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A Study on the effects of dot gain, print contrast and tone reproduction as it relates to increased solid ink density on stochastically screened images versus conventionally screened images

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A Study on the Effects of Dot Gain, Print Contrast and Tone Reproduction as it Relates to Increased Solid Ink Density on Stochastically Screened Images versus Conventionally Screened Images

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Sciences in the College of Imaging Arts and Sciences of the Rochester Institute of Technology

May 1994

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Abstract

Through the evolution of technology both print and process have become more predictable and reliable. As a result, innovations in the press and plate coating technologies along with imaging software technologies have challenged the way we view print. With lithography being the predominantt printing process, printers now have to find ways to differentiate themselves from others especially in the color reproduction arena.

For years, traditional halftoning methods have reproduced original continuous tone images with success. Today, however, the once accepted rosette is now being challenged by a new technology that does away with conventional screen rulings and dot patterns. This new technology called Stochastic Screening, offers many benefits and is loudly touted by its champions.

Tone reproduction whether it be through conventional screening methods or stochastic screening methods is influenced by all parameters in the printing process. In this study, the effects of inking on dot gain and print contrast were studied. A test form was developed to test the prediction that stochastically screened images will perform equally or better than conventionally screened images under normal and increased inking conditions.

Evaluation of the test results shows that conventionally screened images actually performed better than stochastically screened images. Stochastic images actually experienced

increased dot gain and loss of print contrast in the 48% and 70% tint areas under normal and increased inking conditions. Although stochastic images had less of a performance, the images appeared to have less variation throughout the run.

At the height of implementation, it is not likely that stochastic screening will become the standard for industry because there are many unanswered questions that still surround this new technology. It is also obvious that implementation of this new technology is bound to be limited by the challenges of controlling a wide variety of equipment across industry, as well as the need to control the plating and printing processes themselves.

Chapter 1

Introduction

The greatest challenge for the printer since the birth of lithography has been to faithfully reproduce an original continuous tone photograph without loss of tonal value and detail. Besides reproducing a product that would meet or match the original, the printer is also challenged by delivering a product that is timely, predictable and consistent.

Over the years, various methods have been tried, but most were inconsistent, difficult to control and limited to short run lengths.[1,2] Moreover, the methods were hindered by inconsistencies in the plate manufacturing process. As a result, the processes were limited to specialty reproduction work.

For decades, the only two photo-mechanical processes capable of rendering exceptional tonal quality were Collotype and Screenless lithography. Collotype developed in the 1800's used photo-receptive gelatin surfaces and screenless lithography, developed in the 1950's used specially ground aluminum plates.[3] Today only one known practitioner of Collotype, Chicago's Blackbox Collotype, exists in the United States.

Today, there are four predominate printing processes capable of consistently reproducing originals at higher levels of speed, volume and quality. These are letterpress or relief printing, lithography or planographic printing, gravure or intaglio printing and screen or

porous printing. With gravure being the exception, all of the processes lay down ink of a uniform thickness, and therefore, the processes can not produce true variable tone reproductions. The printed page exhibits only two levels of optical density; either the presence or absence of ink.[5] Wherever there is ink, the density is usually uniform. Wherever there is no ink, there is white space (paper). With gravure, depressed cells of varying depths on imaging cylinders represent the tone of an image. The darker the tone of the original, the deeper the cell and the greater the amount of ink transferred to the page. Thus, gravure is capable of reproducing true variable tones.

Since lithography can not print true variable tone images, some means must be provided to render a printable continuous tone image. For years, lithography has converted continuous tone originals into printable images through a photographic conversion process employing a specially designed screen. The screen breaks up the continuous tone image into numerous tiny dots. These dots are equally spaced, center-to-center. However, the dot size varies according to the tone being rendered. The darker the tone of the original, the larger the dot size on the reproduction.

Thus, the basic function of the halftone screen in lithography is to break up the original continuous tone image into a series of dots whose size corresponds to different tonal values from light to dark. This relationship of dot size to continuous tone density is called *tone reproduction,* which can be studied graphically in the form of a *tone reproduction curve.*

The tone reproduction curve is a convenient way to determine the range of gray levels that can be reproduced by a halftone screen. It is also a convenient way to determine the relationship between dot size of the reproduction to the density of the original. When plotted, the shape of the curve is dependent on the nature of the printing process, ink,

screen, and other factors. It tells us how close we came to an ideal reproduction, and how we can make improvements by adjusting highlight to shadow exposures to capture all the detail of the original.

In facsimile reproduction, all areas of the reproduction when compared to corresponding areas of the original would be the same value.[6] If the relationship were plotted graphically, a 45° straight line from the origin of the graph would be obtained. In practice, however, rarely is an ideal tone reproduction curve obtained from a printed sheet. The density or tone range of the original is usually greater than the density range reproduced by a single layer of ink on a press sheet. As a result, it is therefore necessary, to compress the tonal scale of an original to fit that of the reproduction, a phenomenon known as *tone compression.*

Tone compression compromises the density of the shadows and all levels of gray throughout a reproduction. Tones are compressed, because ink on paper is not as dark as silver in a photographic image. For example, if the density range of an original is 0.00 to 1.90 and that of the press sheet is only 1.30, then the tone reproduction curve will have to be compressed in a way so that the 1.30 print density corresponds to the 1.90 density of the original.[7]

Optimizing tone reproduction begins by determining the correct contrast for a halftone, which in turn determines the correct dot size to print.[8] Therefore, the first step to a good reproduction begins with proper tone compression. Analyzing printing conditions and press variables is the next step, followed by control of middletone contrast on press. Consistent quality reproductions are not only dependent on proper tone reproduction

adjustments, other requirements dictated by the halftoning screening process, are required as well. These requirements are:

- Smooth tonal rending of the halftone dots without discernible jumps in tone. (This is dependent on control of the 50 percent dot or middletone, dot gain and solid ink density on press.)
- Freedom from visible dot structures or interference from moiré patterns or rosettes. (This is dependent on the screen ruling and angle chosen.)
- Sharp detail rendition without compromise. (Again this is dependent on the screen ruling chosen. Usually the finer the screen, the more detail or resolution achievable.)
- Ability to produce gray levels as gray without color casts. (This applies to color reproductions, specifically gray balance.)
- Saturated and brilliant colors without compromise.
- Ability to render the range of gray levels without tradeoffs.

For years, traditional halftoning methods have reproduced original continuous tone images with success. In truth, however, the halftone screening methods reduce tonal range, detail in the reproduction and color palette available to the printer, in turn decreasing the fidelity of the original.[9] (It should be noted, that the negativism's associated with halftone screening can be mininized when using a screen with a finer ruling. However, they are more sensitive to press changes, dot gain and fill-in.)

Control of a continuous tone reproduction is affected by numerous variables. These variables are: the original image, screen angle, screen ruling, substrates, ink film thickness, dot gain, dot shape and the printing process itself (slur, doubling, trapping and fill-in). With all of these variables, how does the printer achieve the goal of reproducing an original without loss of tone and detail, and how do they deliver a product that is both consistent and at an acceptable level of quality? With all processes there will always be variables that cause inconsistencies. No two things will ever be alike no matter how carefully we try.

While it is impossible to eliminate variables and variation in a process, they can be minimized and controlled. Minimization can only take place once assignable causes and normal variation have been determined. It is through measurement (dot area) and control (press conditions, ink film thickness, tone reproduction curves,...) that the printer delivers a product that is predictable, controllable and at a level of quality that is near to the original. Seemingly though, "The quest for a halftone screening processes capable of reproducing quality equal to photographic originals still goes on."[10]

Through the evolution of technology both print and process have become more predictable and reliable. As a result, innovations in press and plate coating technologies along with imaging software technologies (faster imagesetters) have challenged the way we expect to view print. With lithography being the predominate printing process, printers now have to find ways to differentiate themselves from others especially in the color reproduction arena. To do this, they must supply a product superior to that of the mass markets, and not a commodity, to remain competitive.

Before the Spring of 1993, the thought of a predictable, controllable screenless reproduction was almost illusive. With recent innovations delivery of a reproduction with previously unprintable screen rulings is now being delivered, rendering superior tone and detail characteristics, along with an increased color palette for the printer. Images appear to be continuous tone and of photographic quality, in effect calling the process an electronic implementation of screenless printing.[11] Unlike its predecessors, collotype and screenless lithography, the new process is statistically controllable and predictable. Additionally, this new process offers a low cost way to obtain photo-realistic images. This alternative screening process called "Stochastic Screening," was developed as a means to avoid the problems associated with conventional screening methods.

Stochastic screening is a system based on doing away with conventional screen rulings and dot patterns that are aligned along a fixed grid.[12] Because the new process eliminates screen rulings, screen angles and dots, the entire concept of ruling and angle is upset. Halftone dots are replaced with "spots" which are randomly controlled. Additionally, spots are of a fixed size, and are made to appear more or less often dependent on the value of the tone being rendered. In stochastic screening, the screen frequency (i.e. screen ruling) changes throughout the image.

The benefits of this new screening process, have been loudly celebrated by its champions. It eliminates unwanted artifacts [noticeable rosettes and angle moiré] by elimination of dots, screen angles and screen rulings, so that the final image appears continuous tone.[13] It allows printers to run to higher ink densities, without loss of tonal value and detail. Stochastic screening also enables the printer to achieve faster make-ready times, because the method is easier to register. Additionally, the new process allows for more saturated colors and a more exact reproduction.[14]

Statement of the Problem

At the height of implementation, it is not likely that stochastic screening will become the standard for the industry because there are many unanswered questions that still surround the new technology. It is obvious that implementation of this new technique is bound to be limited by the challenges of controlling the wide variety of printing equipment across the industry, as well as by the need to control the plating and printing processes themselves. The real challenge as stated by Paul Beyer, sums it up in the following way, "Do we as an industry or as individual companies possess the understanding and tools necessary to

control the print reproduction process carefully enough to implement this new technology?"[15]

As noted earlier, the basis for printing predictable reproductions with traditional halftone screening techniques is through measurement and control of known variables. The most influential of these being screen ruling, solid ink density (SID) and dot gain. Questions surrounding this new technology then are as follows: 1) Do specific traditional variables affect a stochastic screen more than a conventional screen- these being screen ruling, dot gain and solid ink density; 2) Can traditional tools and means of measurement control be applied to the new technology in the same way they are applied to the old- tone reproduction curves; 3) Is tone reproduction met satisfactorily; and 4) Can the printer increase print contrast by increasing solid ink density without loss of midtone value and shadow detail?

This study is interested in answering all of the questions as posed above, and is particularly interested in the relationship between SID and stochastically screened images. Previous studies have shown that there is a direct relationship between increased SID and finer screen rulings. Solid ink density, or the amount of ink applied to the surface of the sheet influences, color saturation, color strength picture darkness and dot gain.[16] By increasing the amounts of ink, contrast increases to a point, but then decreases making the image appear darker. Additionally, excessive ink will be destructive in the middletone area causing unwanted color shifts (changes in hue and brightness.)

This study is based on the to establish a predictable and controllable image that can be implemented for a given set of variables and conditions. For this study, tone reproduction and increased SID will be investigated in relation to stochastic and conventionally screened

images. The aim of the study being two-fold will first determine the optimum tone reproduction curve for a given set of variables under normal printing conditions. Secondly, it will test the following statement: stochastically screened images allow for increased SID resulting in brighter colors and increased contrast without loss of shadow and midtone detail. The hypothesis tested will be that when solid ink densities are increased, stochastic images will display changes that will be equal to or greater than those of an image screened conventionally. As reported by Franz Sigg (TAGA, 1970) tone reproduction curves change along with ink film thickness. The greater the amount of solid ink density, the more gain in the 65% to 85% area of the image.[17] It has been criticized, however, that the greater the solid ink density, the more gain in the 40% to 60% tint areas of and image. Generally, as solid ink density is increased contrast is increased, but then decreased, because the solids gain quickly and fill-in.

Further discussion on optimizing tone reproduction will follow, focusing on the effects of SID and dot gain in relation to finer screen rulings. For this study, the RIT Gray Balance Bar will be imaged both conventionally and stochastically (both versions of th RIT Gray Balance bar will be a beta version supplied by David Cohn of the Technical and Education Center, and will be output by Agfa Div., Miles Inc. using Agfa CristalRaster™ and Agfa Balanced Screening technology. The beta RIT Gray Balance Bar will be sufficient for the purposes of this test.). Statistical analysis will be performed on samples taken and tone reproduction will be determined through graphical evaluations to determine if there is a correlation. Test charts will be imposed on a #1, 100 lb. sheet and printed web offset simultaneously under standard and increased inking conditions.

Endnotes for Chapter 1

1 Richard M. Adams II and Raymond J. Prince, "How I See It: Stochastic Screening," GATF World, vol. 5, issue 5, September/October 1993, p. 36.

2 Bill Esler and Roger Ynostroza, "High-Res Color: New Way to Look at Print," Graphic Arts Monthly, vol. 65, no. 10, October 1993, p. 50.

3 Richard M. Adams II and Raymond J. Prince, "How I See It: Stochastic Screening," GATFWorld, vol. 5, issue 5, September/October 1993, p. 36.

4 Bill Esler and Roger Ynostroza, "High-Res Color: New Way to Look at Print," Graphic Arts Monthly, vol. 65, no. 10, October 1993, p. 50.

5 R.J. Klensch, Dietrich Meyerhofer, and J.J. Walsh, "Electronically Generated Halftone Pictures," TAGA Proceedings, (Rochester, NY.: Technical Association of the Graphic Arts, 1970), p. 303.

6 John A. C. Yule, Principles of Color Reproduction applied to photomechanical reproduction, color photography, and ink, paper and other related industries, (New York: Wiley, 1967), p. 85.

7 John Cogoli et al., Graphic Arts Photography: Black and White, (Pittsburgh, PA: Graphic Arts Technical Foundation, 1985), p. 295.

8 Miles Southworth, "Optimizing Tone Reproduction," The Quality Control Scanner, vol. 2, no. 2, 1981, p. 1.

9 Eugene Hunt, Agfa CristalRaster™ Technology, Product and Technology Overview, (New Jersey: Agfa Div. Miles, Inc. May 1993), p. 1.

10 Ibid., p. 2.

11 Ibid., p. 3.

12 Jim Hamilton, "Random Screening Paves the Way for Sharper Images," Printing News Midwest, vol. 59, no. 12, December 1993, p. 5.

13 Joann Strashun, "Screen Options Gain Momentum," Graphic Arts Monthly, vol. 66, no. 2, February 1994, p. 56.

14 Ibid., p. 56.

15 Paul Beyer, "How Stochastic Technology is Being Implemented," Printing News, December 6, 1993, p. 6.

16 Miles Southworth, "Control the Middletone for the Best Color Reproduction," The Quality Control Scanner, vol. 9, no. 2., 1989, p. 1.

17 Franz Sigg, "A New Densitometric Quality Control System For Offset Printing," TAGA Proceedings, (Rochester, NY.: Technical Association of the Graphic Arts, 1970), p. 212.

Chapter 2

Theoretical Bases of the Study

Halftoning Principles

Traditionally, continuous tone images were produced using photographic conversion processes employing a specially designed screen (usually glass) with numerous *"tiny dots"*. The result of the conversion called a halftone, created the illusion of continuous tone through the combination of ink dots and white space when printed. The halftone consisted of rows of dots fixed along a grid in a regular pattern, equally spaced center-to-center (*screen ruling*). Varying in size dependent on the tone being rendered (tone reproduction). Additionally, the dots were built along a 90° or 180° axis (*screen angle*).[1]

Halftone dots representing the lighter areas of an original photograph are small, while halftone dots representing darker areas are large on the printed sheet. If the tones were even, the dots would be of a fixed size throughout (*screen tint*). The dots representing the light to dark areas of a photograph can be referred to as the highlight dots, midtone dots and shadow dots.

Halftone screens can be classified according to the following characteristics. Dot Shape (Square, round, elliptical...); Screen Angle (Degree in which the axis of the dots are rotated along the baseline of the halftone screen); and by Screen Ruling (Amount of halftone parts per given unit area; usually measured in inches. Hence, lines per inch [lpi]).

Today continuous tone reproduction relies more on digital technologies rather than on photomechanical reproduction processes. Using electronic prepress systems, images are converted electronically using computer generated halftone techniques and lasers to expose the images on to film. Although the technology does not employ a screen, the method attempts to imitate photomechanical screening methods. Because of certain similarities with signal processing, the process is referred to as Amplitude Modulation (AM). "*Amplitude* referring to the size of the dot, *modulation* referring to the relative density of corresponding continuous tone input pixels."[2]

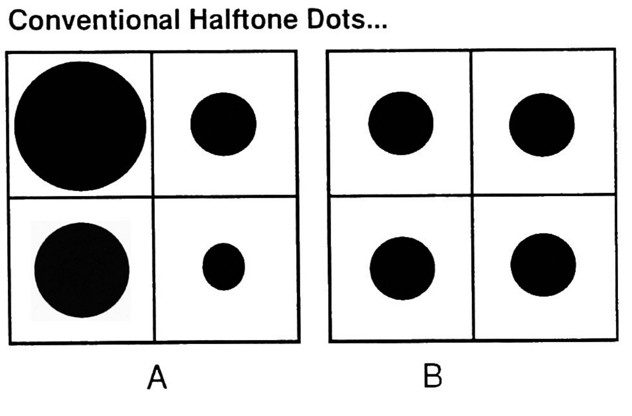

Figure 1.1 Conventional printing employs dots arranged on a fixed grid; they vary in size to reflect density, but always appear a constant fixed distance apart. *A* (halftone) shows variable size, fixed spacing, *B* (tint) shows fixed size, fixed spacing.

As stated by Ira Gold, "The wave form of AM radio signals is similar to the traditional halftone screening process, in that the distance between two waves- or two screen lines- is always the same; the amplitude or size of the wave or dot is what varies."[3] Briefly, digital screening is accomplished by "transforming an array of multi-level pixel values typically ranging from (0-255) into an array of binary numbers (0 and 1).[4] The resulting array of

binary numbers is a bit map. Bitmaps can be used to control the on/off state of devices that make binary dots, such as lasers. In simpler terms, a continuous tone image is divided into thousands of cells or picture elements called pixels. (Pixel is the smallest, most basic element of an imagesetter.) Aligned along a grid with an x an y coordinate or address, the pixel is imaged with individual laser spots one scanline at a time. Forming halftone dots pixel by pixel each time the laser sweeps across a scanline on the grid or raster, and imaged according to address instructions given to the recorder from the raster imaging processor (RIP). Each pixel is an average value, and the actual dot cell increases or decreases in size according to the value assigned. Yet, cell size corresponds directly to the number of lines (*screen ruling*) requested.[5]

Halftoning Principles

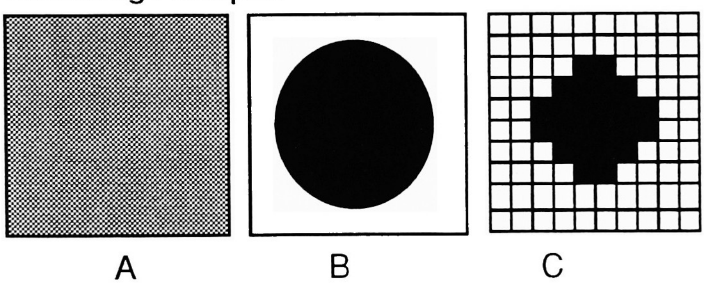

Figure 1.2 *A* represents continuous tone screen; *B* represents conventional (analog); *C* represents conventional (digital).

For years, traditional halftone screening methods have successfully reproduced original continuous tone images with success. In truth however, halftone screening methods reduce tonal range, detail reproduction and color palette available to the printer, in turn decreasing the fidelity of the original.[6] In facsimile reproduction, all areas of the reproduction would have the same density as compared to the corresponding areas of an original. In practice, however, the maximum density of the reproduction is low, exhibiting

loss of highlight and shadow contrast with increased contrast in the middle tones. The printed halftone, therefore, compromises all levels of gray throughout the photograph because the density range of the original is usually, if not always, greater than that reproduced through printing. As a result, it is therefore necessary to compress the tonal scale of an original to fit that of the reproduction, a phenomenon known as *tone compression.*

Resolution or the amount of detail reproduced by a halftone is dependent on screen ruling. The more dots per given unit area, the greater the resolution or detail rendered. Spacing of the dots, is regulated by the smallest printable dot. Since continuous tone halftone images are only an illusion, the preferred number of dots in a given area should generally be fine enough so the naked eye can not distinguish them at normal viewing distances. Resolution is dependent on screen ruling and takes both viewing distances and printing conditions into account. Concerning resolution, the substrate to which the reproduction is being transferred must also be considered.

Regarding screen ruling, studies have shown that the negativism's associated with halftone screening can be diminished when using a finer screen. However, studies have shown that after 200 lpi there is no improvement in detail or quality in multicolor printing. Concluding that screen rulings of 150 lpi yield acceptable quality for all objects with regular contours and good contrast. In fact, after 200 lpi, the quality of a reproduction moves in the opposite direction, sacrificing the fidelity of the original when conditions are out of control. It has been proven that when using higher screen rulings, both printing process and ink film thicknesses must be controlled carefully. By reducing solid ink density, middletone and shadow areas are kept open, and fill-in (*dot gain*) is minimized.

Additional problems with the conventional screening process results when we print a multicolor reproduction. Color reproduction requires a set of four different halftones at four different angles. These being halftones of black, cyan, magenta, and yellow. If dots from one of the four screen angles overlaps with dots from another, an objectionable pattern called *moiré* results. To avoid moiré a 30° separation between each screen angle exists.[7] The fourth screen (usually the yellow) is offset by 15° because the fourth 30° rotation would bring dots into alignment with the first rotation. Therefore, the black halftone is at 75°, cyan at 105°, magenta at 45° and yellow at 15° When printed and in register a desirable circular pattem called a *rosette* is formed, however, if misalignment occurs moiré will result. While visual disturbance pattems can occur as a result of angle misalignment, they can also appear as a result of the subject matter itself. Visual disturbances or "artifacts" are particularly evident when images containing subject matter is textured. i.e.. Herringbone, plaid, and tweed. Problems lie with the clash between texture patterns of the cloth and the pattern of the halftone screen. In other words, there is a frequency clash.[8] When producing a halftone, elimination of the moiré is often accomplished through trial and error and experience.

Lastly, dot shape and size is important in reference to tonal reproduction. If dot shape and size are not controlled, particular patterns can form and lead to abrupt tonal changes in the midtone area of an image. Tonal changes are apparent when dot size percentage is at 50% and the dot shape is square. At 50% the appearance of the dot resembles a checkerboard and when the corners join simultaneously, there is a discernible jump in tone. This effect will eventually lead to ink build up on press and reduced quality. (Midtone or 50% area will begin to fill-in.) When the dot is round and at a dot size percentage of 50%, pin cushioning results making dot control during plating and printing difficult. Additionally, dot size and screen angle make it difficult for the printer to boost the color palette of a

reproduction by adding additional color plates.[9] As stated by Bill Esler, "Some printers for years have been adding one, two or three additional "kiss" plates to boost color saturation and contrast on special jobs. In certain situations, their efforts have been stymied by the size of the dot and the risk of moiré.[10]

At this point, control of continuous tone reproduction is effected by numerous variables. As stated, these variables are the original image, screen angle, screen ruling, substrate, ink film thickness, dot shape an the printing process itself (slur, doubling, and dot gain).

Stochastic Screening Principles

Before the Spring of 1993, the thought of a predictable, controllable screenless reproduction was almost illusive. With recent innovations delivery of a reproduction with previously unprintable screen rulings is now being delivered, rendering superior tone and detail characteristics and an increased color palette for the printer. Images appear to be continuous tone and of photographic quality, in effect calling the process an electronic implementation of screenless printing.[11] Unlike its predecessors, collotype and screenless lithography, the new process is statistically controllable and predictable. Additionally, the new process offers a low cost way to obtain photorealistic images, by eliminating lengthy processing and expenses due to increased raster imaging speeds. This alternative digital screening called "*Stochastic Screening*," was developed as a means to avoid the problems associated with conventional (AM) screening methods. The process, based on German technologies, was developed by Dieter Maetz and the Vignold Group in collaboration with a software house.[12] Though the process has been around for almost 12 years, it was held back as a result of computers not having enough power to decipher large algorithms associated with image processing.

Stochastic Spots...

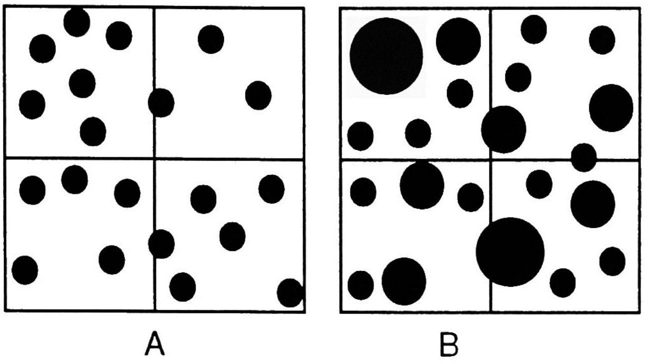

Figure 1.3 The smaller spots constitute stochastic screening with no fixed grid and no screen angles, describe density by "modulating" their frequency and size. *A* represents first order stochastic screening; *B* represents second order stochastic screening.

Conventional screening methods are not likely to disappear, but the vulnerable halftone and once accepted rosette is now being challenged. Announced at the Spring Seybold Show in Boston (1993), [13,14] two new technologies using stochastic screening algorithms are currently on the market turning conventional screening methods upside down. The first system introduced by Agfa is known as CristalRaster™ and the second system introduced by Linotype-Hell is known as Diamond Screening. Stochastic screening methods, do away with screen rulings and patterns fixed along a rigid grid. They replace halftone dots with "spots" (pixels) created by the laser imagesetter, and elimintes screen angles. Measured in microns, the spots range in size from 14 to 21 microns. Comparatively, a 14 micron FM spot is equivalent to a 1% halftone dot and a 21 micron FM spot is equivalent to a 3% halftone dot.[15] The spots unlike conventional dots, are made to appear more or less often dependent on the value of the tone being rendered. Unlike conventional screens, "screen ruling" on the FM screen image changes continuously within the same image. The darker the tone of the original, the more clustered the spots on the reproduction. The

lighter the tone on the original, the more dispersed on the reproduction, essentially resolution and detail are no longer dependent on screen ruling but on the number of spots in a given cluster.

The word *Stochastic* is derived from the Greek work *Stochastikós* meaning to "take aim." In mathematics, the word is used to describe processes in which "the state of a given variable can be based on statistical sampling of preceding states and/or a sampling of random events."[16] In stochastic screening, spots are "randomly" placed through the use of controlled stochastic algorithms. The algorithms statistically average and randomly distribute pixels in relation to neighboring pixels based on the optimum arrangement of binary dots required to faithfully produce a given tone (gray scale) in a continuous tone image. In simpler terms, the algorithms convert what would normally be stored as clustered pixels into distributed dots, all the same size but smaller than a halftone dot.

Stochastic screening has two orders; *First Order Stochastic Screening* and *Second Order Stochastic Screening*. In first order stochastic screening, spot size is fixed and spacing is variable. In second order stochastic screening both spot size and spacing is variable. Again because of certain similarities with signal processing, the process can be referred to as Frequency Modulated Screening.

