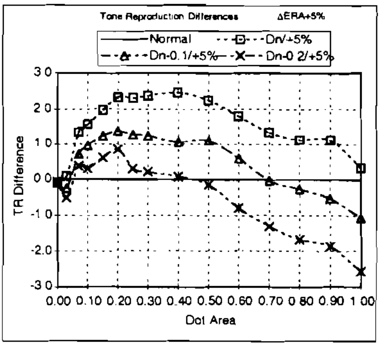

Figure 9. Comparison of TRD

Table 5 shows the summary for the +5% ΔERA experiment. The sample with -0.1 SID condition (actually -0.06 SID) has the smallest average ΔE*ab at 1.81 with the smallest standard deviation at 0.97. And the maximum color difference at 5.21 is because of the colors with more than 90% of magenta. In general, these colors with very high amount of magenta is difficult for human eyes to recognize the color difference, so this researcher thought that the maximum ΔE*ab at 5.21 is not serious problem in this case.

+5% ERA	SID-0.0	SID-0.1	SID-0.2
ΔE*ab_ave.	2.31	1.81	2.28
ΔE*ab_std.	1.44	0.97	2.12
ΔE*ab_max.	5.54	5.21	9.41

Table 5. Color Difference Comparison
(119 patches in IT-8.7/3)

–Dot Loss Experiment–

Table 6 shows that the sample with the -0.1 SID has the smallest TRD at 0.87, so this researcher predicted the color difference of each color in this sample may be the smaller than those of the other conditions.

-5%	Normal	SID+0.0	SID+0.1	SID+0.2
ΔERA	+22%	+17%		
SID	1.16	1.19	1.26	1.32
Crossing Point		90%	65%	45%
TRD		1.27	0.87	0.96

Table 6. TRD Comparison for -5% ΔERA

Table 7 shows the summary for the -5% ΔERA experiment. The sample with +0.1 SID condition has the smallest average ΔE*ab at 1.84 with the smallest standard deviation at 0.92. And the maximum color difference at 3.87 is not a problem at all.

-5% ERA	SID+0.0	SID+0.1	SID+0.2
ΔE*ab_ave.	2.33	1.84	2.08
ΔE*ab_std.	1.37	0.92	1.63
ΔE*ab_max.	5.06	3.87	7.46

Table 7. Color Difference Comparison
(119 patches in IT-8.7/3)

From these analyses, it was concluded that the dot area of around 65% to 70% may be used as the SDA to monitor the image quality for this printing condition, Kodak Approval Proofing System.

These experiments also showed that the quality control using the SDA is useful and practical method to reproduce the picture images, in most of commercial and publishing printing. The general picture images are rich in tone, so the integrated color can be reproduced visually similar to the "Target sheet" by keeping the density of the SDA.

Conclusions

From the simulation using the sine function tone reproduction model, the SDA (Special Dot Area) was estimated around 81%; larger SDA for dot loss, and smaller SDA for dot gain. However, according to the experiment result, the SDA seems to be smaller than that from the simulation, around 60-70%.
This might be the difference between the dot gain model and the actual behavior of the Kodak Approval. The dot gain might be changed differently by the type of offset printing machine, sheet-fed or web. So it is important to investigate the dot gain behavior of each machine to estimate the practical SDA.

There seems to be the SDA which is suitable for the control strip for offset lithography, and when the operator keeps the strip consistent, in terms of density, it makes the integrated color difference smaller, compared to using the other dot area, such as solid ink patch or 50% tint patch.

This study also showed that the same tone reproduction requires the same SID and the same dot gain. So even though keeping the density of the SDA very consistent, some parts of tone curve are different from original density when the operator compensate the dot gain by changing the SID. Further more, when most

of the image are solid or tint of a certain dot area, those colors, solid or tint, should be used in the control strip from these results. As figures 14 and 15 are showing, the colors with larger dot area, 90-100%, were reproduced accurately when the SID was matched, and the colors with smaller dot area, less than 45%, were reproduced accurately when the density at around 45% was matched.
However, for usual publishing and commercial printings, which have many color pictures on the press sheets, the SDA method can be used as a practical way to keep the visual quality of press sheet consistent.

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Appendices

List of Abbreviations

ERA
Effective Relative Absorptance
In the most of the case when we are talking about the dot area, the data is based on the result of the Murray-Davies equation and does not represent the mechanical dot area on the paper accurately. So it is better calling it "Effective Relative Absorptance" or ERA rather than calling it "dot area." The change in dot area called "dot gain" is called "Delta ERA" or ΔERA. (Tangvichachan 1993)

TRD
Tone Reproduction Difference
The difference of two tone reproduction curves which is represented by the area between these two curves.

SDA
Special Dot Area
The dot area which can be used for the quality control for offset lithography. When the density of the SDA is the same for two tone reproduction curves, the TRD of these two curves is minimized.

SID
Solid Ink Density

Tone Reproduction Model

The sine function model which was used as the tone reproduction model is:

$$Dt = Ds\,[\, x + k \sin(\pi x)\,] \tag{4}$$

with,

x : the dot area on a film;
Dt : the Colorimetric Density at the dot area of x;
Ds : the Colorimetric Solid Ink Density; and

k : the coefficient under the specific printing condition, calculated by following equation in the SDA simulation.

from $Dt / Ds = A + k \sin(\pi A)$

$$k = (Dt / Ds - A) / \sin(\pi A) \quad (5)$$

when $A = 0.50$ (50%),

$$\sin(\pi A) = 1 \quad (6)$$

then $$k = (Dt / Ds) - 0.5 \quad (7)$$

From the definition of ΔERA in the SWOP (Murray-Davies);

$$Dt = -\log(1 - ERA(1 - 10^{-Ds})) \quad (8)$$

$$ERA = 0.5 + \Delta ERA \quad (9)$$

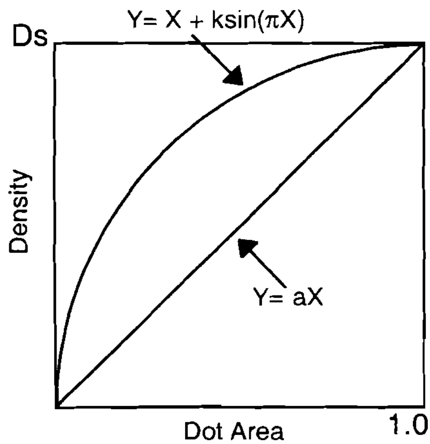

Figure 10. Tone Reproduction Model