"Frequency refers to the 'spatial frequency' or number of spots in a given area while modulation refers to the change in spatial frequency relative to the density or gray levels of the input pixel sampled."[17] As with AM screening techniques, FM screening techniques are also similar to signal processing. As stated by Ira Gold once again, "In FM radio signals or screens, the frequency or distance wave-to-wave or dot-to-dot varies while the amplitude, or size stays the same."[18] Because the spots are so small and placed randomly,

both moiré and rosette patterns associated with conventional AM screens disappears in FM screens, thus enhancing contrast and defining detail. FM screens unlike conventional AM screens adapt locally to image content using randomization, therefore, periodic "artifacts" associated with herringbone, tweed and plaid fabrics disappears. Conventional screens produce moiré because they are periodic. Because of the small spot size, the printer can

Halftoning Principles

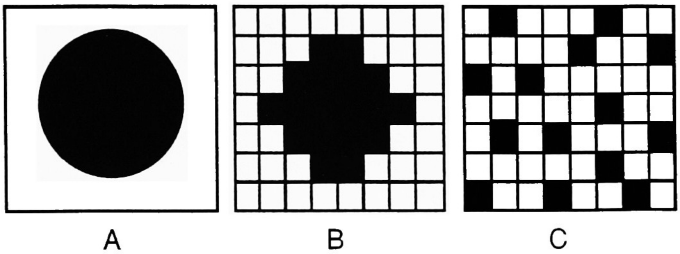

Figure 1.4 *A* represents conventional analog; *B* represents conventional digital; and *C* represents stochastic.

take advantage of the process in a number of ways. First, color can be boosted by adding additional "kiss" plates without having to worry about moiré and dot size, and secondly detail can be achieve and maintained with far less difficulty.[19] Third, a more striking and brilliant reproduction can be produced because the printer can run to higher ink densities (Beta users claim that they can run up to 15% more ink.)[20]

The purpose of an FM screen, therefore, is to eliminate moiré, render higher and controllable detail, use extended ink sets to boost saturation and contrast in an image, (*Hi-Fi Color*) by means of altering the constraints of the rosette and the halftone dot. As this new technology challenges the way we currently view print, the printer is offered the following claimed benefits:[21, 22]

- No visible dot structure due to the elimination of screen angle, screen ruling and halftone dot structure.

- Freedom from moiré patterns and ability to add additional spot, "kiss" plates to boost color saturation and contrast.

- No trade off between gray level and resolution. Spots (pixels) are randomly spaced and not clustered as in conventional screening. In conventional screening, resolution is based on the line screen rulings. Stochastic is not limited in this way. Additionaly, the number of gray levels in conventional methods is determined by the relationship between recorder resolution and line screen ruling.

- Smooth tonal rendering. In conventional screening, there is a discernible jump in tone when the corners of dots simultaneously meet when they are at a dot size of 50%. Stochastic does away with the large halftone dot.

- Lower scans and recording resolutions. Conventional rule of thumb is that the scan resolution should be two times that of the output resolution. i.e. A conventional 150 lpi image requires an input scan of 300 dpi (dots per inch).

- Less need for unsharp masking. While undercolor removal and gray component replacement may still be applied, traditional settings may need to be lowered as a result of the inherent sharpness due to the fineness of the dot.

- Faster press make-ready time because printed sheets can reach desired densities quickly. Supposedly, the FM screen is less sensitive to ink and water balance on press. Registration is also quicker due to the lack of screen angles.

- Ability to run to higher ink densities to increase color brilliance without loss of shadow area detail and midtone values. Color brilliance is believed to be enhanced as a result of less overprinting, less paper show (better distribution of non-ink areas).

- Current press, plating and measuring equipment does not have to be modified.

With all good things, however, there are limitations to this process. Some of these limitations are:

- Plating, contacting, and processing requires a more controlled environment. Additionally, the choice of plating materials may be limited because the surface must be able to hold a finer dot structure.

- Screens are more susceptible to dust and scratches. As a result, the printer will no longer have the ability to do last minute changes by dot etching the film.

- Difficult to proof with standard proofing systems. Systems are designed to hold large halftone dots.

- Screens do not have a tolerance for doubling and slurring on press.

- Midtone areas take on a grainy appearance. (It should be noted, that this graininess has been eliminated in what is now called a Postscript Level 2 system. Postscript level 2 also has a built in "dictionary" on halftoning techniques. (Dictionary is a self-contained description of the halftone process.) The dictionary allows the operator to utilize different dot shapes, press gain tables. etc., all on the same page.)
- Requires greater computational power and speed from the raster imaging processor (RIP).

Tone Reproduction

Tone reproduction can be defined as the reproduction of continuous tone images by means of some printing process that simulates continuous tone.[23] In essence, a halftone reproduction is really an optical illusion accomplished through the combination of ink spots and white space.

In lithography, the basic function of the halftone screen is to breakup the continuous tone image into a series of dots whose size corresponds to different tonal values from light to dark. This relationship of dot size to continuous tone density is also referred to as tone reproduction. Tone reproduction is the technical definition of *density range* or *contrast* and *tone compression*

Tone reproduction refers to all tonal relationships involved from the original to the reproduction of the original.[24] It is the relationship between the density of the original, to the dot size on the negative or positive intermediate (film), to the density produced for each level of gray on the press sheet. (Note, when comparing the relationship between the density of the original and the printed dots on paper we measure their density and not their size.)[25]

In facsimile reproduction, all areas of the reproduction when compared to corresponding areas of an original would be of the same value. If the densities were plotted graphically, the relationship would form a 45° straight line through the origin of the graph, or an ideal curve. In practice, however, rarely is such a graph obtained from a printed sheet. The density or tone range of the original is usually, if not always, greater than the density range reproduced by a single layer of ink on a press sheet. Usually, the maximum density of a reproduction is low and there is loss of highlight and shadow contrast, whereas the middletones have too much contrast.[26]

Tone Compression

Because it is usually impossible to match the density of an original, it is necessary to compress the tonal scale of the original to fit that of the reproduction, a phenomenon known as *tone compression*. Tone compression compromises the density of the shadows and all levels of gray throughout a reproduction. Tones are compressed, because ink on paper is not as dark as silver in a photographic image. For example, if the density range of an original is 0.00 to 1.90 and that of the press sheet is only 1.30, then the tone reproduction curve will have to be compressed in a way so that the 1.30 density corresponds to the 1.90 density of the original.[27]

The key to reproducing a consistent and predictable quality reproduction is by optimizing tone reproduction. Optimizing tone reproduction begins by determining the correct contrast for a halftone, which in turn determines the correct dot size to print.[28] Therefore, the first step to a good reproduction begins with proper tone compression. Analyzing printing conditions and press variables is the next step, followed by control of middletone contrast on press. In addition to proper tone reproduction, consistent and predictable quality reproductions requires several other attributes as well. These requirements are:

- Smooth tonal rendering without discernible jumps in tone.
- Freedom from visible dot structures or interference and loss of detail from moiré and rosettes.
- Sharp detail rendition without compromise.
- Ability to produce gray levels as gray without color casts.
- Saturated and brilliant colors without compromise.
- Ability to render the range of gray levels without tradeoffs.

Contrast

Contrast, describes a relationship between the tones in an original and the tones in the reproduction of the original.[29] Essentially, it is the difference between the whitest white and the blackest blacks that are reproduced as dots. Determining correct contrast for halftone films, which in turn determines the correct dot size to print, is the most important step in determining good tone reproduction.

In color printing, if there is too much or too little contrast in the middletone, the overall appearance of a reproduction will appear too dark or too light (washed out). If there is too much contrast in the middletone, images will appear dark and dirty. Additionally, too much contrast, of any color, in the middletone will lead to unwanted color shifts in the direction of that color. i.e. Too much magenta in the middletone can cause flesh tones to look sunburned.

When a reproduction is described as being *flat*, this means that there is not enough contrast. The image lacks in contrast because the difference between the whitest white and the blackest black is too short or not great enough. This causes all colors to look faded and destaturated or all colors to look too dark or saturated.[30] When a reproduction is described

as being to *contrasty*, this means that there is too much contrast. Or, that the difference between the whitest white and the blackest black is to great or long. In this case, the result may be a loss of detail because the highlights are too weak or faded and the shadows are too dark.[31] Contrast must, therefore, be adjusted to produce a pleasing picture or reproduction. Contrast is controlled by controlling the middletone.

Contrast is influenced by screen range, or the range between the minimum and maximum halftone densities that can be reproduced by a screen. In order to reproduce a quality reproduction, it is important for the printer to know what the smallest and largest non-solid printable dots are for a given screen. By determining these dot sizes, platemaking and printing characteristics- paper, ink and press conditions can be taken into account, giving the printer dot size aim points to control halftone contrast and optimize exposure times.

Contrast can be computed numerically by taking the difference between the lightest and darkest tones as measured by a densitometer.[32] This difference or numerical value, known as density range influences contrast significantly. The shorter the density range, the higher the contrast. The longer the density range, the lower the contrast.

The measure of contrast is concerned with how tones change. For every level of gray input, so many levels of gray are output. Contrast is computed through the evaluation of the original continuous tone image, the intermediate (film) and the printed sheet. Evaluation of the density values are obtained by comparing the critical halftone dot sizes on the print, to the film with the corresponding values of the original.[33] One of the most critical halftone dot size on the print is the 50% area or the middletone area.

When determining contrast or optimum tone reproduction, a graph is constructed that relates the densities of the original to the density of the reproduction. Densities of the original are on the *x* axis, and densities of the reproduction are on the *y* axis. Graphically, contrast is illustrated by the slope of a line. Numerical values are computed by constructing a triangle on the straight line portion of the curve from the data obtained.[34] The constructed curve is referred to as the *tone reproduction curve.* A measure of the length of the *y* axis divided by the measure of the length of the *x* axis is the computed contrast. Or contrast can be determined by use of the following simplified formula that divides the units of the rise (y) by the units of the run (x). Gamma (is the Greek letter that is used to denote contrast).[35]

$$\gamma = \frac{\text{rise}}{\text{run}}$$

Tone Reproduction Curves

The relationship between dot size to continuous tone density, as expressed earlier, is known as tone reproduction. When the relationship of tonal values or control of dot size when compared to continuous tone density is studied graphically the relationship produces an "S" shaped curve, known as the *tone reproduction curve.* The curve appears as an "S" shape because contrast is lower in the highlight and shadow areas of the reproduction. This is a function of tone compression.

The tone reproduction curve is a convenient device for comparing tone values in the original continuous tone copy with corresponding tone values of the reproduction.[36] It is also a convenient way to determine the range of gray levels that can be produced by a halftone screen. The tone reproduction curve is dependent on the nature of the printing

process, ink, paper, screen, etc.. It tells us how close we came to an ideal reproduction and how we can make improvements by adjusting highlight to shadow exposures to capture all of the detail and contrast of the original.

To begin plotting the tone reproduction curve, the printer must first gather information from a typical press run. Secondly, the printer determines the relationship between the dot size on the negative to the density of the reproduction for each gray level produced on the press sheet. Basically, the printer determines the optical densities for particular corresponding tones. Measurement is made with the use of a densitometer and is simplified if a *gray scale* is included with the halftone.

A gray scale is a tone scale, a strip of gray patches or steps ranging from white to black in either varying densities or varying dot sizes from 0% to 100%. The densities of the steps represent the densities found in the original image.[37] Including a gray scale in the halftone is advantageous to the printer. A calibrated gray scale provides a series of gray levels of known density that are large enough to measure and are arranged in an order from lightest to darkest.[38] Gray scales offer a method of accurately setting the highlight-midtone range to provide contrast and to compensate for dot gain on press.

Measured reflection densities of the steps in the original and the reproduction provide the necessary information needed to plot a tone reproduction curve. When plotted, the curve if acceptable can serve as a standard for future copy with similar contrasts. However, the tone reproduction curve needs to be determined for each printing process and paper used. Usually, the tone reproduction curve is adjusted to keep the highlights white and clean and the middletones open and not too dark.

Plotted tone reproduction curves are the plotted reflection densities of the original gray scale along the horizontal (x) axis and the reflection densities of the printed gray scale along the vertical (y) axis. When studying the tone reproduction curve both the height (density) and the slope (contrast) of the curve as it proceeds from highlight to shadow areas is interpreted.[39] Ideally, analysis of the tone reproduction curve should match the original exactly, forming a straight 45° line through the origin of the graph. In practice, we are limited by the printing conditions and the curve is usually lower than 45°.

To achieve a quality reproduction with proper tone reproduction the printer, adjusts highlight, shadow and middletone dot sizes for a given set of press conditions. Dot sizes are adjusted for paper, ink and printing conditions to be used. Ideally, contrast is adjusted to keep the highlights white, shadows dark and middletones open and not too dark. It is important that the intermediate (film) is adjusted for the particular set of conditions, because the two must work in unison to produce a quality reproduction.

As noted, tone reproduction curves are a convenient way to make good reproductions the first time. Once an acceptable tone reproduction curve has been established for a press sheet, for a given set of press conditions, the curve can serve as a future standard for copy with similar contrast.

Printed reproductions, however, are effected by many variables. Again, these variables are:the original image, screen angle, screen ruling, substrates, ink film thickness, dot shape, and the printing process itself (slur, doubling, dot gain, fill-in,...). Control of these variables is just as important as the film making process.

Solid Ink Density

Theoretically, colors will be more saturated on a printed sheet when more ink is applied to the surface of that sheet. Unfortunately, there is a point beyond which too much ink can cause damage to the reproduction.[40]

Solid Ink Density (SID), or the amount of ink applied to the paper during the printing process, influences the color saturation, color strength, picture darkness, and dot gain.[41] When solid ink density is increased, contrast is increased to a point. Then, it decreases the contrast as the reproduction gets darker. The latter occurs because middletone values begin to fill-in (corners start joining) and the shadow areas begin to plug-up. When plotted graphically, an increase in solid ink density tends to flatten the tone reproduction curve causing loss of midtone and shadow detail, and increased dot gain.

Fill-in and plug-in are two terms that indicate a type of dot gain. Often interchangeable, fill-in and plug-up is defined as the condition where ink fills the area between the hafltone dots or plugs-up the type.[42] It should be understood, that by increasing solid ink density, middletone densities and dot gain increases. Too much ink in one place casues unwanted color shifts in the wrong place and overall is not good for the reproduction. Neither is too little ink.

Dot Gain

During the printing process, dot gain is the most important variable to control because it is the most damaging to middletone contrast and the overall reproduction. Dot gain, is the increase in dot size from the film to the final printed sheet. It is a physical enlargement of the dot caused by plating exposures, pressure created by the blanket and impression cylinder on the press, and from the spreading of ink on the sheet.

When printing halftones, dot gain can cause a loss of definition and detail (contrast). It can also lead to plugged or filled in screens and cause a shift in color. Dot gain is unavoidable, and is present in all printing processes. While dot gain is not all that bad, it must be controlled. Dot gain is influenced by the quality of the paper used, by the amount of ink applied to the surface a sheet, and by screen ruling.

Dot gain can be defined as both physical and optical. Physical dot gain is an enlargement of mechanical dot size.[43] Enlargement of the dot occurs between film generations, during platemaking or during printing. Dot gain of this type can be circumferenctional, even all around, or it may be irregular as a result of printing defects. i.e. Slur and doubling.

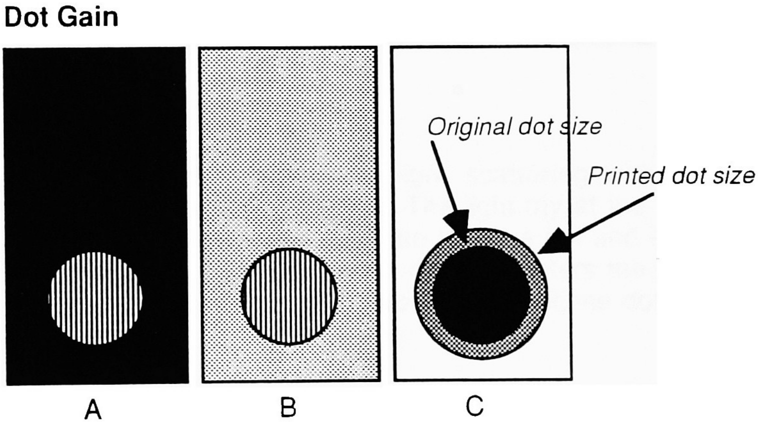

Figure 1.5 *A* represents Film Dot on a negative; *B* represents plate dot; and *C* represents printed dot showing dot gain.

Optical dot gain is present whenever ink is placed on paper. When ink films are discontinuous, as in a halftone or stochastic images, light penetrates the paper and is

scattered sideways. This sideways scattering has an effect on the appearance of the reproduction.[44] Scattering of light occurs when light enters the layer of the halftone dot or when it enters the white paper between the dots. In either case, the scattering light is absorbed by the ink dot and spread within the paper. The light escaping between the dots takes on the color appearance of that dot. Entering light is either lost between the dots, trapped within the paper or trapped underneath and ink dot.

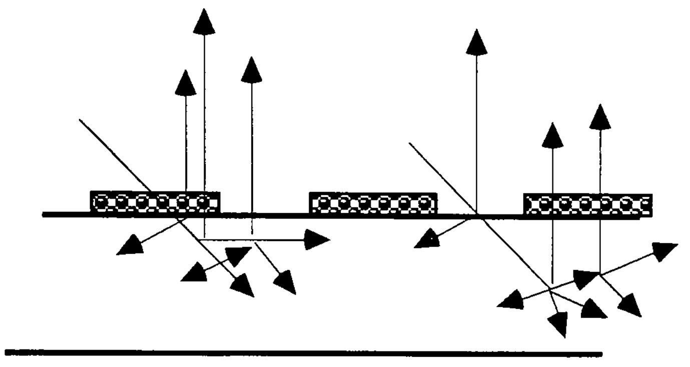

Figure 1.6 Diagram of light scattering within the paper of a fine screen halftone. The light ray at the left enters the paper through the halftone dot and exits between the dots. The light ray on the right enters the paper between the dots and part exits through the halftone dot.

In coarse screen halftones, the effect of light scattering is minimal. However, as the screen ruling is increased the light scattering effect becomes more pronounced.[45] Optical dot gain usually is a uniform expansion of the diameter of the dots of different sizes, making the diameter of the highlight, shadow and middletone change equally. This change in apparent area is most pronounced in the middletones, because the area around the dot will increase more when there is a larger circumference around the dot.[46] This is why it is important to control and measure the middletone or the 50% dot area on both the film and printed sheet.

Total dot gain (physical and optical) is based on calculations based on densitometer readings. When measuring total dot area on the printed sheet, measurement and calculations of percent dot area are derived from the Murray-Davies equation, which incorporates both physical and optical dot gain.

First, what is dot area? As mentioned in the beginning of this chapter, a continuous tone image is converted into a printable image through the use of halftone screens or by imagesetters and lasers. In either case, the result is the same and the continuous tone image is converted into a halftone consisting of numerous "tiny dots" of varying areas. The area of the dot is expressed as a percentage of the total area in the halftone cell.[47] An area of solid ink represents a percent dot area of 100%, while an area of white represents 0% dot area. Although dot areas vary in percentage it is important to note, that all of the areas are reproduced at the same ink density on the printed sheet. It is through varying percentages of ink dots that the illusion of continuous tone is achieved through lithography.

Dot area on film is measured using a transmission densitometer. The equation to calculate dot area on film is as follows:[48, 49]

$$\% \text{ a} = (1 - \text{T}) \times 100$$

where percent a is the dot area and T is the transmittance.

When measuring dot area on the printed sheet, a different calculation called the Murray-Davies equation is used. Dot area measurement of the printed sheet now becomes more complex than measurement of dot area on film. The equation for calculating printed dot area is:[50, 51]

$$ODA = \frac{1 - R_t}{1 \quad R_s} \quad \text{or} \quad \frac{1 - 10^{-D_t}}{1 \quad 10^{-D_s}}$$

ODA is expressed as the percentage of the substrate that would have to be covered with halftone dots to achieve a particular density. R_t is the reflectance of the printed halftone tint and R_s is the the printed solid, or D_t is the density of the tint and D_s is the density of the solid.

When calculated, ODA indicates the total area covered by dots if printing conditions were perfect. The Murray-Davies equation is important to ODA because it takes both physical and optical dot area into account. ODA is a measure of the total amount of relected light of the tint in relation to the total amount of reflected light in the solid.[52] Calculating dot gain in this manner is possible if the dot area of the film is calculated, however, it can only tell you the amount of gain, not the reason why the gain occurred.

Optical and physical dot gain effect the total dot gain on a printed sheet. Both are dependent on the dot size, screen ruling and the quality of paper used for printing. Dot gain of either type is increased when screen rulings are finer and solid ink densities on press are increased. Or, when the quality of the paper used is poor. When using the Murray-Davis equation, dot gain should be progressive for each color used in the printing process; dot gain for each color should not differ by more than 4% according to SWOP standards.

Print Contrast

Print Contrast is an objective characteristic of printing relating to the amount of shadow detail rendered by the process.[53] The value derived from the following formula, correlates

relatively well to subjective visual evaluation and terminology such as "flat" (low print contrast) and "punchy" or "contrasty" (high print contrast).[54]

Print Contrast is measured by subtracting the density of the 75% tint region from the density of the solid, and then dividing by the density of the solid as follows:

$$\text{contrast} = \frac{D_s - D_t}{D_s}$$

where D_s equals the density of the solid and D_t equals the density of the 75% tint region.

Print Contrast is important to quality reproduction and a useful parameter for production control. Simply, Print Contrast is a convenient way to determine tell how well your shadow areas are printing.

Like the middletone, the shadow is also affected by solid ink density, paper, dot gain, etc. If the shadow density is set correctly, the largest printable dot will be imaged as the originals darkest area. All original detail will be reproduced and the halftone will have the maximum amount of contrast achievable with ink and paper.

If the shadow is set too low, the shadow dots (specifically the clearest pin points) will be larger than the largest printable dots, resulting in fill-in and loss of shadow detail.[55] If the shadow is set too high, the largest printable dots will never be attained; the reproduction will look too light and lack contrast.[56] It is, therefore, the printers goal to acheive the maximum ink density without fill-in.

Print Contrast is concerned with the difference between the density of the solid and the density of the 75% tint area. If the difference or range is great, the more contrast achieved. If the difference or range is low, the less contrast achieved. Print contrast is also dependent on the origianls keyness. Keyness describes the tonal values in a picture. It is the distribution of the densities between the highlight and shadow.[57] If the picture has mostly highlights, it is referred to as "high-key." If the picture is mostly shadows it is referred to as "low-key." If the picture has an equal distribution of highlight, shadows and middletones, then it is referred to as "normal-key."

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Chapter 3

A Review of the Literature in the Field

Before the Spring of 1993, the thought of a predictable, controllable, "screenless" reproduction was almost illusive. With recent innovations delivery of such a reproduction can now be accomplished, rendering superior tone and detail characteristics along with an increased color palette for the printer. Images appear continuous tone and of photographic quality, eliminating the problems associated with conventional screening methods.

Announced at the Seybold Spring Show in Boston (1993), Stochastic Screening has garnered great interest. Since this time, it seems as if every printing publication has covered the topic- not just once, but numerous times. Articles addressing the subject abound, boasting of the new technologies many offerings and unresolved questions. In general, available articles mainly cover the basic principles of stochastic screening techniques.

As alluded to in chapter 1, the basis of this experiment involves the study of dot gain, print contrast and tone reproduction as it relates to stochastically screened images versus halftone screened images. Reviews of the literature pertaining to the topic of study are mixed. Numerous articles on halftone screening and how it relates to the specific factors are abundant. Articles or studies, relating stochastically screened images, on the other hand,

were difficult to find due to the fact that the technology is relatively new to industry. At this point, the literature only provided information from beta users.

Many studies have demonstrated the effects of increased solid ink density (SID) on dot gain, print contrast and tone reproduction. Overall, as solid ink density is increased dot gain increases, print contrast decreases and tone reproduction curves change. As solid ink density is increased, shadow areas tend to plug-up and middletones begin to fill-in, decreasing both fidelity and contrast in the reproduction. The effect of increased SID are compounded when higher screen rulings are use.

Franz Sigg[1] reported that control of a quality reproduction requires control of six specific factors. The first two factors being 1) the amount of ink (density of the solid); and 2) tone reproduction (density of the tint). Reported results showed that tone reproduction curves changed as solid ink density was increased. Based on his findings, Sigg concluded that the 45% dot area gained the most, while the 45% - 65% dot areas were the most sensitive to dot gain, and therefore should be used for control purposes.[2]

Calabrò, Fabbri, and Laurenzi found in their research on *Influence of Some Parameters on Tonal Value Reproduction*,[3] that for a given paper and ink, the variables mostly influencing tone rendering are screen ruling and inking. While variables such as packing characteristics and pressure have less influence.[3]

In his test on the *Effect of Printing Characteristics for Offset Newspaper Study,* Alan DePaoli found that dot gain is primarily related to ink film thickness, ink characteristics, and paper characteristics.[4] When the press setting variables were within acceptable limits, DePaoli saw only one variable which caused increased dot gain- ink film settings. He

further concluded, that although dampening levels has no apparent effect on dot size, it did have an affect on apparent dot gain (contrast) by causing lower solid ink densities while leaving tint densities relatively unaffected.[5]

A good halftone reproduction compromises such general requirements as sufficient color contrast, freedom from filling-in and plugging, sufficient rendition of detail, freedom from color casts and "artifacts", and good tone rendition. Achieving all of this, depends on the thickness of the layer of ink. The amount of ink must be considered especially when we consider contrast and filling in. Based on this statement, Tollenaar and Ernst [6] performed a test that showed that a minimum amount of ink film is required for a good reproduction. In their study, Tollenaar and Ernst demonstrated that different ink film thicknesses influence filling-in of a halftone reproduction. Showing that as long as fill-in was absent, the density of the print increases with the printing area in accordance to the Murray-Davies equation. As soon as fill-in occurs, the highest density achieved in the print area is one at a lower value.[7] Based on their findings, they showed that every reproduction has a certain degree of fill-in. Additionally, their study showed that a halftone reproduction shows too much fill-in when using a finer screen because the requirements of high contrast can not be met.

Regarding fine screens, it has been said that they are capable of producing greater detail on film and in the final reproduction. In practice, the use of finer screens requires greater control. Finer screens are more susceptible to fill-in and plugging because they do not tolerate press changes. Regarding screen ruling, studies have shown that the negativism's associated with halftone screening can be diminished when using a screen with a finer ruling, at the same time they can yield greater detail.

Studies, however, have proven otherwise. As demonstrated by both Neugebauer, Bickmore and Rhodes[8], and by Yi-Sheng Lu[9], after 200 lpi (lines per inch) there is no improvement in detail or quality in multicolor prints. Concluding that screen rulings at 150 lpi yield acceptable quality for all objects with regular contours and good contrast. In fact after 200 lpi, the quality of the reproduction moves in the opposite direction, sacrificing the fidelity of the original when conditions are out of control. It has been proven that when using higher screen rulings, both printing process and ink film thicknesses must be controlled carefully. Reducing solid ink density keeps middletones and shadows open, minimizing the tendency for both areas to fill -in.

Based on the review of the above literature, it is apparent that solid ink density must be controlled during the printing process. Quality halftone reproductions require minimal ink film thicknesses. This is not the case with stochastically screened images. If you recall, stochastic technologies claims it can provide the printer with the ability to run higher ink densities without loss of shadow detail and midtone values. As reported by its many beta users- increased solid ink densities to improve color brilliance is a reality.

United Lithographics Prepress Manager, Paula Tognarelli[10], claims that make-ready times have been reduced significantly at United, because the new technology (specifically CristalRaster™) provides faster register and more consistent color on press.

John Gimpel, Manager of Sales for The Hennegan Company, claims "exceptionally high quality results without changing the existing set up and printing process."[11] The company also claims that they "were able to run densities that you couldn't even consider running in normal process and still were able to maintain sharp and definite images."[12] The company

tested this by running extremely high ink film densities for 220 line black and 190 line magenta.

Paul Beyer, Sr. Vice President of Tanagraphics, Inc. believes that "The overall surface appearance, ink/film thickness, and solid ink densities that CristalRaster™ achieves on press all lead to separations that print with extraordinary photographic detail, saturation and clarity."[13]

During the first annual GATF Technology Alert Conference in January 1994, Robert Barbera, Sr. Manager for new technology at Agfa Division Miles Corporation, reported that customers implementing the new technology have reported the ability to run to higher ink densities on press.[14] Barbera makes this same claim in an article entitled, *Screening Options Gain Momentum*, found in the February 1994 issue of Graphic Arts Monthly. "Stochastic screening allows printers to run to higher ink densities, without fear of extra dot gain and screen plugging, thereby producing a final image with more saturated colors and more exact reproduction."[15]

Lastly, Agfa's François Gosseaux in an article entitled *Stochastic Screening Takes Center Stage*, also makes the same claim. "Operators can achieve better ink/water balance faster than with conventional screening and that FM screening is less prone to misregistration. The process also lets press operators run 20 percent higher ink densities for better coverage while lowering the risk of tonal shift and color cast."[16]

Comparatively, stochastic screening techniques can be referred to as a very fine screen with a ruling of approximately 700 lpi. Knowing the effects of increased solid ink density on finer screens, how is it possible that stochastic images are not effected in the same way?

According to Dieter Maetz, Vignold's R + D Director, "The press can run higher ink densities because of the small dot sizes means a more even distribution of dampening solution across the plates surface improving shadow distribution in the shadow areas.

Endnotes for Chapter 3

1 Franz Sigg, "A New Densitometric Quality Control System For Offset Printng," TAGA Proceedings, (Rochester, NY: Technical Association of the Graphic Arts, 1970), p. 197.

2 Ibid., p. 212.

3 G. Calabrò, I. Fabbri and A. Laurenzi, "Influence of Some Parameters on Tonal Value Reproduction", W.H. Banks, Advances in Printing Science and Technology, Proceedings of the 15th International Conference of Printing REsearch Institue, Lilihammer, Norway, June 1979, (London, Plymouth: Pentech Press, 1980), p.186.

4 Ibid., p. 186.

5 Alan DePaoli, "Effects of Printng Conditions on Dot Gain on an Offset Newspaper Study," TAGA Proceedings, (Rochester, NY: Technical Association of the Graphic Arts, 1981), p. 17.

6 Ibid., p. 18.

7 D. Tollenaar and A. H. Ernst, "Conditions for Halftone Printing," Advances in Printing Science and Technology, Proceedings From the 7th International Conference of Printing Research Institutes held in London 1963, W. H. Banks, (New York: MacMillian Company, 1964), p. 2.

8 Ibid., p.3.

9 H.E.J. Neugebauer, J.T. Bickmore, and W.H. Rhodes, "Experimental Investigation of the Effect of Screen Size on the appearance of Mulitcolor Prints," TAGA Proceedings, (Rochester, NY: Technical Association of the Graphic Arts, 1962), p. 1

10 Yi-Sheng Lu, " An Investigation of Quantification of Image Quality with respect to Screen Ruling on the Appearance of Multicolor Print," *R.I.T. Thesis*, 1987, p. 3.

11 Howard Fenton, "Stochastic Screening," Pre-, March/April 1994, vol. 6, no. 2, p. 32.

12 Ibid., p. 32.

13 Ibid., p. 32.

14 Ibid., p. 31.

15 Miles Southworth, "GATF Technology Alert 1994," The Quality Control Scanner, vol. 14, no. 2, 1994, p. 3.

16 Joann Strashun, "Screen Options Gain Momentum," Graphic Arts Monthly, vol. 66, no. 2, February 1994, p. 56.

17 "Stochastic Screening Takes Center Stage," Printing Impressions, vol. 36, no. 6, November 1993, p. 52.

18 Garth Ward, "FM Joins the Cristal Set," Printing World, vol. 242, no. 6, May 12, 1993, p.20.

Chapter 4

Hypotheses

The criteria necessary for consistent and predictable quality reproduction has been established in the previous chapters. In summary, the basis for printing predictable quality reproductions with traditional halftone screening techniques is through measurement and control of known variables. The most influential of these variables being dot gain, solid ink density and screen ruling. Reproducing a predictable quality reproduction with stochastic screening techniques, on the other hand, may require more than just measurement and control.

According to beta testers, the new technology is extremely precise but unforgiving.[1] Traditional halftoning methods are more forgiving and tolerante of deviation that occur in the process. The halftone dot allows deviations to go undetected because it maintains a particular stability. As one beta tester states, "Many who use the new technology will have to adopt a new level of precision throughout their process."[2] Stochastic screening is a new technology that offers many benefits and many unresolved questions; it is truly a technology we know little about.

Questions surrounding the new technology are:

- Do specific traditional variables affect a stochastic screen more than a conventional screen-solid ink density, dot gain and screen ruling?

- Can traditional tools and means of measurement control be applied to the new technology in the same way they are applied to the old technology- tone reproduction curves?
- Is tone reproduction in a stochastic images met satisfactorily?
- Can the printer increase print contrast by increasing solid ink density without loss of midtone value and shadow detail?

Based on the above questions, the following hypotheses have been developed for this study.

H1- Stochastically screened images will exhibit dot gain equal to or greater than conventionally screened images for black, cyan, magenta, and yellow printers at a 48 percent dot area.

H2- Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images for the black, cyan, magenta, and yellow printers at the 48 percent dot area and the 70 percent dot areas.

H3- Stochastically screened images will exhibit dot gain eqaul to or greater than conventionally screened images when solid ink density is increased for magenta.

H4- Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images when solid ink density is increased for magenta at the 48 percent and 70 percent dot areas.

Delimitations: The scope of this study will be limited to a given set of conditions and variables. Therefore, results and conclusions will be based on the following: 1) one type of press; 2) one type of plate; 3) one type of paper; 4) one type of ink and fountain solution; 5) one type of film; 6) one type of output device and stochastic technology; and, 7) two types of halftones (one stochastic screen and one conventional screen).

Limitations: At this time, the author realizes that the conditions under which this experiment will run will have effects on the final results. Some of the contributing variables can not be controlled. Some of these variables are: 1) The press crew- students

will be running the test; 2) Test will be run under classroom conditions and not shop conditions; and 3) Type of paper and supply may be limited. 4) If paper is limited, number of sample pulls may be limited.

Endnotes for Chapter 4

1 Howard Fenton, "Stochastic Screening," Pre-, March/April 1994, vol. 6, no. 2, p. 32.

2 Ibid., p. 34.

Chapter 5

Methodology

Up to this point previous chapters have provided pertinent information on known requirements for good tone reproduction as it relates to halftone reproductions. Enumeration of the essentinal elements comprises such general requirements as sufficient color contrast, freedom from filling in and plugging, sufficient rendition of detail, freedom from color casts and "artifacts", and good tone rendition. In trying to achieve all this, studies have shown that many of the requirements are bound by two variables; ink film thickness and dot gain.

This study will test dot gain, print contrast (shadow detail) and tone reproduction as it relates to increased solid ink densities on stochastically screened images versus conventionally screened images. If an increase in solid ink density has an effect on either of these images, dot gain will increase, print contrast will increase and then decrease, and tone reproduction curves will change.

To test the predictions made, an experiment must be performed and evaluated. If a determination is to be made, the method and test used must be capable of providing averages and ranges of density measurement.

Printing Conditions

Printing conditions is defined as the bounds or limits of this experiment. All possible variables will be peculiar to the specific set of conditions as listed.

I. Film

A. Negatives- Right Reading Emulsion Down

B. RIT Gray Balance Bar- Conventional Image

- Output on Agfa SelectSet™ Avantra 25 Imagesetter at 2400 dpi, 150 lpi, using Agfa Balanced Screening. RIP used was a Star 600 Postscript level 2.

C. RIT Gray Balance Bar- Uncompensated (112)- Stochastic Image

Output on Agfa SelectSet™ Avantra 25 Imagesetter at 2400 dpi, using Agfa CristalRaster™ Technology. Uncompensated (112). RIP used was a Star 600 Postscript level 2.

D. RIT Gray Balance Bar- Compensated (102)-Stochastic Image

- Output on Agfa SelectSet™ Avantra 25 Imagesetter at 2400 dpi, using Agfa CristalRaster™ Technology. Compensated (102). RIP used was a Star 600 Postscript level 2.

E. Film Type- Agfa GS-712 HN Film

F. Imagesetter- Agfa SelectSet™ Avantra 25

G. RIP- Star 600 Postscript Level 2

H. Technology

Agfa Balanced Screening™ (Conventional)

Agfa CristalRaster™ Technology (Stochastic)

II. Plates

A. Negative Working

B. 3M Viking GMX, .0012 thickness

C. Exposure

-40 Units with a post exposure of 160 units

D. Frame

-Initial exposure for K,C,M, and Y on a Teaneck Frame

-Post exposure for K and C made on a Teaneck Frame

-Post exposure for M and Y made on a Delta Frame

D. Ugra Step Wedge for each color

III. Printing

A. Web Offset- Heatset

B. Harris M1000 B- 4 unit

C. Ink- 4 Color Process Cyan, Process Magenta, Process Yellow, and Black

1. Brand

a. Sun Chemical, GPI

b. SWOP densities- see fig. 1.7

D. Fountain Soultion

1. Brand

a. Rosos M-3000 JS

E. See igure 1.7 for additional information

IV. Paper

A. Consolidated Centura Web Offset Plus

B. Characteristics

1. Basis Weight

a. 100#

2. Grade

a. #1 Text

3. Width

a. 35 inches

V. Test Evaluation Method

A. Tone Reproduction Curve

1. R.I.T. Gray Balance Bar

2. R.I.T. Gray Balance Evaluation Sheet

B. Print Contrast Formula

VI. Measurement

A. X-Rite® 418 hand held refection densitometer (Status T)

B. Gretag D200 transmission densitometer

In the conditions established, the problem is to first determine the optimum tone reproduction curve for the given set of conditions. Secondly, it will test the effect of

Figure 1.7 Pressroom Operation Report

Customer Name: Kelly Laughlin and Justine Adamcewicz

Trail Date: April 29, 1994

Pressroom Conditions

Press (Mfg.): Harris M 1000 B

Blankets (Mfg.): Day 9500 ___Conventional___Compressible__X__

Packing:	Unit 1	Unit 2	Unit 3	Unit 4
Top	.005	.004	.004	.004
Bottom	.045	.004	.004	.035

Plate (Mfg.): 3M Viking GMX   Packing: +.001

Fountain Solution (Mfg.: Rosos M-3000 JS

pH: 3.1

Conductivity: 1800

Dampening System: Duotrol

Ink (Mfg.): GPI Sun Chemical

	Unit 1	Unit 2	Unit 3	Unit 4
Color	K	C	M	Y
Tack	12.5	11.7	10.3	9.5
Density +/- .07	1.75	1.20	1.35	.95

Dryer (Mfg.): Tec 2 Zone

increased solid ink densities on print contrast for a stochastically screened image versus a conventionally screened image.

Test Form

The test form for this experiment will consist of the following elements: 1) Conventional 150 line screen RIT Gray Balance Bar; 2) Equivilant stochastic 2400 dpi RIT Gray Balance Bar; 3) Conventional RIT Color Test Strip; 4) Equivilant stochastic RIT Color Test Strip; and 5) Ugra Step Wedge for each color to control exposure during plating;.6) Take up bars of solid black, magenta, cyan and yellow; 7) Test form for Kelly Laughlins thesis; 8) 4 images, screened both conventionally and with UGRA Velvet Sreening (FM Technology)

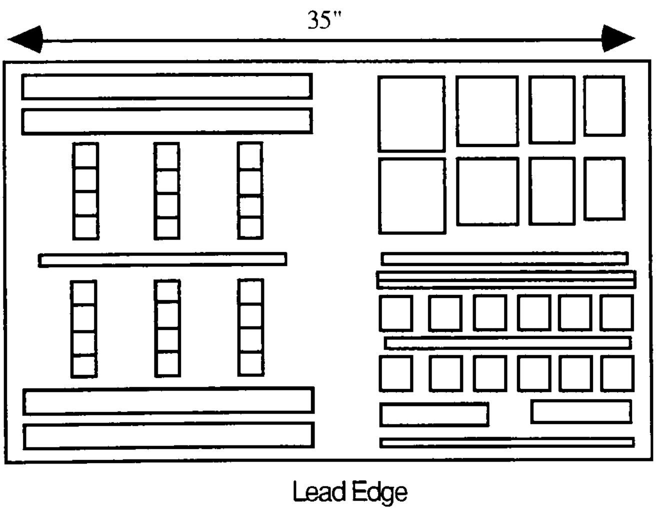

Figure 1.8 Diagram of test form to be used for study.

It should be noted, that the above stated test form was a combination effort that combined two theses projects related to the same subject. For the purpose of this study, the primary elements of concern will be the RIT Gray Balance Bar and Color Test Strip, and the 70

percent tint patch from Kellys test form for both a 150 lpi screen and FM screen. Take up bars and images will be used to assist the pressman with make-ready and allow for even distribution of ink across the web.

The RIT Color Test Strip and Gray Balance Bar will be provided by David Cohn of the Technical and Education Center at the Rochester Institute of Technology. Test targets will be provided on diskette as an encapsulated Postscript file. Conventional and Stochastic output of the information will be provided by Bruce Vir and staff, of Agfa Division, Miles Inc, in Ridgefield, New Jersey. Stochastic technology will be Agfas version called CristaRaster™ and conventional technology will be Agfas Balanced Screening. Imagesetter used will be Agfas Avantra 25 with a Star 600 RIP.

The Test

Part 1- R.I.T. Gray Balance Bar for each condition will be imposed twice into a flat, exposed on plates and printed under standard SWOP conditions using the Technical and Education printing facilities. Just as any job would be, the test plates will be exposed and printed free of any defects.

Experience with plating by beta users has shown that care is particularly needed during the plating process.[1] The plate needs to be as finely grained as possible and exposed precisely. The UGRA step wedge is recommend as a control device for exposure.[2] Slight variations in exposure are immediatley visible with this control device. Additionally, it is important that plate exposure by consistent across the frame and everything is carried out in a dust free environment.[3]

Using the Technical and Education Centers printing facilities, the test form will be printed under SWOP conditions on the Harris M1000B web offset press. Once make-ready is completed and a form has been okayed, 10 samples will be pulled from each stack coming out of the folder of the press . Samples will be pulled every eleven seconds for a total of 36 pulls over the course of 5,000 impressions.

Part one of this experiment will be conducted in an effort to answer hyopotheses one and two. To test hypothesis number one, measurement of the 50 percent dot area will be taken for each color using a hand held densitometer. Percent dot gain values will be calculated for each sample, for a total of 72 readings. Dot gain measurements will be computed using the Murray-Davies equation. An average dot gain value for each condition will be calculated, and placed in an organized table defining each color and condition. Statistical analysis will be performed on the data using a Z-test.

To test hypothesis number two, the 50 and 70 percent dot areas will be measured for each color and condition. Statistical analysis will again be performed on the data using a Z-test.

Part two of this experiment will be conducted in an effort to answer hypotheses three and four. Testing will begin once sampling for part one has been completed. During this stage of testing, the pressman will be asked to adjust inking levels for all inks. Solid ink density will be increased a total of two LEDS with 16 samples being pulled for each increase. A total of four increases is estimated. Sampling will begin approximately one minute after an increase. Once samples have been taken, the pressman will automatically adjust the inking level by two LEDS for each color. Ink increases and sampling will occur every 1000 impressions during the course of six minutes.

Measurments for dot gain and print contrast will be calculated with a hand held densitometer. As in part one of this experiment, dot gain measurments will be taken from the 50 percent dot area and print contrast measurments from the 48 and 70 percent dot areas for magenta only. All densitometer measurments will be referenced accordingly, and based on measured film dot areas.

Statistical analysis will be performed on the collected data using a two way ANOVA to test the difference between solid ink density, dot gain and print contrast. If differences are shown to be significant for this test, a second level statistic will be used to determine which differences are significant.

Endnotes for Chapter 5

1 Garth Ward, "FM Joins the Cristal Set," Printng World, vol. 242, no. 6, May 12, 1993, p. 20.

2 Ibid., p. 20.

3 Ibid., p. 20.

Chapter 6

Results and Conclusions

A total of four hypotheses, containing two treatments, were tested for this study. The original hypothesis number one stated "Stochastically screened images will exhibit dot gain equal to or greater than conventionally screened images." Hypothesis number one was tested four times, once for every printing color, namely black, cyan, magenta and yellow. A *z test* with an alpha (α) value equal to 0.05 was carried out by comparing the calculated absolute *z value* to the *critical z value.*[1]

The z test was used for both hypothesis number one and for hypothesis number two because *n* was greater than 30. (Hypothesis number two will be discussed further in this chapter.) N is equal to the sample size. The total sample size for hypotheses one and two was 36.

When performing a z test, the calculated z value is compared to the critical z value to test each of the hypotheses. If the calculated z value is greater than the critical z value, the null hypothesis is rejected. If the calculated z value is less than the critical z value, the null hypothesis is accepted. The critical z value was obtained from the back of a statistics text book.[2] The critical z value used to test hypothesis number one was found to be 1.96. Symbolically,

$$Z_{\alpha/2} = Z_{0.025} = 1.96$$

where alpha (a) equals 0.05.

The critical value z separates the acceptance and rejection regions for a hypothesis test.[3] The subscript 0.05 indicates the risk factor or the level of confidence chosen. Level of confidence is defined as the maximum probability of making a type I error that the user will tolerate in the hypothesis testing procedure. Type I error is defined as the error of rejecting the null hypothesis when it is true.[4]

Table 1

Summary of Calculated Z Value for each Color and Treatment for Dot Gain at the 48% Tint Patch

	$\bar{G}_S$	$\bar{G}_V$	Z value	Sig. Diff.
K	.430	.297	33.25	Y
C	.423	.281	59.17	Y
M	.437	.310	42.33	Y
Y	.387	.327	30.00	Y

The null hypothesis for each color under study may be indicated as follows:

$$H_o: \bar{G}_{sk} = \bar{G}_{vk}$$

$$H_o: \bar{G}_{sc} = \bar{G}_{vc}$$

$$H_o: \bar{G}_{sm} = \bar{G}_{vm}$$

$$H_o: \bar{G}_{sy} = \bar{G}_{vy}$$

where G is equal to dot gain, $\bar{G}$ is equal to average dot gain at a 48% tint patch, S is equal to stochastic, v is equal to conventional, K is equal to black, c is equal to cyan, m is equal to magenta and y is equal to yellow.

For black the calcualted z value was 33.25. Since this value was greater than the critical z value of 1.96, the null hypothesis H_0: $\bar{G}_{sk} = \bar{G}_{vk}$ is rejected. Meaning that stochastic black experienced greater dot gain than conventional black.

Simialry for cyan, the calculated z value was greater than the critical value. Calculated z value for cyan was 59.16. As with black, the null hypothesis for cyan, H_0: $\bar{G}_{sc} = \bar{G}_{vc}$ was rejected. Meaning that stochastic cyan experienced greater dot gain than conventional cyan.

For magenta the calculated z value was 42.333. When compared to the critical z value of 1.96, the null hypothesis H_0: $\bar{G}_{sm} = \bar{G}_{vm}$ for magenta is also rejected. As was the null hypothesis for yellow H_0: $\bar{G}_{sy} = \bar{G}_{vy}$. The calculated z value for yellow was found to be 30.00.

From the data in table 1, it may be interpreted that conventional 150 line screens when printed under SWOP specifications, performed better in terms of dot gain than stochastic screens. Based on this interpretation of the data, the original hypothesis number one has been accepted. One can also conclude that under the specified printing conditions, stochastic screens for black exhibited 13% more dot gain, cyan experienced 14% more dot gain magenta 12% more dot gain, than those colors for conventional screens. Yellow for stochastic only experienced a dot gain of 6% higher than that for conventional yellow.

It is important to note, that from the trend charts in appendix A it may be seen that although stochastic colors experience a greater dot gain, the gain was consistent across all four colors for the entire run.

As stated earlier in this chapter, the z test was also used to test hypothesis number two. The original hypothesis number two, as stated, claims that "Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images". Hypothesis number two tested two tint patchs for print contrast, the 48% and 70%. As with hypothesis number one, z values were calculated and compared to the critical z value. To test hypothesis number two, the critical z value was found to be 1.96.

Table 2

Summary of Calculated Z value for each Color and Treatment for Print Contrast at the 48% Tint Patch

	$\overline{P}_{s48}$	$\overline{P}_{v48}$	Z value	Sig. Diff.
K	.524	.641	58.50	Y
C	.434	.585	88.82	Y
M	.451	.567	58.00	Y
Y	.447	.450	2.14	Y

The null hypothesis for each color under study in hypothesis 2 may be indicated as follows:

$$H_0: \overline{P}_{48sk} = \overline{P}_{48vk}$$

$$H_0: \overline{P}_{48sc} = \overline{P}_{48vc}$$

$$H_0: \overline{P}_{48sm} = \overline{P}_{48vm}$$

$$H_0: \overline{P}_{48sy} = \overline{P}_{48vy}$$

where P_{48} is equal to Print Contrast at the 48% tint patch, $\overline{P}_{48}$ is equal to the average print contrast at the 48% tint patch, s is equal to stochastic, v is equal to conventional, k is equal to black, c is equal to cyan, m is equal to magenta and y is equal to yellow.

Based on the data in table number two, the null hypothesis was tested for each color by comparing the z value to the critical z value. The z value for print contrast was calculated using a formula based on the average mean and standard deviation for each treatment. Null hypotheses for each color were first tested at the 48% tint patch.

For black, the calculated z value was 58.50. Since this the absolute value of z was greater than the critical z value of 1.96, the null hypothesis for black, H_0: $\bar{P}_{48sk} = \bar{P}_{48vk}$ was rejected. The z value showed that stochastic black actually had less print contrast than the conventional black at the 48% tint patch.

Similarly for cyan, the calculated z value was 88.82 which was also greater than the critical z value. The null hypothesis for cyan, H_0: $\bar{P}_{48sc} = \bar{P}_{48vkc}$ was rejected. Stochastic cyan had less print contrast than conventional cyan.

For magenta, the null hypothesis H_0: $\bar{P}_{48sm} = \bar{P}_{48vm}$ was also rejected. The absolute z value for magenta was 58.00. The null hypothesis for yellow, H_0: $\bar{P}_{48sy} = \bar{P}_{48vy}$ was rejected as well. The absolute z value for yellow was 2.14.

From table 2, it may be interpreted that conventional 150 lpi screens performed better than stochastic screens under standard SWOP conditions. Based on the data, one has to reject the stated hypothesis number two in chapter 4. Stochastically, screened images do not exhibit print contrast equal to or greater than conventionally screened images at the 48% tint patch. Additionally, based on the trend charts in appendix B, print contrast is shown to be lower for stochastic than for conventional. As calculated, print contrast for stochastic black is 12% lower than the print contrast for conventional black. Similarly for cyan, where print

contrast is 15% lower, magenta where it is 12% lower. For yellow, print contrast is approximately 0.3 percent lower. Graphically, this is displayed in appendix B.

Table 3

Summary of Calculated Z Value for each Color and Treatment for Print Contrast at the 70% Tint Patch

	P70s	P70v	Z value	Sig. Diff.
K	.221	.456	78.33	Y
C	.148	.365	1085.00	Y
M	.211	.365	53.33	Y
Y	.170	.220	8.33	Y

The null hypotheses for each color under this portion of study for hypothesis number two may be indicated as follows:

$$H_0: \bar{P}_{70sk} = \bar{P}_{70vk}$$

$$H_0: \bar{P}_{70sc} = \bar{P}_{70vc}$$

$$H_0: \bar{P}_{70sm} = \bar{P}_{70vm}$$

$$H_0: \bar{P}_{70sy} = \bar{P}_{70vy}$$

where P is equal to print contrast, P_{70} is equal to the average print contrast for the 70% tint patch, s is equal to stochastic, v is equal to conventional, k is equal to black, c is equal to cyan, m is equal to magenta and y is equal to yellow.

The above listed null hypotheses were again tested by comparing the a calculated absolute z value to a critical z value. As in table two, the data displayed in table 3 was compared to a critical z value of 1.96. Once again, if the calculated absolute z value was greater than the critical z value, the null hypotheses would be rejected.

For the black, the calculated z value was 78.33. Because this z value was greater than 1.96, the null hypothesis for black, H_0: $\bar{P}_{70sk} = \bar{P}_{70vk}$ was rejected. As was the null hypothesis for cyan, H_0: $\bar{P}_{70sc} = \bar{P}_{70vc}$. Calculated z value forcyan was 1085.00.

Similarly, both the null hypothesis for magenta, H_0: $\bar{P}_{70sm} = \bar{P}_{70vm}$, and for yellow H_0: $\bar{P}_{70sy} = \bar{P}_{70vy}$ were rejected. Z value for magenta was 51.33, and for yellow it was 8.33.

Based on the data illustrated in table 3, it may be interpreted that stochastically screened images for all four colors at the 70% tint patch had significantly less print contrast. Particularly for cyan, which appears to have almost no change in print contrast. Again, the yellow appeared to have no real significant difference. At the 70% tint patch, it appears as if stochastic black, had 24% less print contrast, the cyan 22% less, magneta 15% less and yellow 5% less print contrast. One can also interpret from the data, that the 70% tint patch for the stochastic screen in question, was moving closer to being a solid. Graphically this difference is seen in appendix B.

To test hyptheses three and four, a test based on an "F distribution" was carried out to compare the variances of the two treatments. The treatments can be defined as the different levels of a factor, where factor is defined as another word for variable of interest in an ANOVA procedure.[6] The factor for this study was inking levels, the treatments were stochastic and conventional screens.

Hypothesis tests based around the variances of two populations are based on a calculated F value. The hypothesis test used was a Two Way ANOVA with replication, with an alpha value equal to 0.05. Sample size for each population was 16. The rejection rule of the null

hypothesis is based on the F value in a manner similar to the z test used to test hypothesis one and two. The F factor in this case was compared to the critical F value. Calculated F values and critical F values were found using a spreadsheet program called Microsoft Exel.[7] It should be noted that if the F value was larger than the critical F value, a second level statistic would have to be carried out to determine at what point the differences were significant.

To avoid figuring an F statistic for each mean combination, a critical difference (d_s) value was calculated. The d_s value was calculated using a formula that contained the F value, the critical f value, the means squared (MS) and the total number of samples viewed (32).[9] The critical difference value, can be defined as the magnitude of difference between any pair of means that are significant. The d_s value to test hypothesis number three was found to be 0.03.

Hypothesis number three states that "Stochastic screens will exhibit dot gain equal to or greater than conventionally screened images when solid ink density is increased." To test this hypothesis, the differences between each combination of means was calculated and compared to the critical difference value.

Table 4

Summary of Average Dot Gain for Magenta at 48% Tint Patch at Five Different Levels

	STD	1	2	3	4
Gsm	.43	.44	.44	.46	.47
Gvm	.32	.35	.35	.40	.44

where G is equal to dot gain, G is equal to the average dot gain at 48%, s is equal to stochastic, v is equal to conventional, m is equal to magenta, STD is equal to standard SWOP inking level, 1 is equal to first level of ink increase, 2 is equal to second level of ink increase, 3 is equal to the third level of increase and 4 is equal to the fourth level of increase.

The calculated F value ($\alpha = 0.05$) was 14.27646 for the interation of the population. Since this value is greater than the critical F value of 2.43 a second level statistic, Scheffé, was performed. The Scheffé test is a simple procedure and is based on the vales of the F statistic obtained form the equation.[8] Simply it is a comparison and contrast test of the means of two populations.

Based on table 4, the difference between the means of stochastic screens and conventional screens was statistically significant throughout the first two levels of increased inking. At the third level of inking the difference begins to dissipate and at the fourth level of inking, there is no difference in dot gain between the two screen types. At the fourth level of ink increase, the dot gain was less than or equal to that of the conventional screen. Statistically, one can accept the stated hypothesis number three.

It may also be interpreted from the table, that within each level of the stochastic screen, that when the mean difference was compared, there was no difference in dot gain from standard inking levels until the third ink increase. Meaning that the diffemence of the means with in the level were not significantly different. At the fourth level of ink increase, however, dot gain for stochastic was significant. When comparing the difference of means within only the conventional level, the difference in dot gain between the standard and first two levels

of increase was not significant. At the third level of increase, however, the difference in dot gain was significant.

To test hypothesis number four, "Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images when solid ink density is increased," a Two way ANOVA with replication was repeated.. However, the hypothesis test was repeated twice. Once to test the hypothesis at the 48% tint patch and once to test the 70% tint patch.

Again, the hypothesis test was based around the variance of two populations or treatments (stochastic and conventional) with an $\alpha = 0.05$. F values were again compared to the critical F values. A Scheffé test was performed for hypothesis number four, because the F values for both the 48% tint and the 70% tint were greater than the F critical value.

Table 5
Summary of Average Print Contrast for Magenta at the 48% Tint Patch at Five Different Levels

	STD	1	2	3	4
P_{sm}	.45	.48	.43	.42	.50
P_{vm}	.57	.55	.54	.51	.45

where P is equal to Print Contrast, P is equal to average print contrast at 48% tint patch, s is equal to stochastic, v is equal to conventional, m is equal to magenta, STD is equal to standard SWOP inking level, 1 is equal to first level of ink increase, 2 is equal to second level of ink increase, 3 is equal to the third level of increase and 4 is equal to the fourth level of increase.

The calculated F value (α =0.05) was 70.60 for the interaction of the population. Since this F value was greater than the F critical value of 2.43, the Scheffé test was performed and the critical difference value determined. The d_s value for hypothesis four at the 48% tint patch was found to be 0.03.

Based on table 5, the difference between the means of stochastic screens and conventional screens for print contrast was significant throughout the standard and first two levels of increase. At the third level of increase, the difference was also significant, however, when the third stochastic mean was compared to the third conventional mean, there was no significant difference in print contrast between the two. At the fourth level of increase, print contrast for the two treatments appeared to be quite similar. However, when the 4th mean of stochastic was compared to the fourth mean of conventional, the difference was again significant.

It may also be interpreted from the table, that with in each level of stochastic, there was no significant difference in print contrast between the standard, first, second, and third levels of inking. At the fourth level, however, there was a significant difference between the standard and the fourth level. Additionally, there was a significant difference between the second and first level, the third and the first level and the fourth and the third level.

When comparing the means with in conventional itself, there was no significant difference between the first and second levels when compared to the standard. At the third an fourth levels, however, there was a significant difference. When comparing the third and second level, there was no significant statistical difference.

Based on the above, one would accept hypothesis number four, because stochastic screens exhibited print contrast equal to or greater than conventional screens at the fourth level of increase. It should also be noted, that at the fourth level of increase for stochastic, as solid ink density increased, contrast increased, which was the opposite for conventionally screened images. As solid ink density increased, conventional images decreased in print contrast. For a graphical description please see appendix C.

Table 6
Summary of Average Print Contrast for Magenta at the 70% Tint Patch at Five Different Levels

	STD	1	2	3	4
P_{sm}	.23	.22	.22	.22	.21
P_{vm}	.34	.31	.31	.22	.13

where P is equal to Print Contrast, P is equal to average print contrast at 70% tint patch, s is equal to stochastic, v is equal to conventional, m is equal to magenta, STD is equal to standard SWOP inking level, 1 is equal to first level of ink increase, 2 is equal to second level of ink increase, 3 is equal to the third level of increase and 4 is equal to the fourth level of increase.

The calculated F value (α =0.05) was 220.0676 for the interaction of the population. Since this F value was greater than the F critical value of 2.43, the Scheffé test was performed and the critical difference value determined. The d_s value for hypothesis four at the 48% tint patch was found to be 0.02.

Based on table 6, the difference in means were significant throughout the standard and first and second level of increases. Statistically, when all of the means of the stochastic were

compared to the standard, first and second level means of conventional, there was a large difference between the two. Based on this, conventionally screen images displayed greater print contrast at the 70% tint patch than the stochastic. When all means were compared at the fourth third level of increase, print contrast for the two populations was the same. At the fourth level, they were again different, and stochastically screened images were actually greater than conventionally screened images.

It may also be interpreted from this table, that within each level for stochastic, the means were not significantly different. When comparing just the conventional means against themselves, it was found that there was no difference between the standard sample and the first two levels. After the second level, however, the differences were significantly greater and print contrast decreased.

Based on the above, hypothesis number 4 is accepted, because stochastic screened images were equal to or greater than conventional screens at the thrid and fourth levels of increase. For a graphical description please see appendix D.

<u>Summary and Conclusions</u>:

The following conclusions have been made based on the stated findings. Stochastic images experience dot gain greater than conventionally screened images when printed under normal (SWOP) printing conditions. Additionally, the percentage of dot gain is approximately 14% more than conventional screens. It is also important to note, that although stochastic screens undergo more dot gain, the gain between all four colors seems to be consistent throughout the run.

It may also be interpreted from the data that stochastic screens do not exhibit print contrast greater than or equal to conventional screens. Print contrast for stochastic screens was found to be significantly lower.

With regards to the performance of stochastic screens and increased solid ink densities, stochastically screened images seemed to maintain the same amount of dot gain throughout each level of ink increase. However, at the fourth level, dot gain for stochastic screens increased. With regards to stochastic screens and print contrast under increased inking conditions, print contrast appeared to be lower than that of conventionally screened images. However, as solid ink density was increased, stochastic images exhibited print contrast equal to or greater than conventionally screened images.

Regarding each hypothesis, three were accepted and one was rejected.

H1- Stochastically screened images will exhibit dot gain equal to or greater than conventionally screened images for black, cyan, magenta, and yellow printers at the 48% tint patch. Hypothesis has been accepted.

H2- Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images for the black, cyan, magenta and yellow printers at the 48% and 70% dot areas. Hypothesis was rejected.

H3- Stochastically screened images will exhibit dot gain equal to or greater than conventionally screened images when solid ink density is increased for magenta. Hypothesis was accepted.

H4- Stochastically screened images will exhibit print contrast equal to or greater than conventionally screened images when solid ink density is increased for magents. Hypothesis was accepted.

Recommendations for Further Investigation

This test, was limited to one roll of paper. As a result, make-ready time and running was limited. To get a better idea of how stochastic screens perform under increased solid ink densities, it is recommended that the test be rerun with a longer running time. Additionally, it is recommended that inking levels be increased more than 4 times. This recommendation is being made, because one is curious to know if after the fourth inking level, will the dot gain remain consistent for a period of time, as it did for the first, second and third ink increases in this experiment. One is also curious to know, if print contrast really increases after the fourth level. .As stated in the results section, stochastic screens actually increased in print contrast as solid ink density was increased at the fourth level.

Further recommendations for this test, would be a change in the test form used. It would be wise to add additional tint patchs, ie. 25%, 40%, 60% and 75%, to get a better idea of what is really happening throughout the image. Further recommendations would also be to see if the the color gamut is greater for stochastically screened images.

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3 Ibid., p. 331.

4 Ibid., p. 497.

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Appendices

Appendix A

Dot Gain Measurments for Conventional and Stochastic Screens at the 48% Tint Patch for all four colors printed under SWOP Conditions

Table 7
Data Collection Sheet for Conventional Black Dot Gain

Solid Ink Density for Conventional Black

1.56	1.59	1.56	1.89	1.89	1.9
1.6	1.58	1.59	1.9	1.89	1.88
1.57	1.58	1.59	1.9	1.88	1.91
1.59	1.6	1.58	1.89	1.9	1.9
1.59	1.58	1.59	1.9	1.88	1.81
1.56	1.58	1.56	1.87	1.91	1.91
1.58	1.58	1.57	1.89	1.88	1.91
1.58	1.59	1.57	1.87	1.89	1.88
1.59	1.58	1.6	1.89	1.9	1.89
1.6	1.57	1.58	1.9	1.89	1.93
1.58	1.58	1.57	1.88	1.89	1.92
1.58	1.59	1.61	1.88	1.88	1.89

Percent Dot Gain for Conventional Black

0.26	0.29	0.28	0.32	0.32	0.32
0.28	0.27	0.26	0.32	0.32	0.32
0.27	0.27	0.26	0.32	0.32	0.33
0.27	0.28	0.27	0.33	0.33	0.32
0.27	0.27	0.27	0.32	0.32	0.31
0.27	0.26	0.27	0.31	0.32	0.32
0.27	0.27	0.28	0.33	0.31	0.33
0.27	0.28	0.26	0.31	0.32	0.31
0.27	0.28	0.28	0.31	0.33	0.31
0.29	0.28	0.26	0.33	0.32	0.32
0.28	0.27	0.27	0.32	0.32	0.34
0.27	0.28	0.29	0.31	0.32	0.32

N=72 data points
Mean=.297
Standard Deviation (Sample)=.025
Range=.08
Max. Value=.34
Min. Value=.26
Sum= 21.35
Sum Squared=6.3759
Standard Error of the Mean= 2.947

Table 8
Data Collection Sheet for Conventional Cyan Dot Gain

Solid Ink Density for Conventional Cyan

1.41	1.4	1.37	1.37	1.37	1.3
1.41	1.42	1.32	1.36	1.37	1.29
1.43	1.41	1.29	1.37	1.37	1.29
1.42	1.41	1.28	1.36	1.37	1.27
1.42	1.41	1.26	1.37	1.37	1.27
1.41	1.42	1.26	1.37	1.36	1.27
1.41	1.4	1.26	1.36	1.36	1.27
1.43	1.42	1.25	1.36	1.37	1.27
1.42	1.4	1.26	1.37	1.37	1.25
1.41	1.41	1.25	1.39	1.37	1.26
1.42	1.42	1.26	1.38	1.36	1.26
1.42	1.41	1.25	1.37	1.37	1.27

Percent Dot Gain for Conventional Cyan

0.29	0.29	0.28	0.29	0.29	0.28
0.29	0.29	0.27	0.29	0.28	0.27
0.29	0.29	0.26	0.3	0.28	0.27
0.29	0.29	0.25	0.29	0.29	0.26
0.29	0.29	0.26	0.3	0.3	0.27
0.29	0.29	0.26	0.29	0.29	0.28
0.28	0.29	0.26	0.29	0.28	0.26
0.29	0.29	0.25	0.28	0.28	0.26
0.29	0.29	0.26	0.29	0.29	0.26
0.3	0.29	0.25	0.3	0.29	0.27
0.29	0.28	0.26	0.28	0.29	0.28
0.28	0.29	0.25	0.29	0.29	0.27

N=72 data points
Mean=.280833
Standard Deviation (sample)= .0138147
Range=.05
Max. Value=.30
Min. Value=.25
Sum=20.22
Sum Squared=5.692
Standard Error of the Mean=1.6167

Table 9
Data Collection Sheet for Conventional Magenta Dot Gain

Solid Ink Density for Conventional Magenta

1.38	1.33	1.33	1.55	1.5	1.43
1.37	1.33	1.32	1.54	1.51	1.44
1.4	1.35	1.32	1.52	1.49	1.48
1.37	1.31	1.35	1.52	1.49	1.42
1.38	1.32	1.31	1.53	1.5	1.47
1.34	1.34	1.35	1.51	1.51	1.47
1.34	1.36	1.35	1.45	1.5	1.41
1.33	1.36	1.37	1.51	1.49	1.42
1.33	1.35	1.46	1.48	1.51	1.38
1.34	1.36	1.5	1.55	1.42	1.44
1.36	1.29	1.52	1.51	1.45	1.36
1.36	1.32	1.48	1.48	1.44	1.34

Percent Dot Gain For Conventional Magenta

0.29	0.28	0.28	0.34	0.33	0.32
0.29	0.29	0.28	0.34	0.33	0.33
0.29	0.29	0.27	0.34	0.33	0.33
0.31	0.29	0.28	0.35	0.34	0.32
0.31	0.29	0.28	0.35	0.35	0.32
0.28	0.29	0.28	0.34	0.34	0.33
0.29	0.29	0.29	0.33	0.34	0.32
0.29	0.28	0.28	0.33	0.34	0.32
0.29	0.29	0.31	0.33	0.33	0.31
0.3	0.29	0.32	0.33	0.32	0.32
0.29	0.29	0.32	0.33	0.32	0.31
0.28	0.28	0.32	0.33	0.32	0.31

N=72 data points
Mean=.310278
Standard Deviation (sample)= .0227647
Range=.08
Max. Value=.35
Min. Value=.27
Sum=22.34
Sum Squared=22.34
Standard Error of the Mean=2.6641

Table 10
Data Collection Sheet for Conventional Yellow Dot Gain

Solid Ink Density for Conventional Yellow

1	1	0.99	1.08	1.1	1.06
1	0.99	0.99	1.09	1.09	1.08
1	0.98	0.99	1.07	1.09	1.09
1	0.98	0.98	1.09	1.09	1.09
0.99	1.01	0.98	1.07	1.08	1.09
0.96	0.99	0.97	1.09	1.09	1.08
0.99	0.99	0.98	1.08	1.09	1.08
0.99	0.99	0.98	1.07	1.1	1.07
0.99	0.98	1	1.09	1.08	1.06
1	0.99	1	1.08	1.09	1.09
1	1	0.99	1.08	1.09	1.09
1	0.99	0.99	1.09	1.1	1.1

Percent Dot Gain for Conventional Yellow

0.31	0.32	0.32	0.32	0.33	0.34
0.32	0.32	0.32	0.33	0.34	0.34
0.31	0.31	0.31	0.34	0.35	0.34
0.31	0.31	0.32	0.34	0.34	0.34
0.31	0.31	0.31	0.34	0.35	0.34
0.32	0.32	0.31	0.34	0.34	0.35
0.32	0.31	0.32	0.34	0.33	0.34
0.32	0.31	0.32	0.33	0.34	0.34
0.32	0.32	0.32	0.34	0.34	0.34
0.32	0.31	0.32	0.34	0.33	0.33
0.32	0.32	0.32	0.34	0.34	0.34
0.31	0.32	0.32	0.34	0.34	0.34

N=72 data points
Mean=.327361
Standard Deviation (sample)= .0125589
Range=.04
Max. Value=.35
Min. Value=.31
Sum=23.57
Sum Squared=7.7271
Standard Error of the Mean=146977

Table 11
Data Collection Sheet for Stochastic Black Dot Gain

Solid Ink Density for Stochastic Black

1.58	1.57	1.54	1.87	1.88	1.88
1.61	1.58	1.54	1.84	1.87	1.88
1.58	1.56	1.57	1.89	1.87	1.86
1.58	1.56	1.59	1.9	1.89	1.87
1.56	1.57	1.55	1.88	1.88	1.88
1.54	1.6	1.56	1.85	1.88	1.86
1.59	1.58	1.58	1.86	1.89	1.87
1.55	1.58	1.53	1.88	1.88	1.87
1.58	1.58	1.55	1.89	1.87	1.9
1.59	1.58	1.6	1.89	1.86	1.87
1.58	1.58	1.57	1.87	1.86	1.88
1.54	1.57	1.55	1.88	1.88	1.92

Percent Dot Gain For Stochastic Black

0.44	0.41	0.42	0.44	0.46	0.45
0.44	0.41	0.41	0.45	0.44	0.43
0.44	0.41	0.42	0.45	0.45	0.44
0.42	0.41	0.41	0.45	0.46	0.44
0.41	0.4	0.4	0.45	0.43	0.45
0.4	0.42	0.41	0.44	0.44	0.44
0.43	0.4	0.41	0.44	0.45	0.44
0.4	0.4	0.39	0.45	0.44	0.44
0.42	0.42	0.41	0.44	0.45	0.45
0.43	0.42	0.43	0.46	0.45	0.44
0.41	0.41	0.43	0.45	0.44	0.44
0.4	0.41	0.41	0.44	0.44	0.46

N=72 data points
Mean= .430
Standard Deviation (sample)= .019
Range=.07
Max. Value=.46
Min. Value=.39
Sum=30.94
Sum Squared=13.30206
Standard Error of the Mean=2.19578

Table 12
Data Collection Sheet for Stochastic Cyan Dot Gain

Dot Gain For Stochastic Cyan

1.33	1.3	1.29	1.37	1.37	1.34
1.31	1.31	1.27	1.39	1.38	1.32
1.31	1.32	1.26	1.38	1.37	1.29
1.31	1.31	1.27	1.38	1.38	1.3
1.32	1.31	1.27	1.37	1.37	1.28
1.3	1.31	1.27	1.38	1.38	1.27
1.32	1.3	1.26	1.37	1.36	1.28
1.3	1.31	1.27	1.37	1.37	1.26
1.31	1.32	1.24	1.38	1.38	1.28
1.33	1.3	1.26	1.39	1.38	1.25
1.32	1.3	1.25	1.37	1.38	1.26
1.3	1.31	1.26	1.4	1.38	1.27

Percent Dot Gain for Stochastic Cyan

0.42	0.42	0.41	0.44	0.44	0.43
0.42	0.42	0.41	0.44	0.44	0.43
0.42	0.41	0.41	0.44	0.44	0.42
0.42	0.42	0.4	0.44	0.44	0.41
0.42	0.42	0.4	0.43	0.44	0.42
0.42	0.42	0.42	0.44	0.45	0.41
0.42	0.42	0.4	0.43	0.44	0.42
0.41	0.41	0.4	0.44	0.44	0.42
0.42	0.41	0.41	0.44	0.44	0.43
0.43	0.41	0.41	0.45	0.43	0.41
0.42	0.41	0.41	0.44	0.43	0.42
0.41	0.41	0.4	0.44	0.44	0.42

N=72 data points
Mean=.423194
Standard Deviation (sample)= .0134087
Range=.05
Max. Value=.45
Min. Value=.40
Sum=30.47
Sum Squared=12.9075
Standard Error of the Mean=1.5692

Table 13
Data Collection Sheet for Stochastic Magenta Dot Gain

Solid Ink Density for Stochastic Magenta

1.35	1.31	1.3	1.54	1.5	1.45
1.36	1.33	1.3	1.55	1.51	1.46
1.31	1.3	1.35	1.57	1.54	1.48
1.33	1.32	1.37	1.55	1.5	1.5
1.32	1.33	1.34	1.55	1.49	1.41
1.32	1.35	1.31	1.57	1.5	1.5
1.27	1.33	1.29	1.53	1.54	1.47
1.3	1.31	1.39	1.52	1.52	1.46
1.31	1.36	1.46	1.5	1.48	1.45
1.32	1.27	1.47	1.52	1.51	1.42
1.36	1.29	1.42	1.54	1.44	1.4
1.35	1.3	1.38	1.55	1.48	1.37

Percent Dot Gain for Stochastic Magenta

0.42	0.42	0.41	0.44	0.43	0.43
0.43	0.41	0.42	0.44	0.44	0.43
0.42	0.42	0.41	0.44	0.44	0.43
0.42	0.42	0.41	0.45	0.44	0.43
0.42	0.42	0.42	0.45	0.43	0.42
0.41	0.42	0.42	0.44	0.44	0.43
0.41	0.42	0.4	0.44	0.44	0.43
0.41	0.44	0.42	0.44	0.44	0.43
0.41	0.42	0.42	0.44	0.43	0.43
0.41	0.43	0.42	0.45	0.43	0.43
0.42	0.42	0.42	0.44	0.44	0.43
0.42	0.41	0.42	0.44	0.43	0.43

N=72 data points
Mean=.426806
Standard Deviation (sample)= .011485
Range=.05
Max. Value=.45
Min. Value=.40
Sum=30.73
Sum Squared=13.1251
Standard Error of the Mean=1.34409

Table 14
Data Collection Sheet for Stochastic Yellow Dot Gain

Solid Ink Density for Stochastic Yellow

1.01	1.01	0.99	1.06	1.07	1.05
1.02	1.04	1.03	1.07	1.07	1.06
1	1.03	1.04	1.07	1.06	1.06
1.04	1.02	1.05	1.07	1.05	1.07
1.01	1.01	1.01	1.07	1.07	1.07
1.01	1.01	1	1.06	1.07	1.07
1.01	1.04	1.01	1.06	1.05	1.05
1	1.05	1.01	1.07	1.06	1.05
1.04	1.01	1.03	1.07	1.06	1.07
1.02	1.04	1.05	1.08	1.07	1.07
1.03	1.01	1.04	1.07	1.07	1.06
1.04	1.06	1.06	1.07	1.06	1.07

Percent Dot Gain Stochastic Yellow

0.38	0.37	0.38	0.38	0.38	0.38
0.38	0.36	0.37	0.38	0.38	0.38
0.39	0.38	0.37	0.39	0.38	0.38
0.37	0.37	0.37	0.38	0.38	0.38
0.37	0.38	0.37	0.38	0.39	0.38
0.37	0.37	0.38	0.38	0.37	0.38
0.37	0.37	0.37	0.38	0.38	0.39
0.37	0.37	0.38	0.38	0.37	0.38
0.37	0.37	0.37	0.38	0.39	0.38
0.37	0.37	0.37	0.38	0.39	0.37
0.37	0.38	0.37	0.38	0.39	0.38
0.38	0.38	0.37	0.38	0.38	0.38

N=72 data points
Mean=.376944
Standard Deviation (sample)= 6.63726
Range=.03
Max. Value=.39
Min. Value=.36
Sum=27.14
Sum Squared=10.2334
Standard Error of the Mean=7.76757

Figure 1.9
SK vs. CK

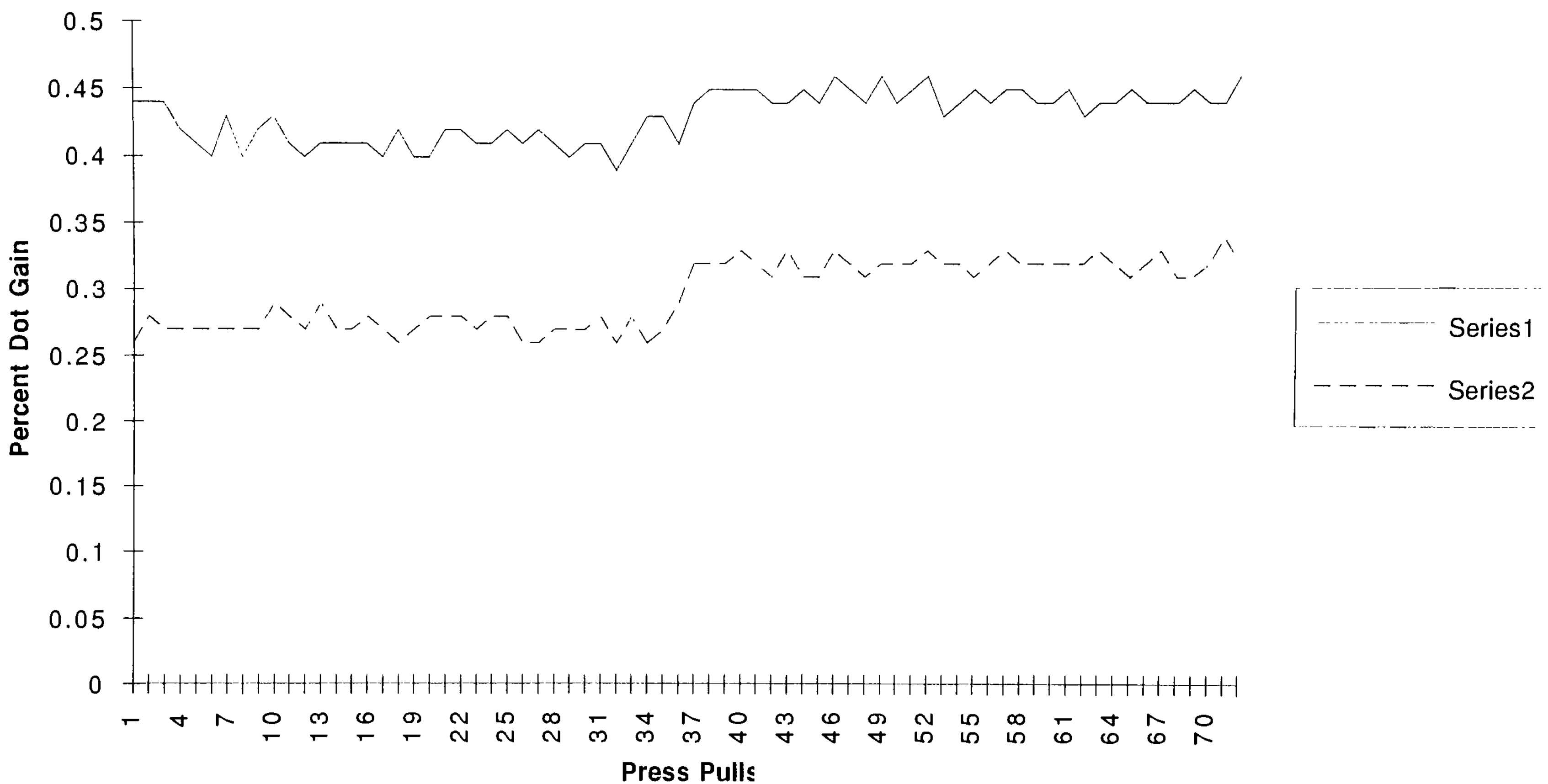


Figure 1.10
SC vs. CC

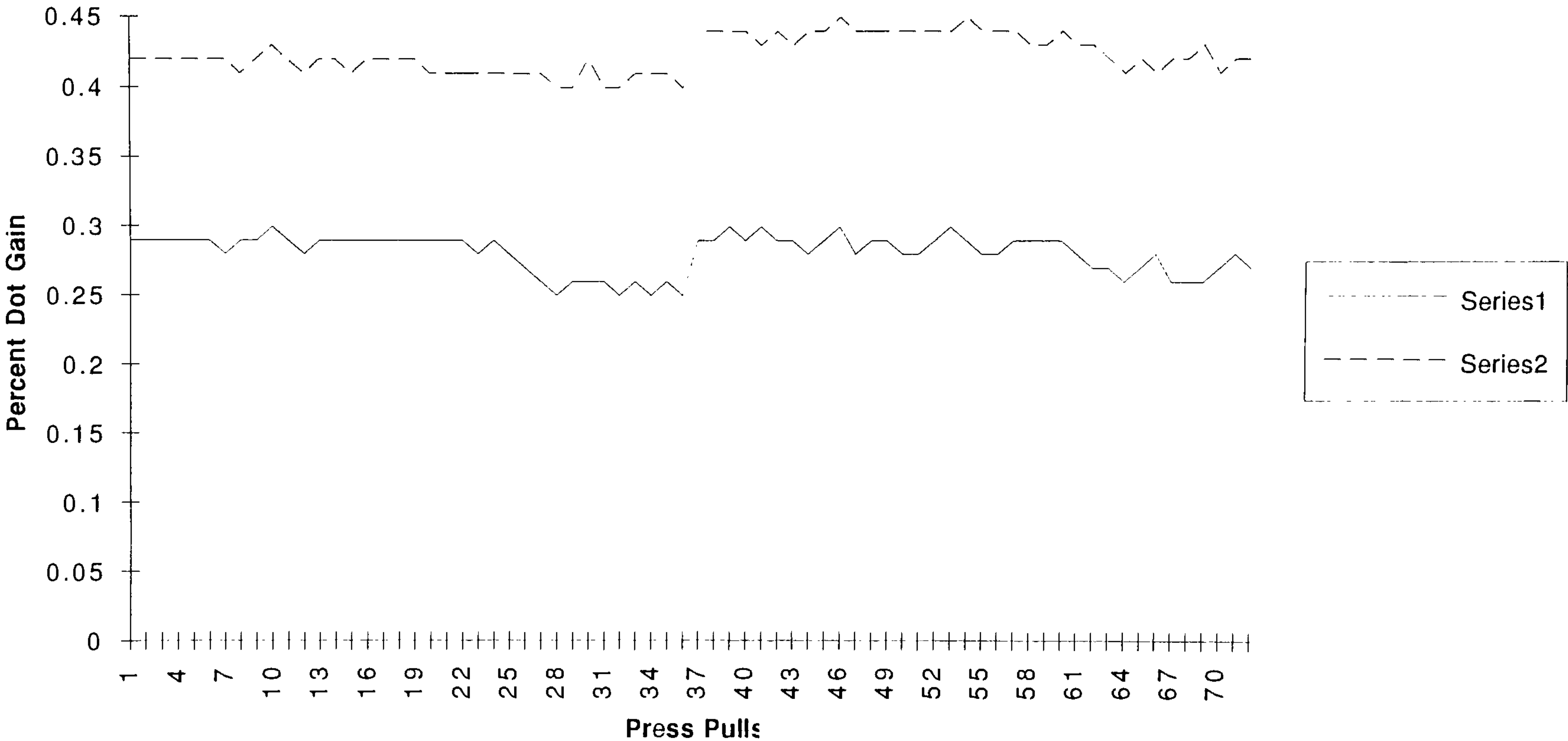


Figure 1.11
SM vs. CM

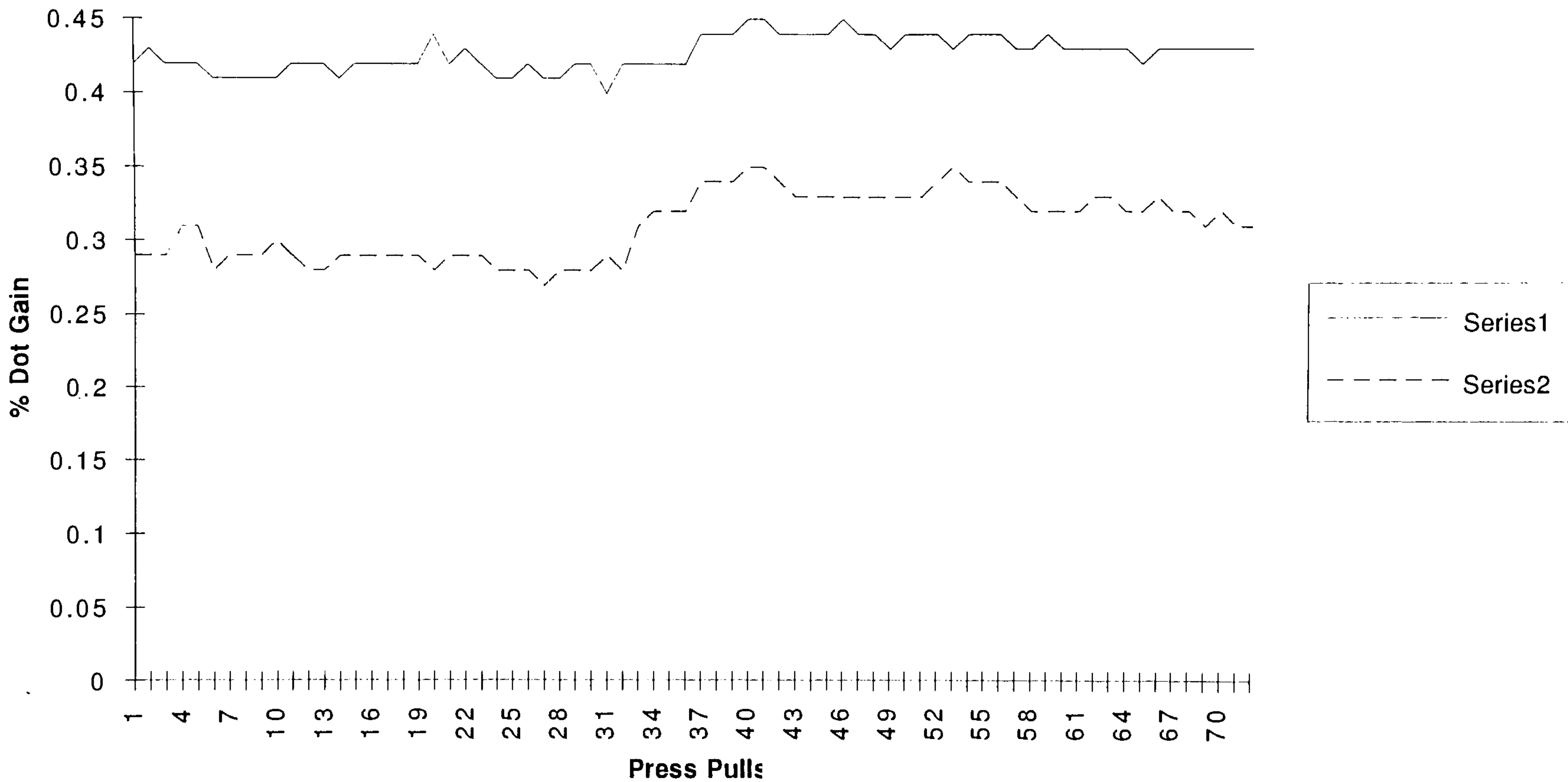
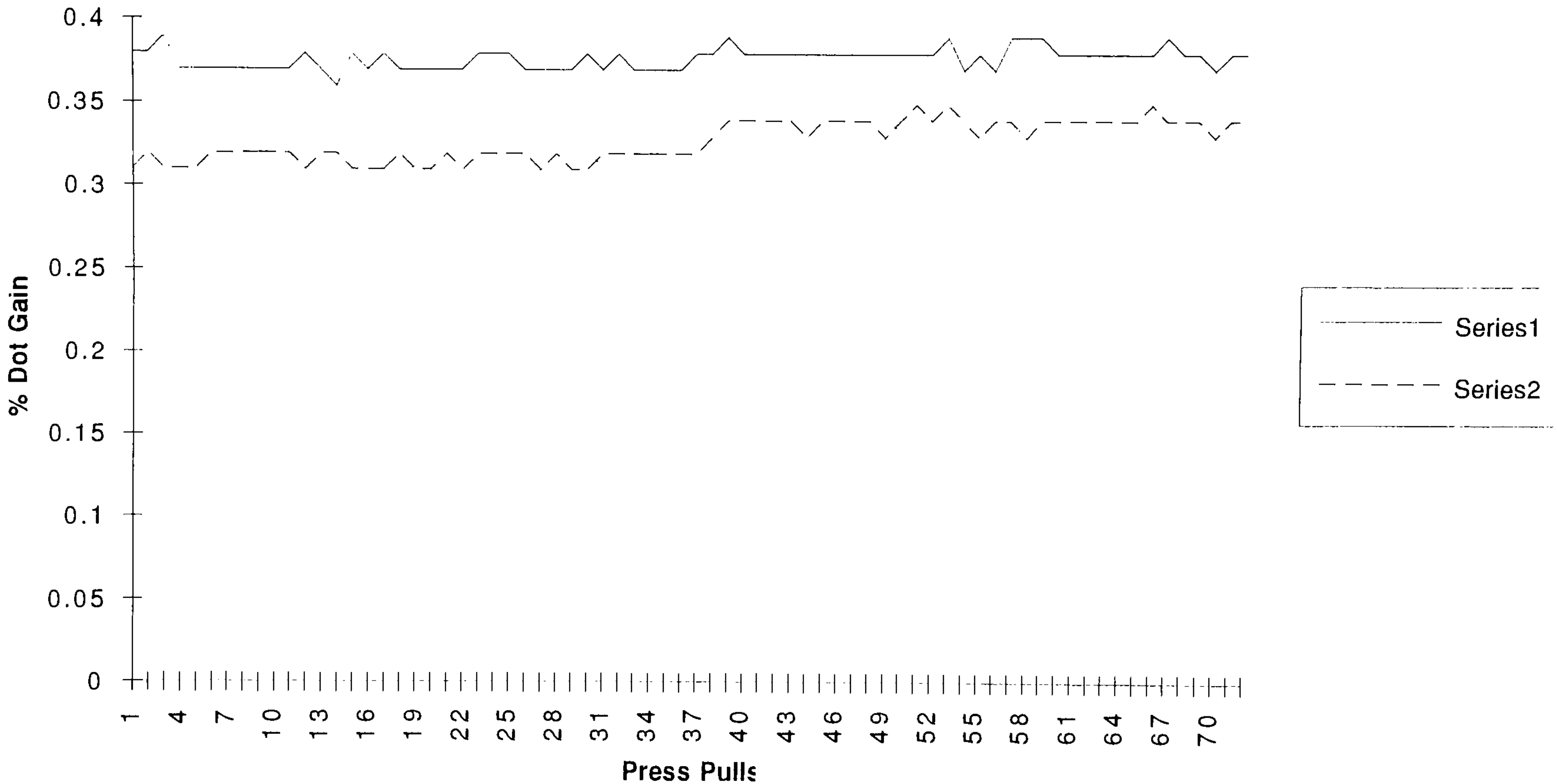


Figure 1.12
SY vs. CY



Appendix B

Print Contrast Measurments for Conventional and Stochastic
Screens at the 48% and 70% Tint Patch
for all colors printed under SWOP Coonditions

Table 15
Data Collection Sheet for Conventional Black Print Contrast at 48% Tint Patch

Solid Ink Density for Conventional Black

1.88	1.88	1.88	1.54	1.57	1.56
1.89	1.89	1.88	1.57	1.58	1.56
1.91	1.87	1.9	1.57	1.59	1.57
1.89	1.89	1.89	1.57	1.59	1.58
1.89	1.88	1.88	1.57	1.56	1.58
1.89	1.89	1.91	1.54	1.59	1.56
1.88	1.9	1.89	1.56	1.59	1.59
1.89	1.88	1.88	1.56	1.58	1.56
1.87	1.89	1.92	1.57	1.58	1.59
1.88	1.89	1.88	1.59	1.56	1.53
1.9	1.89	1.93	1.56	1.57	1.56
1.88	1.89	1.88	1.56	1.59	1.61

Percent Print Contrast at the 48% tint Patch for Conventional Black

0.65	0.65	0.64	0.66	0.62	0.63
0.65	0.64	0.64	0.64	0.64	0.64
0.64	0.65	0.64	0.65	0.65	0.64
0.64	0.64	0.65	0.65	0.64	0.64
0.64	0.64	0.65	0.64	0.64	0.63
0.65	0.64	0.64	0.65	0.65	0.64
0.64	0.64	0.66	0.65	0.64	0.64
0.64	0.64	0.65	0.65	0.63	0.64
0.65	0.63	0.64	0.65	0.64	0.63
0.65	0.64	0.65	0.63	0.63	0.64
0.63	0.64	0.63	0.63	0.64	0.64
0.65	0.64	0.64	0.64	0.63	0.63

N=72 data points
Mean=.641153
Standard Deviation (sample)= 7.42409
Range=.04
Max. Value=.66
Min. Value=.62
Sum=46.163
Sum Squared=29.6014
Standard Error of the Mean=8.68841

Table 16
Data Collection Sheet for Conventional Cyan Print Contrast at 48% Tint Patch

Solid Ink Density for Conventional Cyan

1.36	1.36	1.3	1.41	1.41	1.37
1.35	1.36	1.28	1.41	1.42	1.32
1.37	1.36	1.27	1.41	1.4	1.29
1.36	1.37	1.26	1.43	1.41	1.27
1.37	1.36	1.27	1.4	1.43	1.25
1.37	1.37	1.27	1.4	1.43	1.26
1.37	1.36	1.27	1.41	1.41	1.26
1.36	1.37	1.27	1.42	1.41	1.25
1.36	1.37	1.26	1.41	1.41	1.25
1.37	1.36	1.25	1.41	1.41	1.25
1.38	1.37	1.26	1.41	1.42	1.24
1.36	1.37	1.26	1.42	1.41	1.25

Percent Print Contrast for Conventional Cyan at 48% Tint Patch

0.59	0.58	0.59	0.59	0.59	0.59
0.59	0.59	0.58	0.58	0.59	0.58
0.58	0.58	0.58	0.59	0.58	0.59
0.57	0.58	0.58	0.59	0.59	0.59
0.57	0.58	0.58	0.59	0.59	0.59
0.59	0.58	0.57	0.59	0.58	0.59
0.59	0.58	0.59	0.6	0.59	0.59
0.57	0.58	0.58	0.6	0.58	0.59
0.58	0.58	0.58	0.59	0.58	0.58
0.58	0.58	0.58	0.58	0.59	0.6
0.57	0.59	0.57	0.59	0.59	0.58
0.58	0.59	0.58	0.59	0.58	0.6

N=72 data points
Mean=.584583
Standard Deviation (sample)= 7.30377
Range=.03
Max. Value=.60
Min. Value=.57
Sum=42.09
Sum Squared=24.6089
Standard Error of the Mean=8.54759

Table 17
Data Collection Sheet for Conventional Magenta Print Contrast at 48% Tint Patch

Solid Ink Density for Conventional Magenta

1.49	1.5	1.43	1.36	1.34	1.33
1.51	1.44	1.42	1.34	1.32	1.32
1.52	1.51	1.46	1.41	1.35	1.33
1.5	1.53	1.51	1.35	1.36	1.34
1.49	1.53	1.47	1.37	1.34	1.32
1.47	1.52	1.45	1.33	1.36	1.34
1.5	1.54	1.41	1.32	1.37	1.34
1.49	1.55	1.41	1.32	1.36	1.36
1.47	1.51	1.42	1.3	1.35	1.46
1.51	1.42	1.38	1.34	1.36	1.5
1.53	1.44	1.37	1.37	1.29	1.53
1.47	1.44	1.34	1.33	1.33	1.48

Percent Print Contrast for ConventionalMagenta at 48% tint Patch

0.55	0.55	0.56	0.58	0.58	0.58
0.56	0.55	0.56	0.57	0.57	0.58
0.55	0.56	0.55	0.59	0.57	0.58
0.55	0.56	0.55	0.56	0.58	0.59
0.55	0.53	0.57	0.58	0.58	0.59
0.55	0.55	0.55	0.58	0.58	0.58
0.55	0.55	0.56	0.58	0.58	0.59
0.55	0.56	0.55	0.59	0.58	0.58
0.56	0.56	0.55	0.58	0.58	0.57
0.55	0.58	0.56	0.57	0.59	0.58
0.55	0.55	0.57	0.58	0.57	0.57
0.56	0.55	0.55	0.58	0.58	0.57

N=72 data points
Mean=.566667
Standard Deviation (sample)= .0144338
Range=.06
Max. Value=.59
Min. Value=.53
Sum=40.80
Sum Squared=23.135
Standard Error of the Mean=1.70103

Table 18
Data Collection Sheet for Conventional Yellow Print Contrast at 48% Tint Patch

Solid Ink Density for Conventional Yellow

1.1	1.08	1.06	0.98	0.99	0.97
1.1	1.08	1.08	0.98	1	0.99
1.07	1.09	1.08	0.98	0.98	0.99
1.09	1.08	1.1	0.99	0.97	0.98
1.08	1.11	1.09	0.98	1	0.98
1.09	1.07	1.06	0.95	0.98	0.98
1.08	1.09	1.05	0.97	0.96	0.98
1.09	1.08	1.07	0.96	0.99	0.98
1.08	1.08	1.09	0.97	0.98	1
1.09	1.11	1.07	0.98	0.98	1
1.08	1.09	1.08	0.99	1.01	0.99
1.11	1.1	1.09	0.99	0.99	0.99

Percent Print Contrast for Conventional Yellow at the 48% tint patch

0.46	0.45	0.44	0.46	0.45	0.44
0.46	0.43	0.45	0.46	0.46	0.45
0.45	0.45	0.44	0.46	0.46	0.45
0.44	0.44	0.45	0.46	0.44	0.45
0.44	0.47	0.45	0.45	0.46	0.45
0.44	0.44	0.43	0.45	0.44	0.45
0.45	0.45	0.43	0.46	0.44	0.45
0.45	0.46	0.44	0.44	0.45	0.45
0.43	0.45	0.45	0.45	0.44	0.45
0.45	0.45	0.46	0.46	0.45	0.45
0.44	0.45	0.45	0.44	0.45	0.44
0.45	0.44	0.44	0.46	0.45	0.44

N=72 data points
Mean=.448333
Standard Deviation (sample)= .008558
Range=.04
Max. Value=.47
Min. Value=.43
Sum=32.28
Sum Squared=14.4774
Standard Error of the Mean=1.00154

Table 19
Data Collection Sheet for Stochastic Black Print Contrast at 48% Tint Patch

Solid Ink Denstiy For Stochastic Black

1.59	1.47	1.55	1.85	1.87	1.87
1.6	1.59	1.59	1.87	1.86	1.88
1.59	1.57	1.58	1.88	1.88	1.85
1.59	1.58	1.55	1.88	1.89	1.85
1.57	1.58	1.59	1.86	1.84	1.86
1.57	1.61	1.57	1.83	1.87	1.86
1.59	1.59	1.55	1.85	1.88	1.86
1.56	1.58	1.56	1.87	1.87	1.83
1.6	1.56	1.58	1.86	1.87	1.89
1.6	1.58	1.59	1.87	1.86	1.86
1.57	1.57	1.58	1.88	1.85	1.86
1.55	1.6	1.59	1.88	1.88	1.91

Percent Print Contrast for Stochastic Black at the 48% tint patch

0.52	0.51	0.54	0.53	0.49	0.52
0.51	0.52	0.51	0.52	0.53	0.54
0.51	0.52	0.52	0.53	0.54	0.53
0.49	0.51	0.52	0.52	0.51	0.53
0.51	0.52	0.51	0.52	0.53	0.51
0.54	0.5	0.49	0.53	0.53	0.53
0.49	0.53	0.51	0.53	0.52	0.52
0.52	0.52	0.51	0.52	0.52	0.52
0.51	0.51	0.51	0.53	0.52	0.51
0.5	0.51	0.51	0.5	0.51	0.53
0.51	0.48	0.5	0.51	0.53	0.52
0.51	0.49	0.49	0.53	0.5	0.5

N=72 data points
Mean=.515417
Standard Deviation (sample)= .0135249
Range=.06
Max. Value=.54
Min. Value=.48
Sum=37.11
Sum Squared=19.1401
Standard Error of the Mean=1.58282

Table 20
Data Collection Sheet for Stochastic Cyan Print Contrast at 48% Tint Patch

Solid Ink Density for Stochastic Cyan

1.33	1.3	1.27	1.36	1.36	1.34
1.31	1.31	1.26	1.37	1.38	1.31
1.31	1.32	1.28	1.36	1.35	1.29
1.31	1.32	1.27	1.37	1.37	1.28
1.32	1.32	1.27	1.37	1.39	1.26
1.3	1.32	1.27	1.35	1.36	1.26
1.32	1.31	1.27	1.36	1.36	1.28
1.31	1.31	1.29	1.36	1.37	1.25
1.32	1.26	1.32	1.37	1.37	1.28
1.34	1.26	1.3	1.37	1.37	1.24
1.32	1.25	1.31	1.35	1.39	1.26
1.3	1.27	1.32	1.38	1.38	1.25

Percent Print Contrast for Stochastic Cyan at the 48% tint patch

0.45	0.44	0.46	0.42	0.43	0.43
0.43	0.44	0.45	0.43	0.43	0.41
0.45	0.45	0.43	0.41	0.42	0.43
0.43	0.44	0.46	0.41	0.42	0.43
0.44	0.43	0.45	0.43	0.43	0.42
0.44	0.43	0.44	0.43	0.41	0.44
0.44	0.44	0.44	0.44	0.42	0.43
0.45	0.45	0.44	0.41	0.42	0.43
0.44	0.46	0.45	0.42	0.43	0.43
0.42	0.44	0.44	0.41	0.44	0.43
0.45	0.43	0.45	0.42	0.42	0.43
0.44	0.43	0.45	0.42	0.43	0.43

N=72 data points
Mean=.4333472
Standard Deviation (sample)= .0126891
Range=.05
Max. Value=.46
Min. Value=.41
Sum=31.21
Sum Squared=13.5401
Standard Error of the Mean=.001485

Table 21
Data Collection Sheet for Stochastic Magenta Print Contrast at 48% Tint Patch

Solid Ink Density for Stochastic Magenta

1.37	1.32	1.39	1.53	1.49	1.46
1.37	1.33	1.29	1.54	1.5	1.45
1.31	1.3	1.32	1.57	1.52	1.47
1.34	1.32	1.35	1.54	1.51	1.49
1.35	1.35	1.37	1.55	1.48	1.4
1.32	1.36	1.35	1.54	1.49	1.49
1.28	1.33	1.32	1.53	1.52	1.46
1.31	1.31	1.3	1.51	1.52	1.45
1.32	1.4	1.3	1.49	1.47	1.43
1.34	1.43	1.29	1.49	1.5	1.41
1.38	1.46	1.28	1.52	1.47	1.4
1.37	1.48	1.37	1.52	1.49	1.36

Percent Print Contrast for Stochastic Magentaat the 48% tint patch

0.45	0.44	0.44	0.46	0.46	0.46
0.45	0.44	0.45	0.46	0.45	0.45
0.43	0.43	0.43	0.46	0.46	0.46
0.45	0.43	0.45	0.45	0.46	0.46
0.44	0.44	0.45	0.46	0.46	0.45
0.45	0.44	0.46	0.48	0.45	0.47
0.44	0.44	0.44	0.47	0.46	0.46
0.45	0.44	0.45	0.46	0.46	0.45
0.44	0.45	0.45	0.46	0.45	0.44
0.45	0.46	0.43	0.44	0.47	0.43
0.45	0.47	0.43	0.47	0.46	0.46
0.46	0.47	0.43	0.46	0.46	0.42

N=72 datapoints
Mean=.450972
Standard Deviation (sample)=.0122371
Range=.06
Max. Value=.48
Min. Value=.42
Sum=32.47
Sum Squared=14.6537
Standard Error of the Mean=.0014321

Table 22
Data Collection Sheet for Stochastic Yellow Print Contrast at 48% Tint Patch

Solid Ink Density for Stochastic Yellow

1.03	1.01	1.01	1.06	1.06	1.05
1.03	1.05	1.02	1.05	1.06	1.06
1.02	1.04	1.02	1.06	1.05	1.07
1.03	1.03	1.03	1.07	1.04	1.06
1.05	1.02	1.05	1.06	1.06	1.06
1.02	1.04	1.04	1.04	1.07	1.04
1.04	1.05	1.04	1.05	1.05	1.05
1	1.04	1.01	1.06	1.05	1.04
1.05	1.06	1.07	1.06	1.05	1.07
1.04	1.03	1.02	1.06	1.05	1.06
1.03	1.04	1.04	1.06	1.05	1.06
1.05	1.04	1	1.07	1.05	1.06

Percent Print Contrast for Stochastic Yellow at the 48% tint patch

0.44	0.44	0.42	0.45	0.44	0.45
0.43	0.45	0.42	0.43	0.44	0.45
0.42	0.43	0.42	0.44	0.43	0.44
0.44	0.44	0.44	0.45	0.43	0.43
0.44	0.42	0.43	0.44	0.43	0.44
0.43	0.44	0.43	0.43	0.45	0.44
0.43	0.43	0.44	0.44	0.44	0.43
0.43	0.44	0.42	0.43	0.45	0.44
0.44	0.44	0.44	0.44	0.42	0.45
0.43	0.44	0.42	0.43	0.43	0.45
0.43	0.44	0.44	0.44	0.43	0.44
0.43	0.43	0.43	0.45	0.43	0.44

N=72 data points
Mean=.435694
Standard Deviation (sample)= 8.69294
Range=.05
Max. Value=.45
Min. Value=.42
Sum=31.37
Sum Squared=13.6731
Standard Error of the Mean=1.01733

Figure 1.13
Print Contrast 48%
PSK vs. PCK

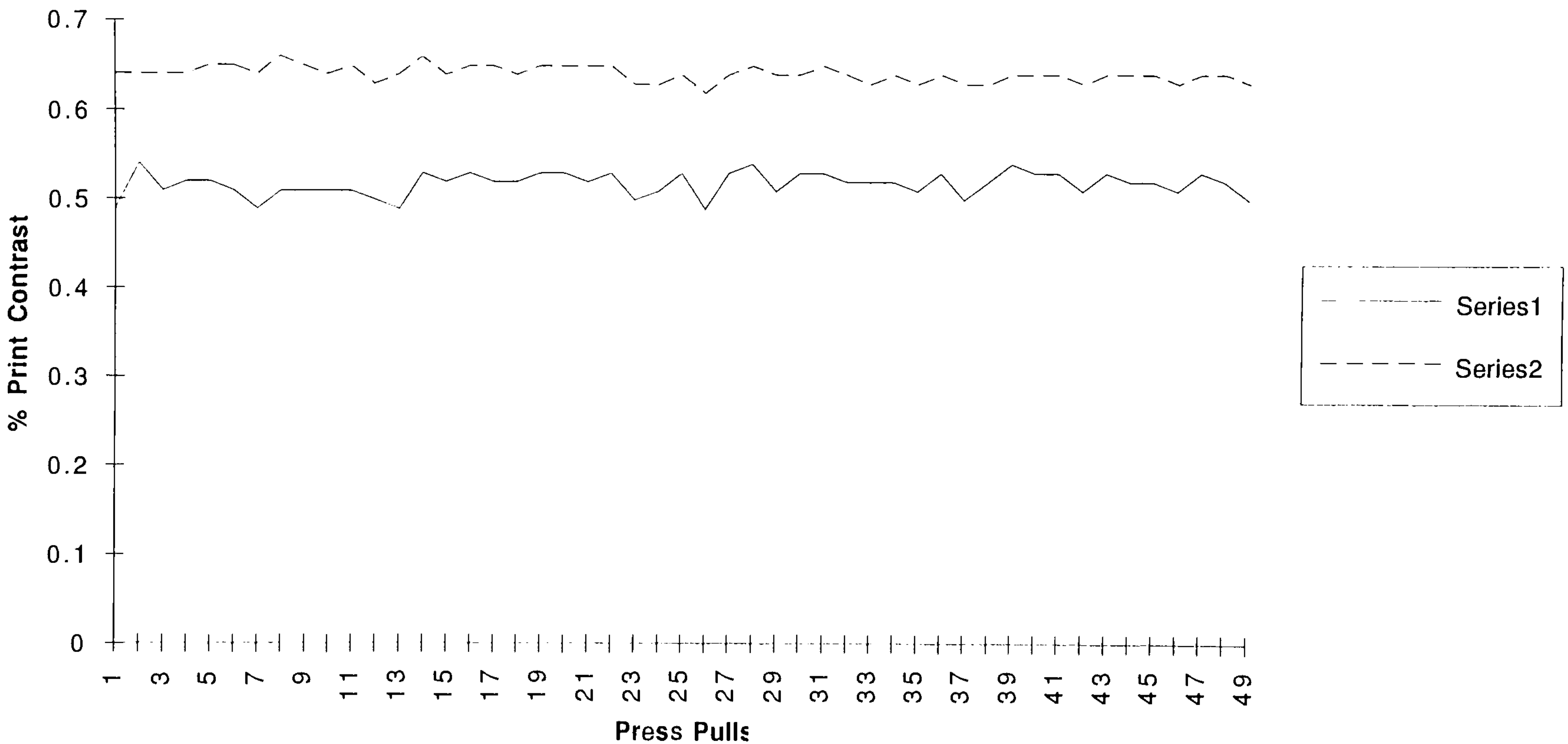


Figure 1.14
Print Contrast 48%
PSC vs. PCC

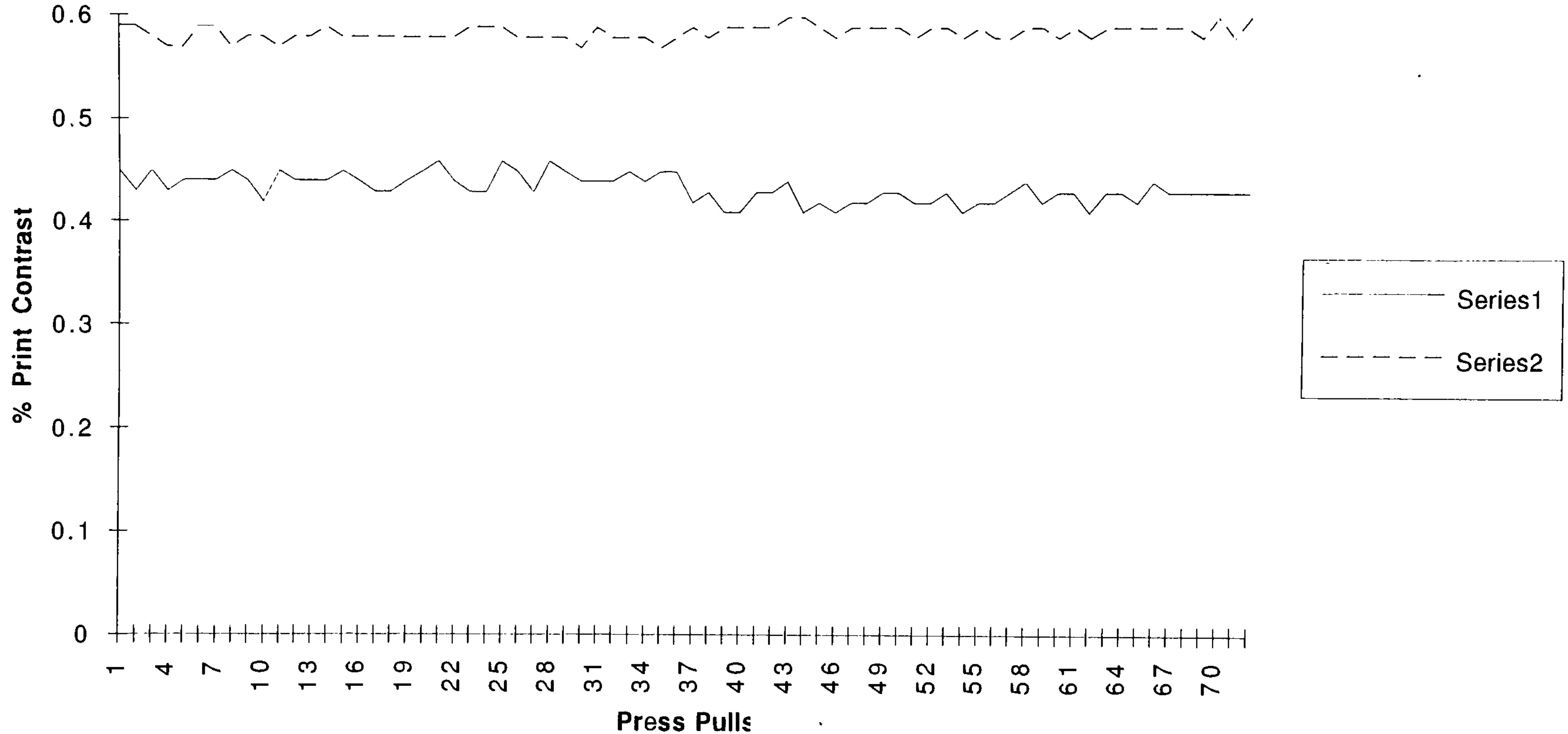


Figure 1.15
Print Contrast 48%
PSM vs. PCM

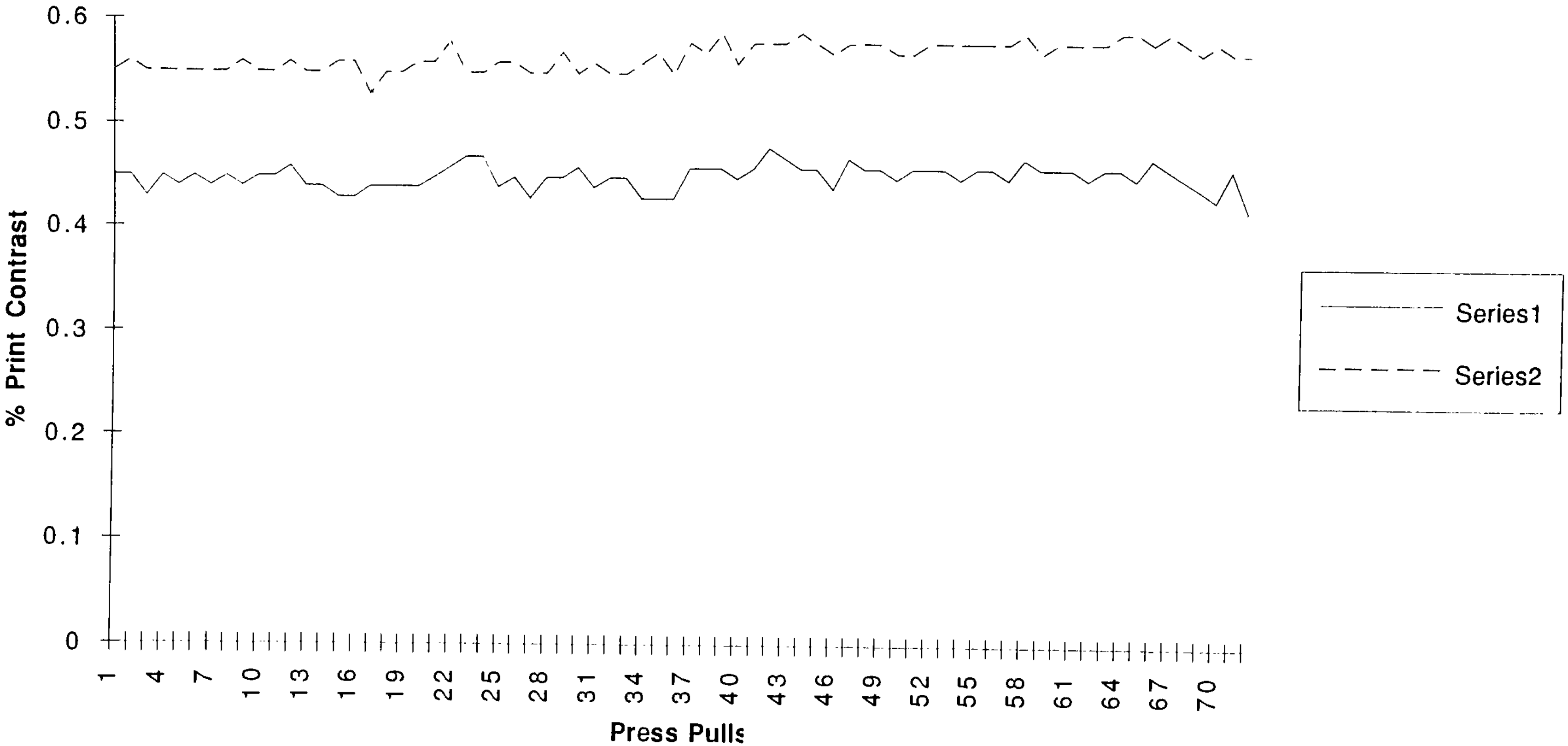


Figure 1.16
Print Contrast 48%
PSY vs. PCY

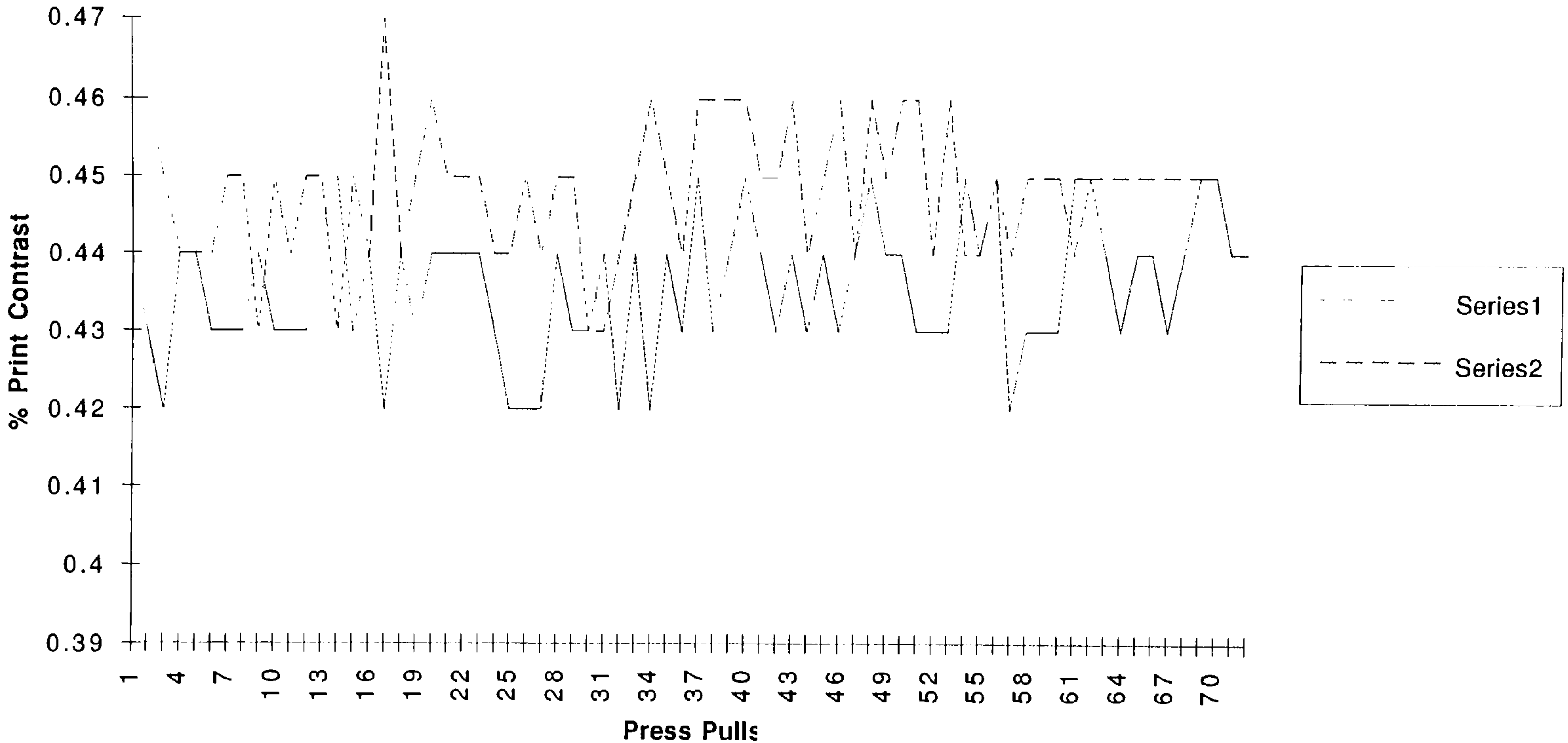


Table 23
Data Collection Sheet for Conventional Black Print Contrast at 70% Tint Patch

Solid Ink Density for Conventional Black

1.62	1.68	1.72	1.75	1.71	1.7
1.63	1.67	1.72	1.71	1.71	1.69
1.65	1.67	1.74	1.72	1.71	1.67
1.67	1.72	1.72	1.75	1.71	1.7
1.65	1.64	1.71	1.71	1.73	1.69
1.63	1.64	1.72	1.71	1.71	1.68
1.63	1.67	1.74	1.71	1.72	1.7
1.68	1.67	1.73	1.72	1.7	1.68
1.67	1.66	1.7	1.73	1.69	1.67
1.66	1.66	1.7	1.71	1.67	1.69
1.69	1.67	1.7	1.74	1.7	1.68
1.69	1.7	1.64	1.72	1.67	1.66

Percent Print Contrast for Conventional Black at the 70% tint patch

0.43	0.44	0.46	0.45	0.48	0.43
0.44	0.45	0.47	0.49	0.48	0.45
0.42	0.45	0.47	0.46	0.48	0.45
0.43	0.44	0.47	0.45	0.48	0.46
0.44	0.45	0.47	0.46	0.46	0.44
0.44	0.47	0.48	0.48	0.46	0.46
0.44	0.46	0.48	0.49	0.46	0.45
0.44	0.45	0.45	0.49	0.48	0.45
0.43	0.48	0.43	0.48	0.42	0.44
0.45	0.47	0.44	0.48	0.45	0.45
0.44	0.48	0.44	0.47	0.45	0.45
0.45	0.46	0.44	0.48	0.41	0.44

N=72 data points
Mean=.455694
Standard Deviation (sample)= .0186764
Range=.08
Max. Value=.49
Min. Value=.41
Sum=32.81
Sum Squared=14.9761
Standard Error of the Mean=2.18569

Table 24
Data Collection Sheet for Conventional Cyan Print Contrast at 70% Tint Patch

Solid Ink Density for Conventional Cyan

1.32	1.33	1.34	1.35	1.34	1.33
1.33	1.32	1.34	1.34	1.33	1.32
1.33	1.32	1.35	1.36	1.35	1.32
1.33	1.32	1.35	1.36	1.35	1.31
1.32	1.32	1.34	1.36	1.35	1.31
1.33	1.36	1.34	1.34	1.34	1.31
1.32	1.36	1.32	1.35	1.33	1.29
1.34	1.37	1.32	1.36	1.33	1.3
1.34	1.35	1.32	1.34	1.32	1.3
1.31	1.36	1.3	1.34	1.32	1.3
1.33	1.35	1.3	1.33	1.33	1.31
1.33	1.36	1.31	1.34	1.33	1.31

Percent Print Contrast for Conventional Cyan at the 70% tint patch

0.38	0.38	0.33	0.36	0.36	0.38
0.38	0.37	0.36	0.35	0.36	0.38
0.37	0.38	0.37	0.33	0.36	0.38
0.38	0.37	0.36	0.35	0.35	0.39
0.38	0.33	0.34	0.35	0.34	0.38
0.39	0.36	0.34	0.37	0.36	0.37
0.38	0.36	0.35	0.36	0.37	0.38
0.37	0.36	0.33	0.36	0.34	0.38
0.38	0.35	0.37	0.35	0.38	0.38
0.39	0.36	0.37	0.37	0.38	0.38
0.39	0.35	0.38	0.35	0.37	0.38
0.38	0.34	0.37	0.36	0.37	0.38

N=72 data points
Mean=.365556
Standard Deviation (sample)= .161759
Range=.06
Max. Value=.39
Min. Value=.33
Sum=26.32
Sum Squared=9.64
Standard Error of the Mean=1.89306

Table 25
Data Collection Sheet for Conventional Magenta Print Contrast at 70% Tint Patch

Solid Ink Density for Conventional Magenta

1.35	1.18	1.29	1.31	1.29	1.25
1.45	1.24	1.3	1.29	1.29	1.23
1.46	1.29	1.27	1.27	1.26	1.22
1.33	1.21	1.24	1.3	1.24	1.29
1.3	1.26	1.27	1.29	1.24	1.26
1.41	1.33	1.26	1.3	1.25	1.23
1.43	1.3	1.28	1.3	1.29	1.28
1.31	1.28	1.27	1.28	1.28	1.27
1.35	1.3	1.23	1.32	1.25	1.29
1.43	1.33	1.22	1.29	1.22	1.27
1.38	1.29	1.23	1.28	1.28	1.16
1.22	1.29	1.24	1.3	1.32	1.19

Percent Print Contrast for Conventional Magenta at the 70% tint patch

0.32	0.36	0.37	0.37	0.36	0.33
0.32	0.34	0.34	0.36	0.36	0.33
0.3	0.35	0.36	0.36	0.36	0.34
0.32	0.34	0.35	0.36	0.36	0.35
0.33	0.36	0.36	0.37	0.36	0.33
0.31	0.37	0.36	0.35	0.37	0.33
0.31	0.36	0.37	0.36	0.37	0.35
0.33	0.36	0.36	0.36	0.36	0.34
0.32	0.36	0.35	0.36	0.33	0.34
0.31	0.36	0.35	0.36	0.34	0.34
0.33	0.36	0.34	0.36	0.34	0.36
0.33	0.36	0.34	0.36	0.33	0.33

N=72 data points
Mean=.365556
Standard Deviation (sample)= .0161759
Range=.06
Max. Value=.39
Min. Value=.37
Sum=26.32
Sum Squared=9.64
Standard Error of the Mean=1.89306

Table 26
Data Collection Sheet for Conventional Yellow Print Contrast at 70% Tint Patch

Solid Ink Density for Conventional Yellow

1.03	1	0.95	0.9	0.91	1.04
1.04	1.05	0.93	0.92	0.89	1.01
1.03	1	0.94	0.89	0.89	1.01
1.01	0.99	0.93	0.94	0.9	1.04
1.02	0.91	0.92	0.92	0.91	1.02
1.01	0.94	0.92	0.91	0.89	1.02
1	0.93	0.92	0.91	0.92	1.01
1.02	0.91	0.89	0.92	0.91	1.01
1.04	0.93	1.01	0.92	1.01	1.02
1.03	0.91	1	0.88	1.04	1
1.02	0.9	1.03	0.9	1.01	1
1.03	0.93	1	0.9	1.03	1.01

Percent Print Contrast for Conventional Yellow at the 70% tint patch

0.25	0.24	0.2	0.19	0.2	0.26
0.25	0.25	0.2	0.2	2	0.23
0.24	0.24	0.19	0.2	2	0.25
0.24	0.24	0.2	0.21	0.21	0.25
0.24	0.2	0.17	0.21	0.2	0.25
0.24	0.19	0.2	0.18	0.2	0.25
0.24	0.19	0.18	0.22	0.2	0.24
0.24	0.19	0.19	0.21	0.2	0.23
0.26	0.21	0.25	0.21	0.24	0.25
0.24	0.19	0.26	0.18	0.25	0.24
0.24	0.19	0.24	0.21	0.24	0.25
0.24	0.18	0.23	0.18	0.25	0.26

N=72 data points
Mean=.220417
Standard Deviation (sample)= .0258619
Range=.09
Max. Value=.26
Min. Value=.17
Sum=15.87
Sum Squared=3.5455
Standard Error of the Mean=3.02661

Table 27
Data Collection Sheet for Stochastic Black Print Contrast at 70% Tint Patch

Solid Ink Density for Stochastic Black

1.67	1.72\1.73	1.75	1.77	1.75	1.77
1.72	1.74	1.74	1.72	1.76	1.78
1.77	1.76	1.75	1.74	1.74	1.77
1.77	1.48	1.74	1.78	1.8	1.79
1.75	1.48	1.75	1.75	1.79	1.81
1.72	1.5	1.75	1.75	1.86	1.76
1.71	1.5	1.77	1.72	1.73	1.7
1.76	1.56	1.75	1.75	1.76	1.73
1.77	1.64	1.72	1.7	1.8	1.75
1.74	1.65	1.72	1.73	1.75	1.78
1.77	1.72	1.76	1.76	1.78	1.7
1.75	1.73	1.76	1.73	1.83	1.75

Percent Print Contrast for Stochastic Black at the 70% tint patch

0.18	0.2	0.21	0.21	0.24	0.2
0.21	0.22	0.24	0.24	0.22	0.22
0.21	0.21	0.24	0.22	0.25	0.23
0.19	0.21	0.23	0.22	0.24	0.22
0.21	0.21	0.23	0.2	0.22	0.22
0.22	0.24	0.25	0.24	0.24	0.22
0.22	0.21	0.23	0.25	0.23	0.21
0.21	0.21	0.21	0.24	0.24	0.2
0.22	0.22	0.22	0.21	0.2	0.22
0.21	0.25	0.19	0.25	0.22	0.21
0.21	0.24	0.22	0.24	0.21	0.22
0.23	0.21	0.22	0.24	0.21	0.2

N=72 data points
Mean=.220833
Standard Deviation (sample)= .0159002
Range=.07
Max. Value=.25
Min. Value=.18
Sum=15.09
Sum Squared=3.5292
Standard Error of the Mean=.0018608

Table 28
Data Collection Sheet for Stochastic Cyan Print Contrast at 70% Tint Patch

Solid Ink Density for Stochastic Cyan

1.45	1.46	1.39	1.4	1.41	1.45
1.46	1.46	1.37	1.44	1.39	1.45
0.14	1.48	1.39	1.41	1.44	1.45
1.45	1.42	1.4	1.42	1.43	1.41
1.46	1.39	1.4	1.42	1.44	1.42
1.47	1.4	1.41	1.38	1.44	1.43
1.44	1.4	1.39	1.44	1.39	1.4
1.49	1.39	1.39	1.43	1.4	1.4
1.45	1.41	1.41	1.42	1.46	1.38
1.44	1.43	0.14	1.43	1.45	1.4
1.44	1.39	1.4	1.4	1.44	1.4
1.46	1.4	0.158	1.42	1.47	1.42

Percent Print Contrast for Stochastic Cyan at the 70% tint patch

0.14	0.14	0.14	0.14	0.14	0.15
0.15	0.15	0.15	0.15	0.14	0.14
0.11	0.17	0.13	0.15	0.14	0.15
0.14	0.13	0.13	0.16	0.15	0.14
0.15	0.14	0.15	0.14	0.14	0.15
0.15	0.14	0.14	0.14	0.16	0.17
0.13	0.14	0.14	0.15	0.14	0.15
0.15	0.14	0.14	0.15	0.15	0.14
0.13	0.14	0.15	0.15	0.15	0.14
0.15	0.15	0.14	0.15	0.14	0.16
0.14	0.14	0.16	0.15	0.14	0.14
0.15	0.14	0.14	0.15	0.16	0.16

N=72 data points
Mean=.145
Standard Deviation (sample)= .9.49425
Range=.06
Max. Value=.17
Min. Value=.11
Sum=10.44
Sum Squared=1.5202
Standard Error of the Mean=1.1111111

Table 29
Data Collection Sheet for Stochastic Magenta Print Contrast at 70% Tint Patch

Solid Ink Density for Stochastic Magenta

1.27	1.24	1.44	1.44	1.43	1.24
1.33	1.22	1.45	1.41	1.44	1.2
1.31	1.24	1.43	1.44	1.44	1.19
1.3	1.23	1.4	1.41	1.43	1.22
1.36	1.39	1.41	1.43	1.43	1.21
1.34	1.46	1.45	1.42	1.46	1.2
1.32	1.47	1.44	1.42	1.43	1.19
1.33	1.43	1.22	1.45	1.42	1.18
1.34	1.45	1.22	1.45	1.23	1.22
1.33	1.46	1.22	1.46	1.2	1.18
1.29	1.44	1.22	1.43	1.19	1.24
1.25	1.45	1.22	1.43	1.22	1.25

Percent Print Contrast for Stochastic Magenta at the 70% tint patch

0.2	0.21	0.21	0.2	0.21	0.21
0.22	0.21	0.21	0.21	0.21	0.19
0.23	0.22	0.21	0.21	0.22	0.2
0.2	0.19	0.19	0.22	0.22	0.21
0.21	0.19	0.21	0.22	0.22	0.21
0.23	0.21	0.21	0.21	0.21	0.21
0.21	0.22	0.21	0.21	0.2	0.21
0.21	0.21	0.21	0.21	0.21	0.21
0.21	0.21	0.2	0.21	0.22	0.2
0.21	0.21	0.2	0.23	0.19	0.22
0.21	0.22	0.22	0.21	0.2	0.22
0.2	0.21	0.19	0.21	0.21	0.22

N=72 data points
Mean=.209722
Standard Deviation (sample)= 9.18851
Range=.04
Max. Value=.23
Min. Value=.19
Sum=15.1
Sum Squared=3.1728
Standard Error of the Mean=.001485

Table 30
Data Collection Sheet for Stochastic Yellow Print Contrast at 70% Tint Patch

Solid Ink Density for Stochastic Yellow

0.81	0.79	1.1	0.82	0.83	1.11
0.79	0.82	1.08	0.85	0.82	1.12
0.84	0.82	1.08	0.83	0.82	1.11
0.8	0.81	1.1	0.84	0.82	1.1
0.83	1.07	1.07	0.85	0.84	1.11
0.8	1.08	1.12	0.83	0.84	1.1
0.82	1.1	1.11	0.84	0.84	1.1
0.81	1.09	1.11	0.84	0.83	1.1
0.82	1.09	1.11	0.87	1.09	1.1
0.8	1.09	1.11	0.81	1.12	1.13
0.8	1.1	1.12	0.81	1.12	1.09
0.79	1.09	1.12	0.81	1.1	1.1

Percent Print Contrast for Stochastic Yellow at the 70% tint patch

0.14	0.14	0.2	0.13	0.14	0.2
0.12	0.15	0.19	0.15	0.13	0.2
0.15	0.16	0.2	0.12	0.14	0.2
0.14	0.15	0.22	0.14	0.12	0.22
1.5	0.21	0.2	0.14	0.14	0.19
0.13	0.19	0.22	0.13	0.14	0.21
0.15	0.2	0.21	0.15	0.16	0.19
0.14	0.21	0.22	0.14	0.15	0.18
0.16	0.2	0.22	0.16	0.19	0.18
0.14	0.2	0.2	0.11	0.22	0.21
0.14	0.19	0.2	0.09	0.22	0.19
0.12	0.2	0.22	0.09	0.22	0.2

N=72 data points
Mean=.170417
Standard Deviation (sample)= .0362479
Range=.13
Max. Value=.22
Min. Value=.09
Sum=12.27
Sum Squared=2.1843
Standard Error of the Mean=4.24208

Figure 1.17
Print Contrast 70%
PSK vs. PCK

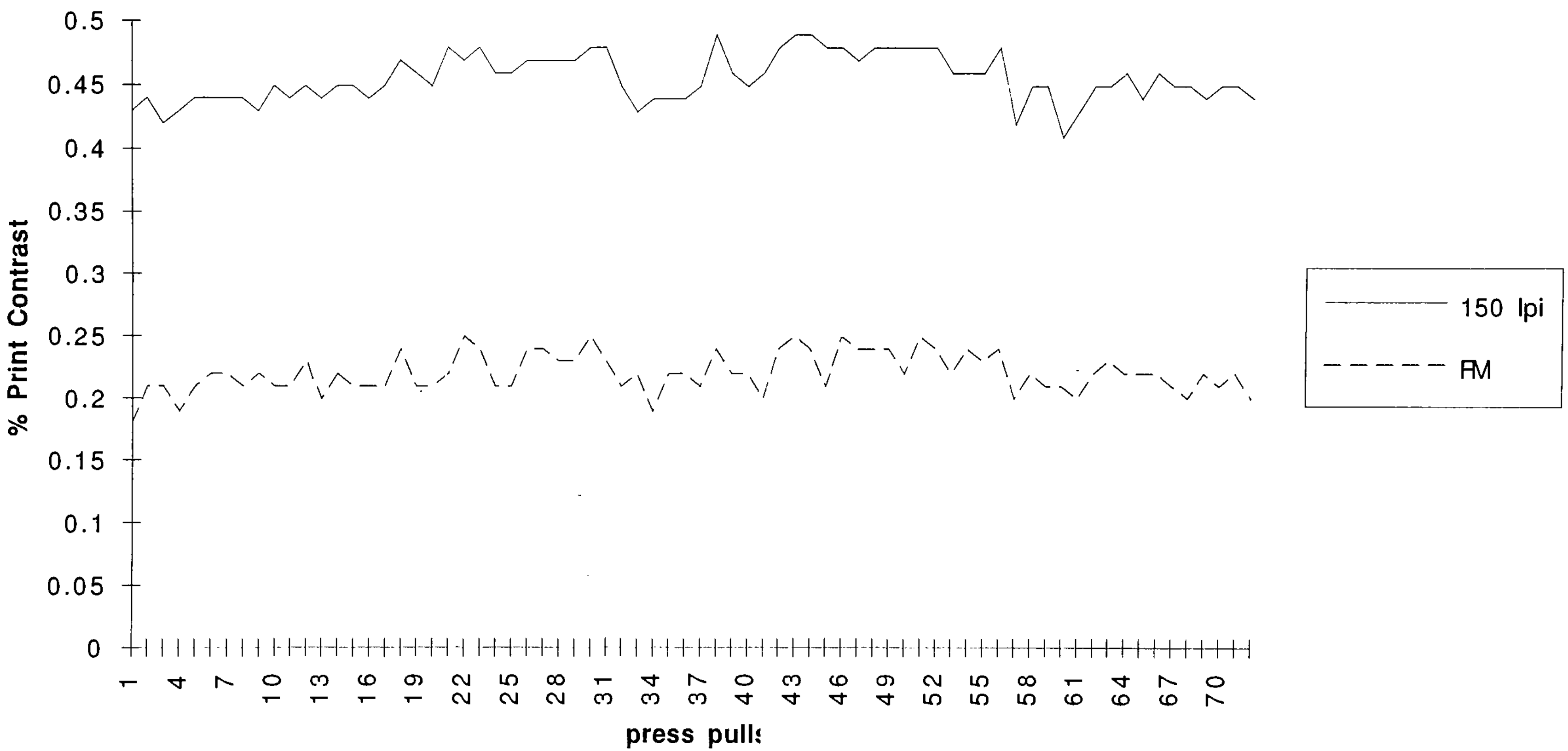


Figure 1.18
Print Contrast 70%
PSC vs. PCC

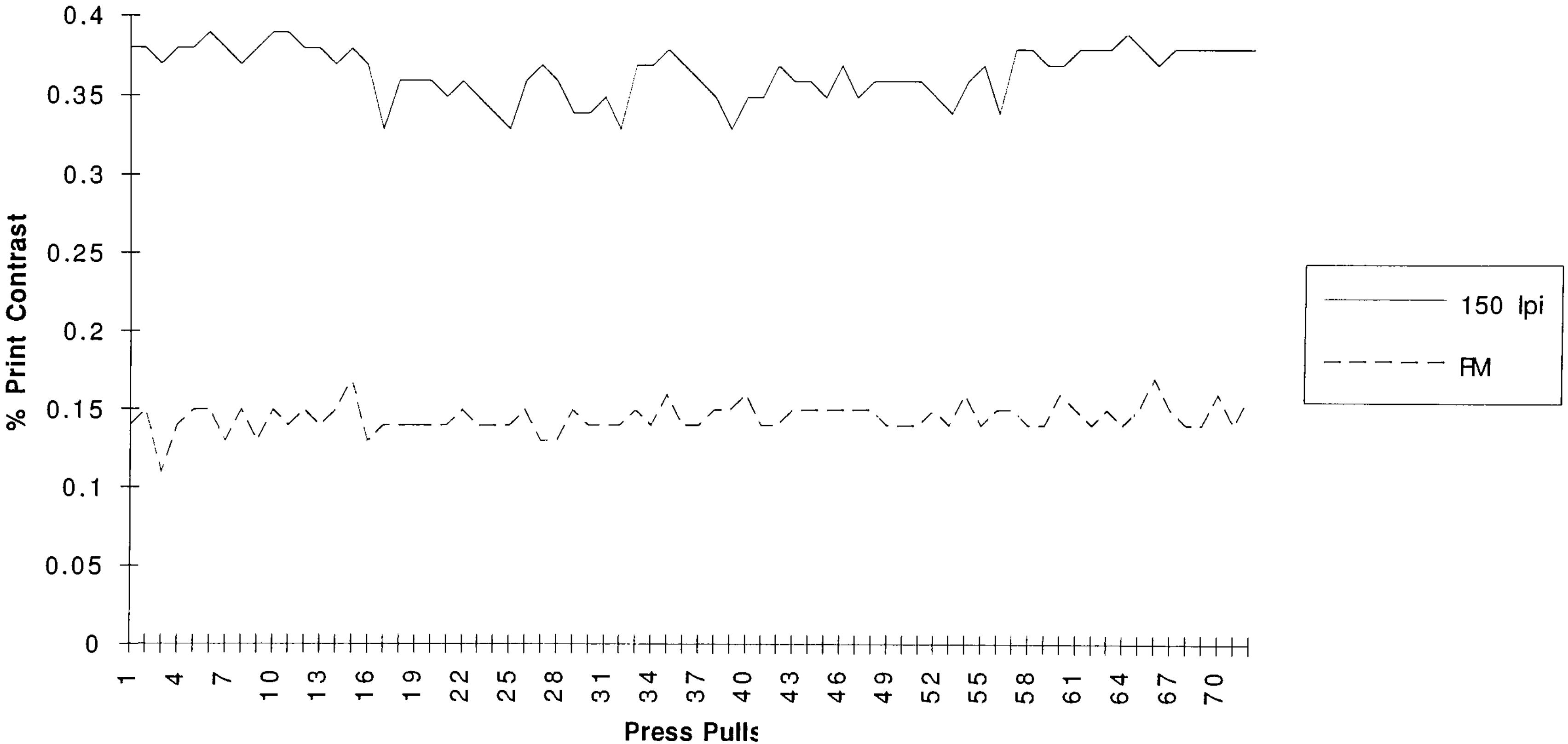


Figure 1.19
Print Contrast 70%
PSM vs. PCM

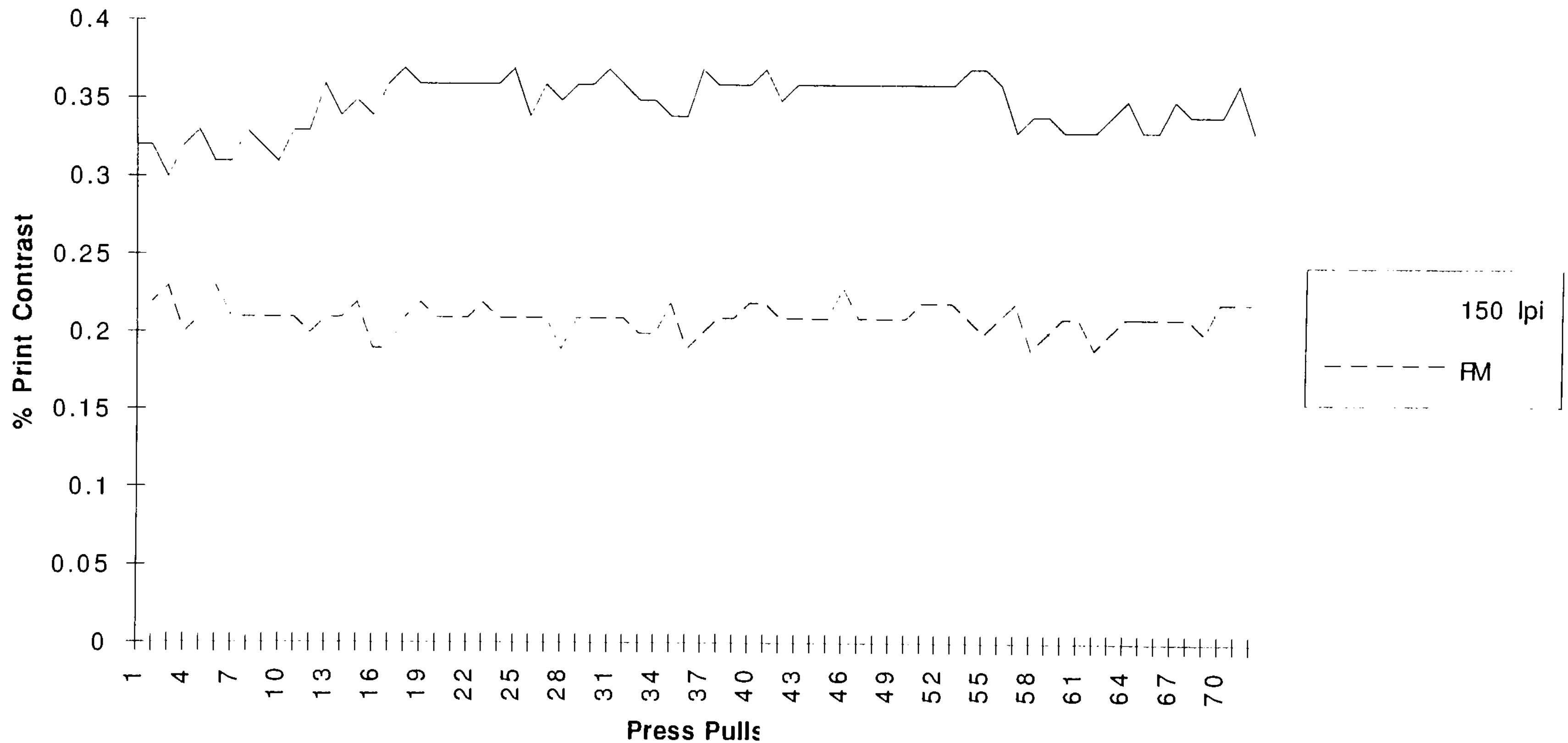
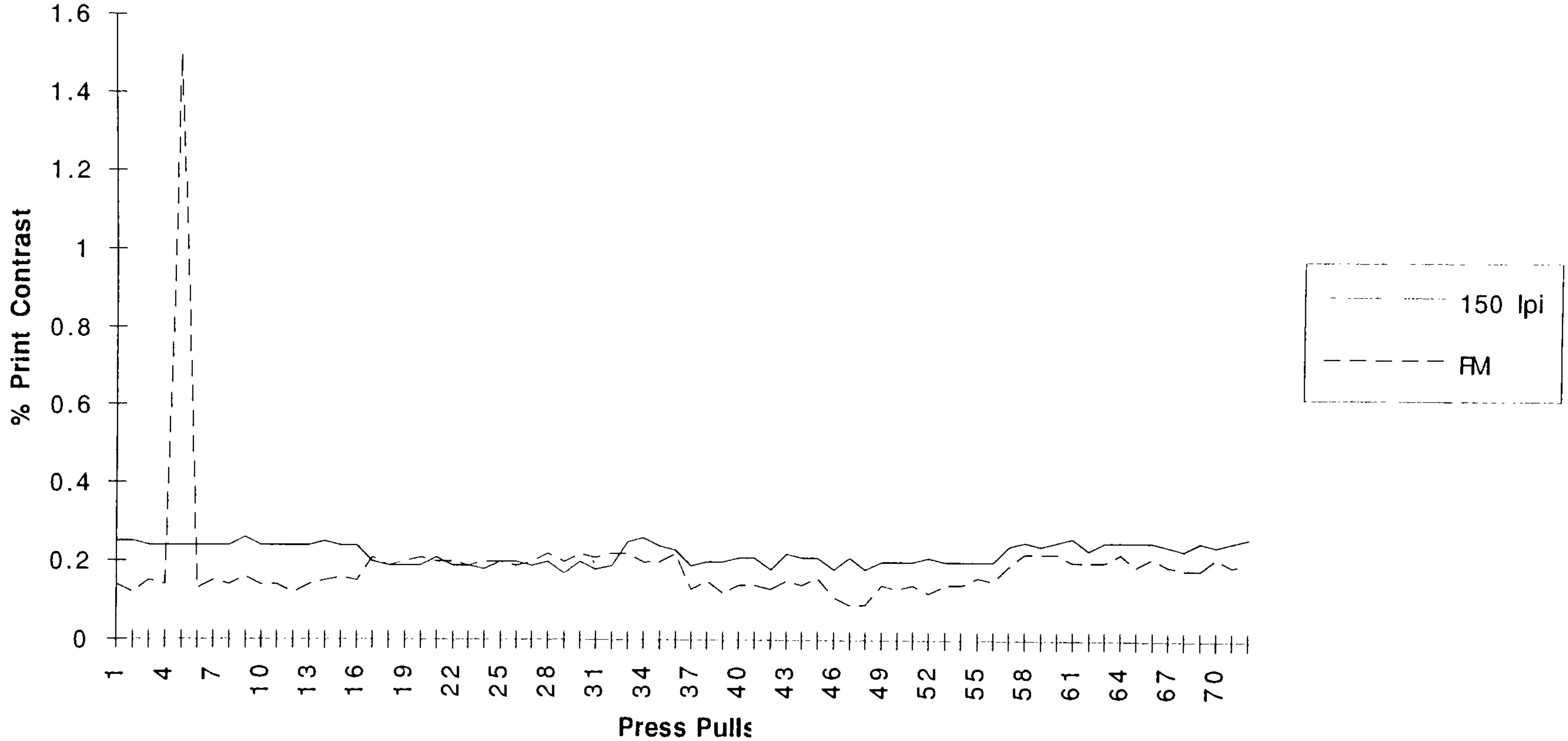


Figure 1.20
Print Contrast 70%
PSY vs. PCY



Appendix C

Dot Gain Measurments for Conventional
and Stochastic Magenta at
Five Different Inking Levels

Table 31
Data Collection Sheet
For Stochastic and Conventional Magenta Dot Gain
Showing Five Different Inking Levels

	standard	level1	level2	level3	level4
gs50	0.42	0.45	0.38	0.45	0.48
	0.43	0.44	0.39	0.44	0.48
	0.42	0.45	0.43	0.44	0.48
	0.42	0.47	0.43	0.45	0.48
	0.42	0.46	0.43	0.45	0.49
	0.41	0.45	0.44	0.45	0.48
	0.41	0.45	0.44	0.45	0.48
	0.41	0.44	0.43	0.46	0.47
	0.44	0.43	0.46	0.46	0.46
	0.44	0.43	0.45	0.46	0.46
	0.44	0.43	0.45	0.46	0.46
	0.45	0.43	0.46	0.47	0.46
	0.45	0.43	0.45	0.46	0.46
	0.44	0.43	0.45	0.46	0.46
	0.44	0.43	0.45	0.46	0.46
	0.44	0.43	0.45	0.48	0.47
gc50	0.34	0.3	0.38	0.36	0.48
	0.34	0.32	0.38	0.37	0.48
	0.34	0.32	0.38	0.35	0.48
	0.35	0.31	0.39	0.36	0.48
	0.35	0.31	0.39	0.36	0.48
	0.34	0.31	0.39	0.36	0.48
	0.33	0.31	0.39	0.36	0.48
	0.33	0.38	0.38	0.45	0.48
	0.29	0.38	0.32	0.45	0.42
	0.29	0.38	0.31	0.44	0.41
	0.29	0.37	0.32	0.44	0.41
	0.31	0.38	0.31	0.44	0.41
	0.31	0.33	0.32	0.44	0.41
	0.28	0.38	0.32	0.43	0.41
	0.29	0.38	0.32	0.44	0.42
	0.29	0.38	0.33	0.44	0.41

Table 31a
Statistical Analysis of Data
Two Way ANOVA with Replication

Summary

	standard	*level1*	*level2*	*level3*	*level4*	*Total*
gs50						
Count	16	16	16	16	16	80
Sum	6.88	7.05	6.99	7.3	7.53	35.75
Average	0.43	0.440625	0.436875	0.45625	0.470625	2.234375
Variance	0.0002	0.000166	0.000516	0.000105	0.000113	0.0011
gc50						
Count	16	16	16	16	16	80
Sum	5.07	5.54	5.63	6.49	7.14	29.87
Average	0.316875	0.34625	0.351875	0.405625	0.44625	1.866875
Variance	0.00065	0.001172	0.001203	0.00176	0.001225	0.006009
Total						
Count	32	32	32	32	32	
Sum	11.95	12.59	12.62	13.79	14.67	
Average	0.746875	0.786875	0.78875	0.861875	0.916875	
Variance	0.00085	0.001338	0.001719	0.001865	0.001338	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0.21609	1	0.21609	303.9597	6.75E-38	3.904205
Column	0.148473	4	0.037118	52.21164	1.73E-27	2.431968
Interaction	0.040597	4	0.010149	14.27646	6.74E-10	2.431968
Within	0.106638	150	0.000711			
Total	0.511798	159				

Table 31b
Data Collection Sheet for Conventional Magenta Solid Ink Density at Five Different Ink Settings

Solid Ink Density at Standard Ink Setting

1.55	1.53	1.38	1.38
1.54	1.51	1.37	1.34
1.52	1.45	1.4	1.34
1.52	1.51	1.37	1.33

Solid Ink Density at First Ink Increase

1.38	1.38	1.82	1.73
1.37	1.36	1.81	1.79
1.38	1.38	1.83	1.81
1.39	1.81	1.81	1.81

Solid Ink Density at Second Ink Increase

1.8	1.78	1.41	1.42
1.78	1.81	1.41	1.42
1.78	1.8	1.4	1.43
1.8	1.81	1.39	1.42

Solid Ink Density at Third Ink Increase

1.61	1.63	2	2.01
1.6	1.62	2.01	2.01
1.62	1.64	2.03	1.97
1.64	2.03	2	2

Solid Ink Density at Fourth Ink Increase

2.12	2.07	1.83	1.83
2.12	2.11	1.8	1.81
2.11	2.12	1.82	1.78
2.12	2.14	1.81	1.83

Table 31c
Data Collection Sheet for Stochastic Magenta Solid Ink Density at Five Different Ink Settings

Solid Ink Denstiy at Standard Ink Settings

1.55	1.55	1.35	1.32
1.55	1.57	1.36	1.32
1.57	1.53	1.31	1.27
1.55	1.52	1.33	1.3

Solid Ink Density at First Ink Increase

1.77	1.76	1.44	1.45
1.76	1.74	1.45	1.44
1.75	1.75	1.45	1.45
1.76	1.75	1.46	1.45

Solid Ink Density at Second Ink Increase

1.41	1.43	1.76	1.77
1.42	1.42	1.76	1.77
1.39	1.41	1.77	1.79
1.41	1.42	1.74	1.7

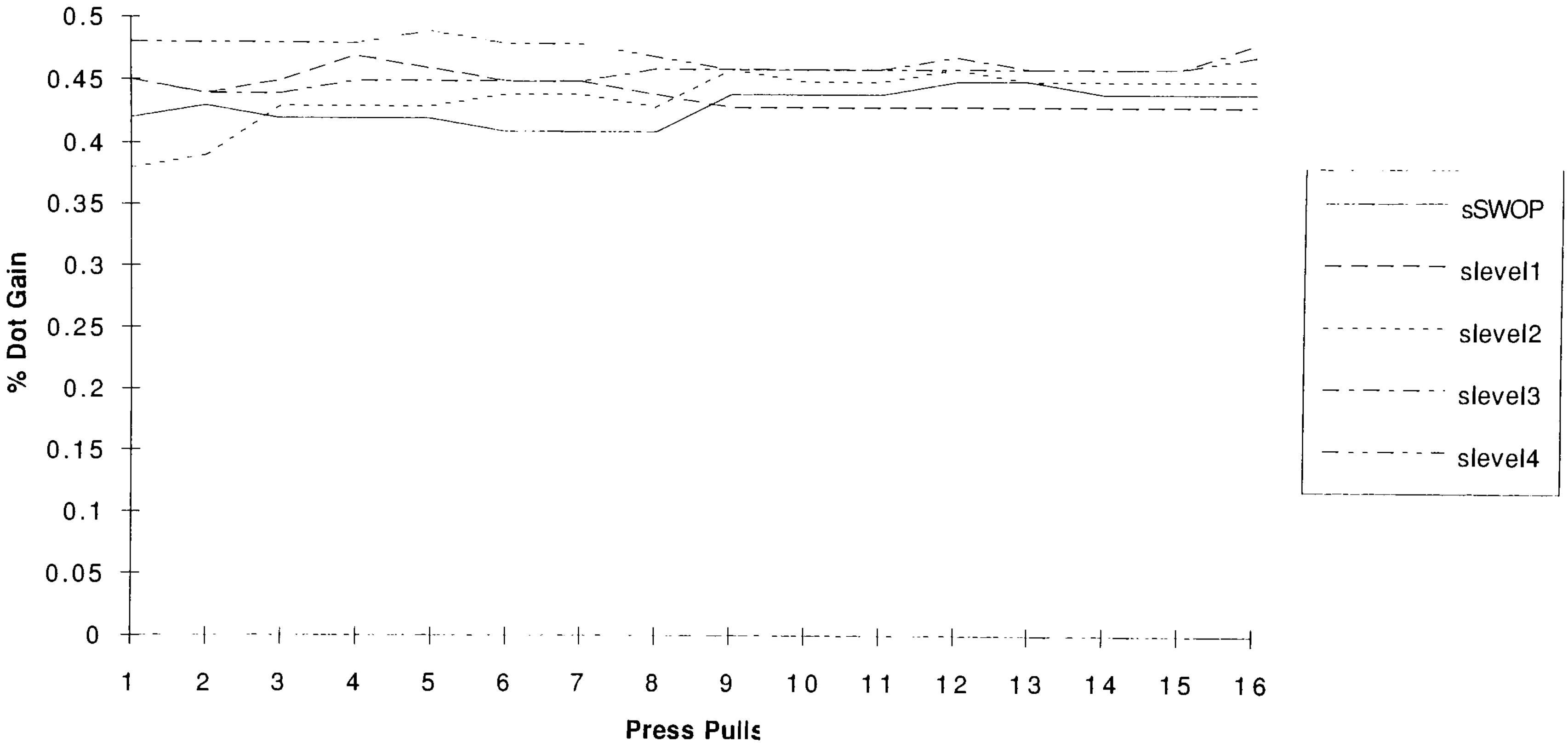
Solid Ink Density at Third Ink Increase

1.66	1.65	1.66	1.96
1.66	1.67	1.95	1.97
1.66	1.66	1.95	1.93
1.68	1.67	1.96	1.97

Solid Ink Density at Fourth Ink Increase

2.08	2.05	1.92	1.93
2.05	2.06	1.92	1.95
2.07	2.08	1.92	1.94
2.06	2.07	1.93	

Figure 1.21
FM Magenta
at 5 Ink Levels



Appendix D

Print Contrast Measurments
at the 48% and 70% Tint Patch
at Five Different Ink Levels for
Stochastic and Conventional Magenta

Table 32
Data Collection Sheet
For Stochastic and Conventional Magenta
Print Contrast at 48%
Showing Five Different Inking Levels

	standard	level1	level2	level3	level4
ps48m	0.46	0.45	0.45	0.47	0.5
	0.46	0.46	0.45	0.47	0.51
	0.46	0.45	0.46	0.48	0.5
	0.45	0.49	0.46	0.47	0.49
	0.46	0.46	0.45	0.46	0.5
	0.48	0.45	0.44	0.47	0.5
	0.47	0.44	0.44	0.46	0.5
	0.46	0.45	0.43	0.48	0.51
	0.45	0.44	0.42	0.44	0.5
	0.45	0.48	0.41	0.5	0.49
	0.43	0.48	0.41	0.5	0.51
	0.45	0.48	0.42	0.49	0.51
	0.44	0.48	0.43	0.5	0.49
	0.45	0.48	0.43	0.51	0.49
	0.44	0.5	0.42	0.5	0.5
	0.45	0.49	0.43	0.51	0.5
pc48m	0.58	0.56	0.55	0.47	0.39
	0.57	0.55	0.55	0.47	0.41
	0.59	0.54	0.55	0.49	0.38
	0.56	0.54	0.54	0.47	0.4
	0.58	0.56	0.54	0.49	0.39
	0.58	0.55	0.53	0.46	0.36
	0.58	0.53	0.52	0.47	0.39
	0.59	0.55	0.55	0.44	0.39
	0.55	0.55	0.54	0.47	0.51
	0.56	0.56	0.56	0.53	0.48
	0.55	0.55	0.54	0.53	0.5
	0.55	0.55	0.55	0.54	0.49
	0.55	0.55	0.55	0.54	0.5
	0.55	0.54	0.55	0.54	0.49
	0.55	0.55	0.55	0.52	0.5
	0.55	0.55	0.54	0.53	0.49

Table 32a
Statistical Analysis of Data
Two Way Anova with Replication

Summary

	standard	level1	level2	level3	level4	Total
ps48m						
Count	16	16	16	16	16	80
Sum	7.26	7.48	6.95	7.71	8	37.4
Average	0.45375	0.4675	0.434375	0.481875	0.5	2.3375
Variance	0.000145	0.00038	0.000266	0.000416	5.33E-05	0.001261
pc48m						
Count	16	16	16	16	16	80
Sum	9.04	8.78	8.71	7.96	7.07	41.56
Average	0.565	0.54875	0.544375	0.4975	0.441875	2.5975
Variance	0.000253	6.5E-05	9.29E-05	0.00118	0.00315	0.004741
Total						
Count	32	32	32	32	32	
Sum	16.3	16.26	15.66	15.67	15.07	
Average	1.01875	1.01625	0.97875	0.979375	0.941875	
Variance	0.000398	0.000445	0.000359	0.001596	0.003203	

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0.10816	1	0.10816	180.2166	1.73E-27	3.904205
Column	0.032209	4	0.008052	13.41659	2.27E-09	2.431968
Interaction	0.169446	4	0.042362	70.583	1.66E-33	2.431968
Within	0.090025	150	0.0006			
Total	0.39984	159				

Table 32b
Data Collection Sheet for Stochastic Magenta Solid Ink Density at Five Different Ink Settings

Solid Ink Density at Standard Ink Settings

1.37	1.35	1.53	1.55
1.37	1.32	1.54	1.54
1.31	1.28	1.57	1.53
1.34	1.31	1.54	1.51

Solid Ink Density at First Ink Increase

1.46	1.46	1.46	1.77
1.47	1.49	1.74	1.76
1.45	1.45	1.75	1.77
1.77	1.46	1.76	1.77

Solid Ink Density at Second Ink Increase

1.81	1.75	1.43	1.4
1.79	1.78	1.42	1.39
1.78	1.79	1.42	1.41
1.78	1.77	1.4	1.41

Solid Ink Density at Third Ink Increase

1.67	1.65	1.67	1.96
1.66	1.68	1.98	1.96
1.67	1.67	1.94	1.96
1.69	1.68	1.96	1.95

Solid Ink Density at Fourth Ink Increase

2.07	2.08	1.95	1.92
2.07	2.07	1.93	1.93
2.08	2.05	1.94	1.92
2.06	2.07	1.95	1.93

Table 32c
Data Collection Sheet for Conventional Magenta Solid Ink Density at Five Different Ink Settings

Solid Ink Density at Standard Ink Settings

1.49	1.49	1.36	1.37
1.51	1.47	1.34	1.33
1.52	1.5	1.41	1.32
1.5	1.49	1.35	1.32

Solid Ink Density at First Ink Increase

1.4	1.42	1.82	1.4
1.39	1.4	1.83	1.81
1.39	1.38	1.81	1.83
1.39	1.81	1.83	1.82

Solid Ink Density at Second Ink Increase

1.82	1.81	1.41	1.42
1.81	1.82	1.41	1.43
1.79	1.77	1.41	1.43
1.81	1.85	1.4	1.43

Soliid Ink Density at Third Ink Increase

2.01	2.03	2.02	1.65
2.01	2.03	1.63	1.63
2.03	2.01	1.63	1.62
2.03	2.05	1.63	1.64

Solid Ink Density at Fourth Ink Increase

2.12	2.14	1.84	1.84
2.12	2.14	1.82	1.83
2.11	2.14	1.82	1.81
2.13	2.15	1.82	1.85

Figure 1.23
FM Magenta
Print Contrast at 48%
at 5 Ink Levels

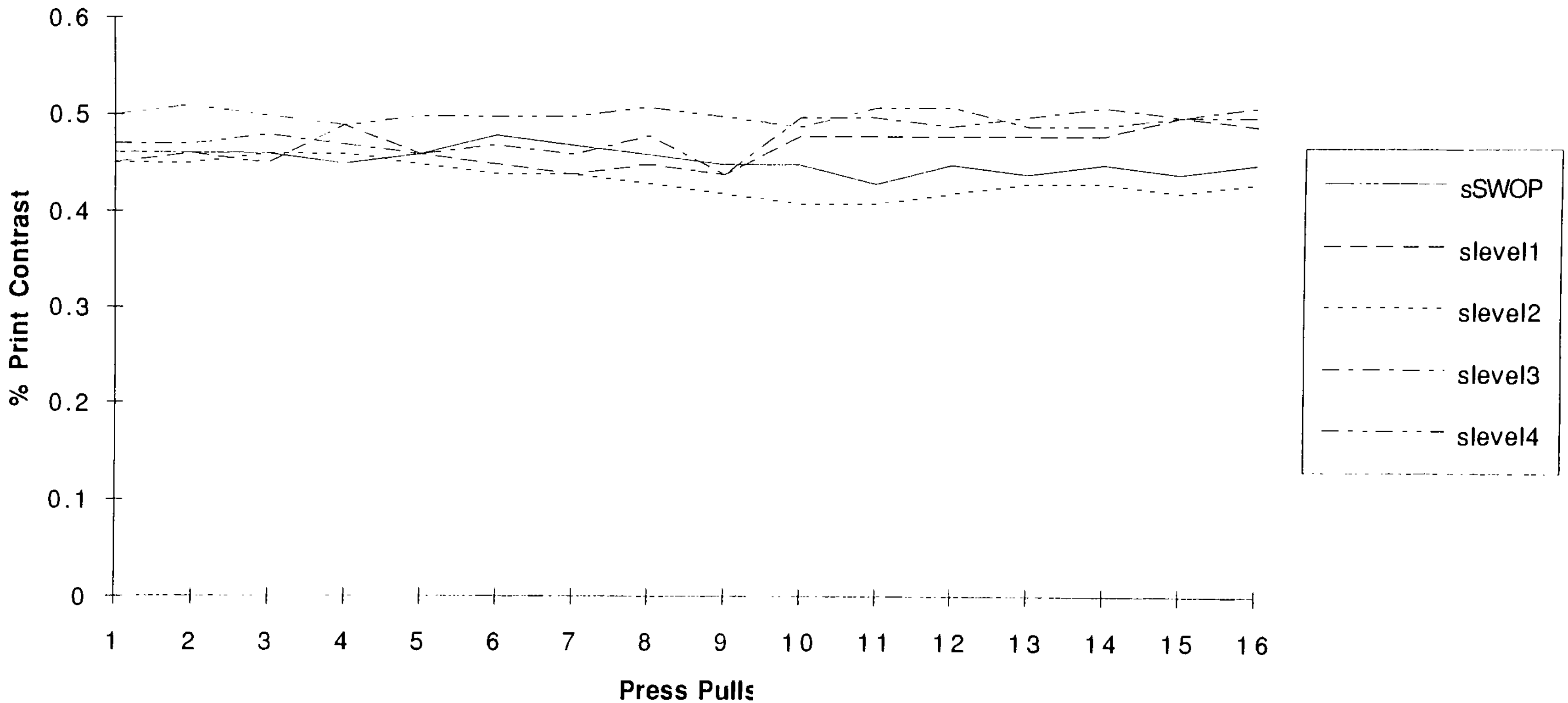


Figure 1.24
150 lpi Magenta
Print Contrast at 48%
at 5 Ink Levels

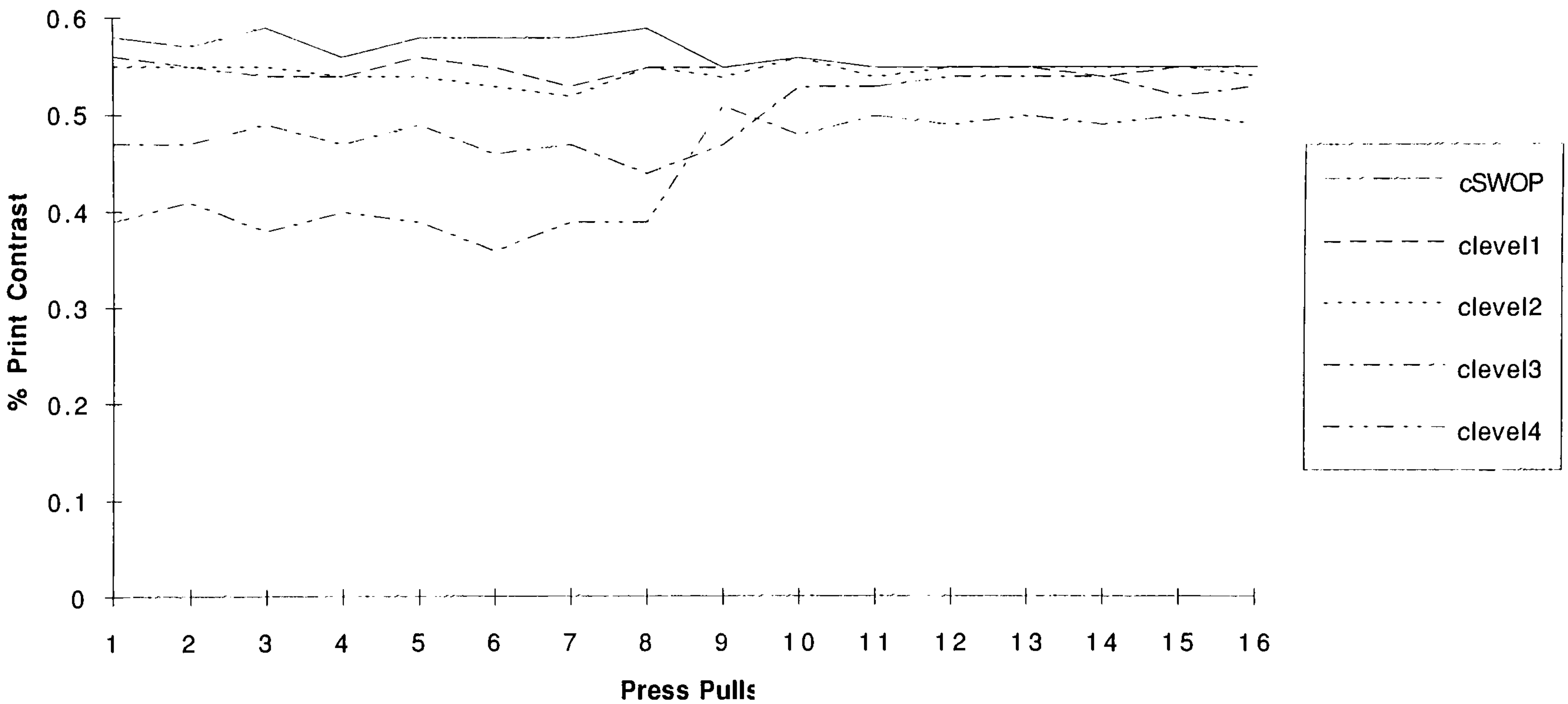


Table 33
Data Collection Sheet
For Stochastic and Conventional Magenta
Print Contast at 70% Tint
Showing Five Different Inking Levels

	standard	level1	level2	level3	level4
ps70m	0.2	0.21	0.22	0.21	0.24
	0.22	0.21	0.22	0.21	0.18
	0.23	0.21	0.21	0.22	0.24
	0.2	0.21	0.22	0.22	0.16
	0.21	0.21	0.21	0.22	0.22
	0.23	0.21	0.23	0.22	0.19
	0.21	0.21	0.2	0.23	0.25
	0.21	0.2	0.22	0.21	0.16
	0.2	0.22	0.2	0.24	0.23
	0.21	0.23	0.21	0.22	0.19
	0.21	0.22	0.2	0.24	0.24
	0.22	0.23	0.22	0.22	0.19
	0.22	0.22	0.2	0.25	0.23
	0.21	0.23	0.23	0.22	0.19
	0.21	0.23	0.22	0.23	0.25
	0.21	0.23	0.23	0.22	0.2
pc70m	0.37	0.3	0.31	0.21	0.12
	0.36	0.3	0.31	0.22	0.15
	0.36	0.3	0.32	0.19	0.11
	0.36	0.32	0.31	0.21	0.12
	0.37	0.3	0.31	0.19	0.12
	0.35	0.32	0.31	0.22	0.16
	0.36	0.3	0.31	0.2	0.13
	0.36	0.32	0.31	0.21	0.14
	0.32	0.32	0.3	0.21	0.12
	0.32	0.32	0.3	0.22	0.16
	0.3	0.32	0.31	0.22	0.12
	0.32	0.32	0.3	0.23	0.15
	0.33	0.31	0.32	0.22	0.12
	0.31	0.32	0.31	0.23	0.16
	0.31	0.32	0.31	0.22	0.12
	0.33	0.32	0.31	0.24	0.16

Table 33a
Statistical Analysis of Data
Two Way ANOVA with Replication

Summary

	standard	*level1*	*level2*	*level3*	*level4*	*Total*
ps70m						
Count	16	16	16	16	16	80
Sum	3.4	3.48	3.44	3.58	3.36	17.26
Average	0.2125	0.2175	0.215	0.22375	0.21	1.07875
Variance	8.67E-05	1E-04	0.00012	0.000132	0.00096	0.001398
pc70m						
Count	16	16	16	16	16	80
Sum	5.43	5.01	4.95	3.44	2.16	20.99
Average	0.339375	0.313125	0.309375	0.215	0.135	1.311875
Variance	0.00058	8.96E-05	3.29E-05	0.000187	0.000347	0.001235
Total						
Count	32	32	32	32	32	
Sum	8.83	8.49	8.39	7.02	5.52	
Average	0.551875	0.530625	0.524375	0.43875	0.345	
Variance	0.000666	0.00019	0.000153	0.000318	0.001307	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0.086956	1	0.086956	330.159	9.91E-40	3.904205
Column	0.236856	4	0.059214	224.828	2.84E-62	2.431968
Interaction	0.231841	4	0.05796	220.0676	1.12E-61	2.431968
Within	0.039506	150	0.000263			
Total	0.595159	159				

Table 33b
Data Collection Sheet for Stochastic Magenta Solid Ink Density at Five Different Levels

Solid Ink Density at Standard Ink Settings

1.27	1.36	1.44	1.43
1.33	1.34	1.41	1.42
1.31	1.32	1.44	1.42
1.3	1.33	1.41	1.45

Solid Ink Density at First Ink Increase

1.22	1.22	1.7	1.68
1.23	1.24	1.69	1.69
1.23	1.25	1.71	1.71
1.24	1.24	1.7	1.69

Solid Ink Density at Second Ink Increase

1.2	1.18	1.18	1.17
1.25	1.73	1.74	1.73
1.17	1.19	1.18	1.21
1.71	1.74	1.75	1.75

Solid Ink Density at Third Ink Increase

1.44	1.36	1.38	1.37
1.91	1.91	1.92	1.92
1.36	1.36	1.35	1.35
1.92	1.89	1.91	1.93

Solid Ink Density at Fourth Ink Increase

1.55	1.55	1.54	1.56
2	2.02	2.03	2.04
1.56	1.56	1.58	1.57
1.91	1.95	2.03	2.04

Table 33c
Data Collection Sheet for
Copnventional Magenta Solid Ink Density
at Five Different Levels

Solid Ink Density at Standard Ink Settings

1.35	1.3	1.31	1.298
1.45	1.41	1.29	1.3
1.46	1.43	1.27	1.3
1.33	1.31	1.3	1.28

Solid Ink Density at First Ink Increase

1.47	1.46	1.51	1.52
1.47	1.45	1.52	1.54
1.48	1.49	1.54	1.53
1.48	1.46	1.53	1.52

Solid Ink Density at Second Ink Increase

1.41	1.39	1.41	1.41
1.56	1.56	1.55	1.55
1.41	1.41	1.41	1.41
1.55	1.57	1.55	1.57

Solid Ink Density at Third Ink Increase

1.64	1.65	1.65	1.65
1.78	1.78	1.78	1.77
1.63	1.63	1.63	1.64
1.78	1.77	1.76	1.78

Solid Ink Density at Fourth Ink Increase

1.87	1.87	1.87	1.9
1.92	1.92	1.92	1.93
1.88	1.89	1.91	1.9
1.87	1.92	1.94	1.93

Figure 1.25
FM Magenta
Print Contrast at 70%
at 5 Ink Levels

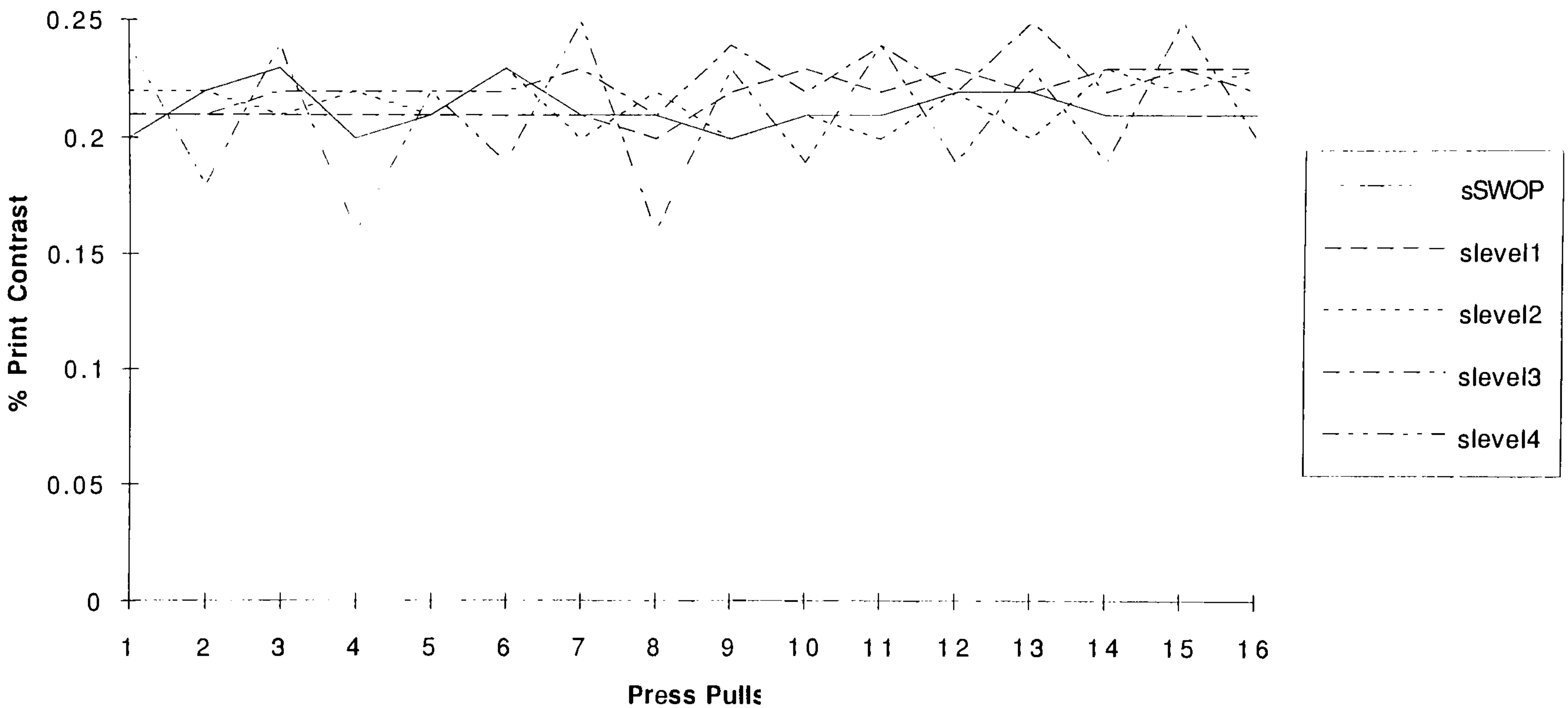
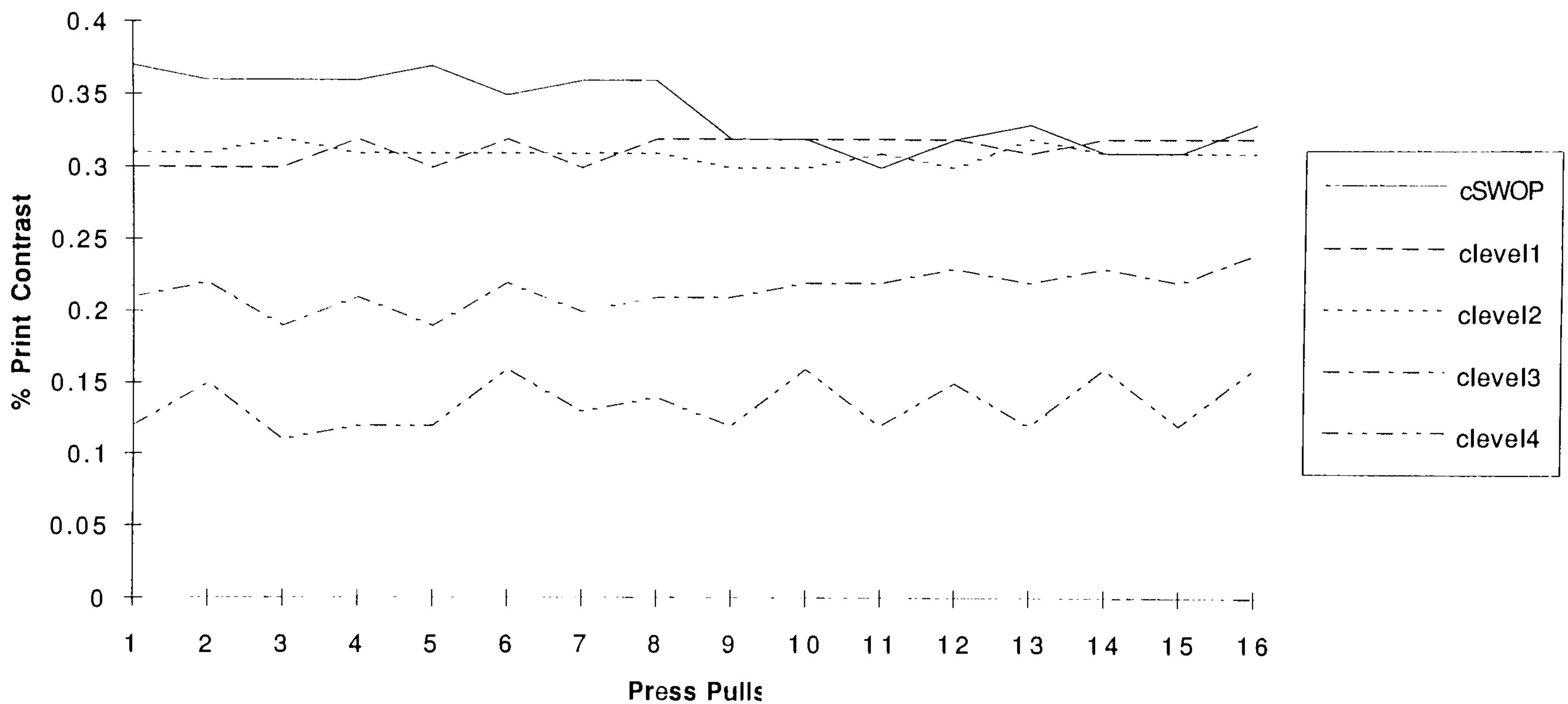


Figure 1.26
150 lpi Magenta
Print Contrast at 70%
at 5 Ink Levels



Appendix E

Tone Reproduction Curves for
FM Screen and 150 lpi Screen

Tone Reproduction curve FM screen

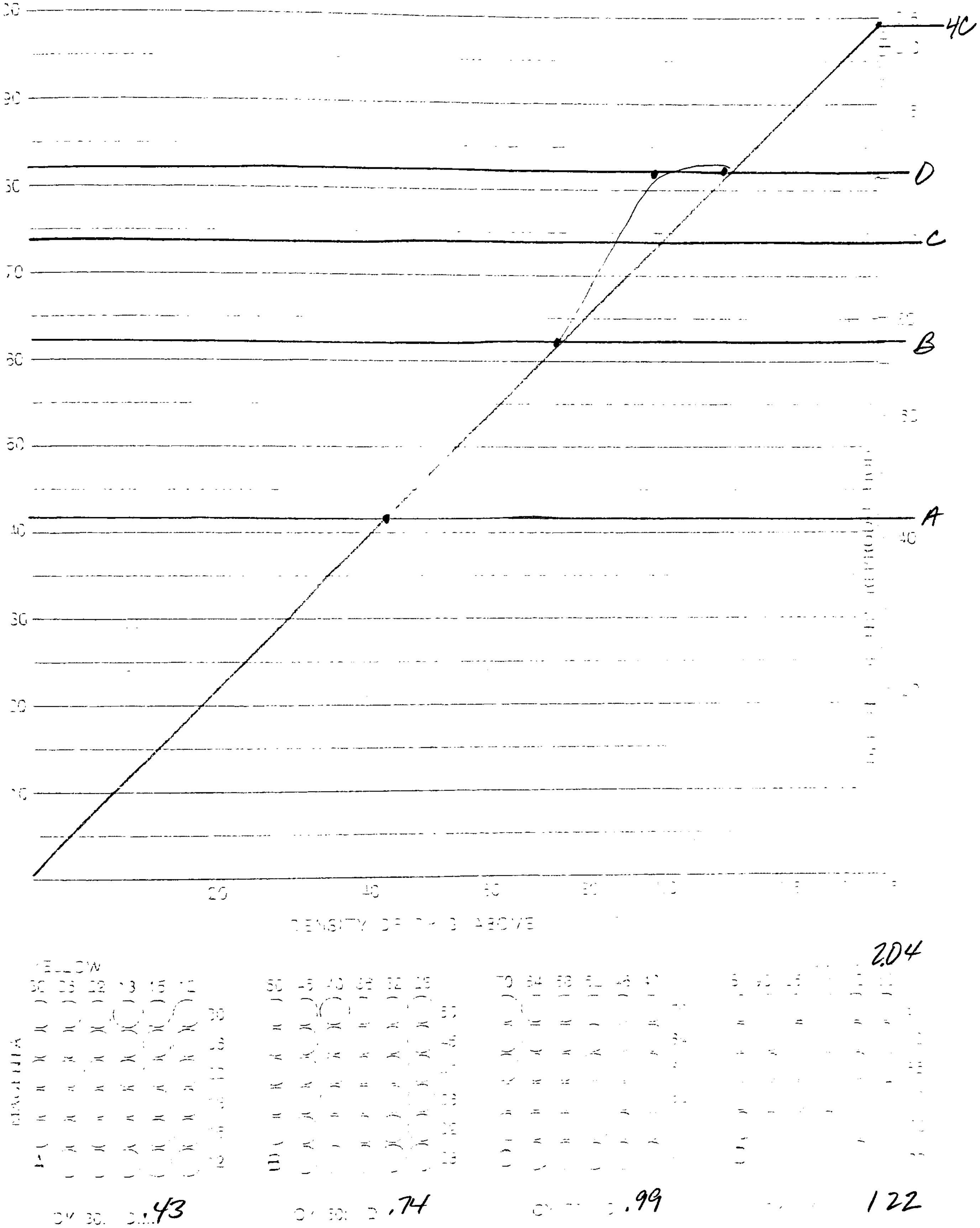


Figure 1.27

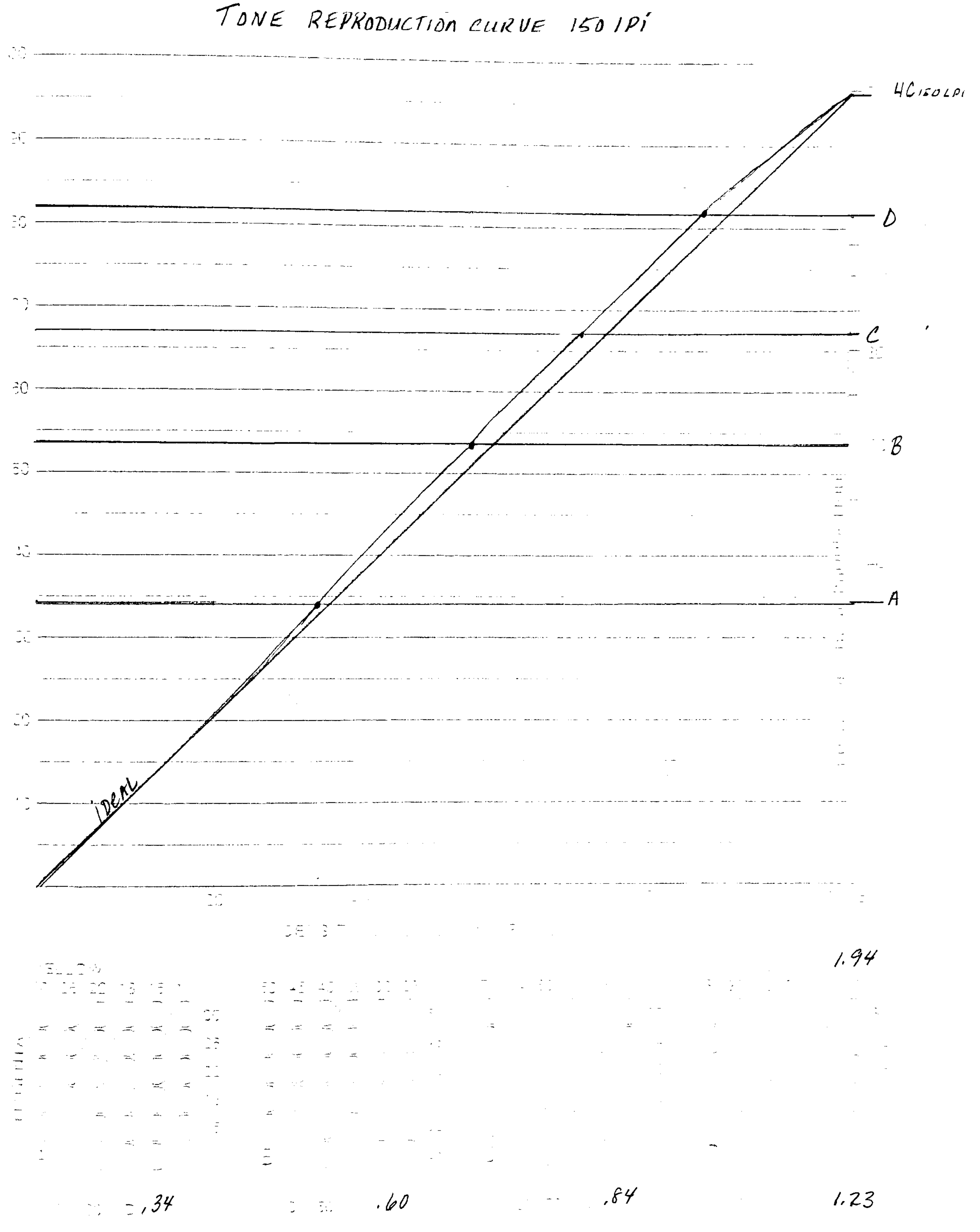

TONE REPRODUCTION CURVE 150 LPI
4C 150 LPI
D
C
B
A
IDEAL
1.94
.34
.60
.84
1.23

Figure 1.28