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Analysis of color variation during four-color offset lithographic press runs by monitoring changes in three-filter density values of overprint tints

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ANALYSIS OF COLOR VARIATION DURING FOUR-COLOR OFFSET LITHOGRAPHIC PRESS RUNS BY MONITORING CHANGES IN THREE-FILTER DENSITY VALUES OF OVERPRINT TINTS

by

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Certificate of Approval -- Master's Thesis

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

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With a major in Printing Technology
has been approved by the Thesis Committee as satisfactory
for the thesis requirement for the Master of Science
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ABSTRACT

A densitometric method of monitoring color variation during four-color offset lithographic press runs is proposed. Once an 'OK' press sheet has been approved for the run, a standard color reference is established with which successive sheet pulls can be compared. In order to develop an accurate and repeatable system for monitoring and controlling color variation, densitometric analysis of three color overprinted tints can be utilized. In relation to the OK sheet, changes in the three-filter density readings measured at specific points across successive press sheets, indicate the visual change in color hue and strength that occurs during the press run. This work suggests that offset printers could use the following color control technique: zero the densitometer on a seventy percent overprint control point or dark neutral image area of the OK sheet and compare the difference in density of the same point of any sample sheet. The difference will indicate the change in the amount of red, green and blue light being reflected from that point in the sample relative to the OK sheet and suggest the corrective action necessary to control color variability during the press run.

CHAPTER I

INTRODUCTION

The goal of achieving commercially successful color reproduction in offset lithography revolves around meeting the quality expectations defined by the customer while achieving productivity goals set by the printer. In order to maintain product consistency, the printer must be able to provide the print buyer with a tiered framework of print quality specifications and be able to produce the color job within the tolerances defined by the customer.

In commercial and publication printing markets, successful communication of acceptable levels of print quality are based on setting tolerances of acceptable color variation. [1]

Areas of color reproduction requiring a high degree of color consistency such as packaging or trademark color printing, make use of color tolerance charts such as Allen charts. For the most part, these systems of color control rely on visual reference to light, dark and target proofs chosen by the customer.

The most widely used method of color control in four-color printing, is based upon visual comparison of the sample press sheet to a specific press sheet (OK) or proof that has been approved by the customer. Printers and print buyers rely primarily on visual comparison of overprint color hues such as reds, greens and blues to determine whether the sample sheet is acceptable or not.[2]

Although the human eye is very sensitive to variations in color hue when

used as a comparison device, it cannot assign values to color differences. There are other disadvantages to reliance on visual judgement such as, visual fatigue on the part of the viewer and the fact that some of the people who are responsible for making color decisions and judgements, suffer various forms of color vision deficiencies.[3] Thus, when judgements are made as to whether or not a color falls within specified tolerances, there may be disagreements between printer and print buyer due to the subjective nature of the analysis. Printers and customers both agree however, that, the most important aspect of controlling color variation on press lies in maintaining consistent color hues throughout the job.

It is important to make a distinction between color tolerances and color variability. Color tolerances are the limits within which a color may be printed and still be deemed acceptable. Color variability on the other hand, is a function of press process capability. The press process encompasses the specific press, blankets and plates, the press crew and the ink and paper utilized in printing the job. Color variability can be expressed as a statistical variance in product color uniformity due to the press process itself. In terms of optimum color control, color variability limits (process variability) should be well within the color tolerance limits specified by the customer; otherwise, a portion of the printed output will be out of tolerance and deemed defective.

Much applied research has been directed toward minimizing color variation in four-color offset lithographic presswork. Color control bars, test forms, process capability studies and sophisticated quality control methods have been developed over the years, yet color variation on press continues to be a significant cause of waste and customer rejected jobs.

Maintaining color consistency during an offset lithographic press run is a difficult job due to a set of interactive variables that are constantly changing. From the time the press starts running, ink characteristics such as tack, water pick-up and viscosity begin to change.[4] The printing plates begin wearing and even the paper may exhibit variation in characteristics that were presumed to be uniform. Each press unit on a four-color press will experience various amounts of change in the above mentioned variables. The effect of these variables on the factors that cause color variation (dot gain, trapping and ink densities) will thus be different for each color.

In order to cope with color variation, the press operators compensate for changing variables by adjusting the ink film thickness. However, it is not always a simple matter to "visually balance" the inking to achieve color hues consistent with the hues in the OK sheet. Often a trial and error method is relied upon in adjusting ink flow to match color hues. An excess reddishness in the image, for example, may be compensated for by reducing the magenta or increasing the cyan ink. This approach of visually balancing the inks to maintain consistent hues during the press run is only marginally adequate. The problem is that, although color hues remain relatively consistent, color strength fluctuations will occur as the ink densities are adjusted to maintain color balance. It is, by no means, always clear to the press operators, which of the inks should be increased or decreased, when a change is necessary to maintain color hues.

The difficulties in maintaining consistent color quality require that a more quantitative approach be utilized in four color offset lithography. The need to define color tolerance limits, direction and magnitude of color variation, and the effects of change in inking has led to the need for instrumental measurement of

color. Pressroom color densitometry would appear to be an ideal solution; providing efficient and accurate measurement of ink density changes and thus color variation.

FOOTNOTES FOR CHAPTER I

1. Miles Southworth, "Controlling Color on a Printing Press," The Quality Control Scanner, (April, 1983), p. 1.

2. Ibid., p. 2.

3. Miles Southworth, "Standard Viewing Conditions," The Quality Control Scanner, (April, 1982), p. 3.

4. Miles Southworth, "Controlling Color on a Printing Press," The Quality Control Scanner, (April, 1983), p. 3.

CHAPTER II

BACKGROUND THEORY

Web offset press speeds have been accelerating through the years, and today speeds of 900 to 1,400 feet per minute are common. Visual comparision of sample sheets to O.K. sheets or proofs, combined with trial and error adjustments of inking at such rapid press speeds is a woefully inadequate method of controlling color on a web offset press. Color variation of web offset output is a major problem that is made more acute as customer quality expectations continue to increase because of competing forms of color media. In order to overcome losses due to waste and customer rejection attributable to color variation, many printers have turned to the use of densitometers. There has been a problem however, in successfully monitoring hue changes using reflection densitometry in the pressroom. This has not been due to instrument measurement inaccuracies; rather the problem lies in how the measurements are taken.

It has been standard practice to measure densities of the solid ink patches in control bars and to maintain a narrow range of solid ink densities (plus or minus point zero five) during the press run. This method of control was based on the asssumption that if the densities of the solid patches remained consistent, the hues in the halftone prints would also remain consistent.

Maintaining solid ink densities throughout the press run does not ensure

color consistency, because of the effects that dot gain and trapping variation have on the halftone reproduction.

> "An increase in the halftone dot size of three percent from 65 to 68 percent has the same effect as an increase in ink film thickness, requiring a solid density increase of 0.8, from 1.3 to 2.10." [1]

There has been a tendency for four-color press operators to ignore density measurements in control bars and rely on visual analysis to monitor changes in hues of overprint colors. Although the human eye is very sensitive to changes in hue, and provides a better indicator of hue change than solid ink density analysis; reliance on visual judgement does have the disadvantages previously mentioned.

Other attempts to control color during lithographic press runs have made use of densitomtric analysis and multiple measurements of various control patch tints and solids. Certain control patches are designed for visual analysis, while others are to be measured with a densitometer. The drawback however, is that multiple measurements must be made followed by calculations of dot gain, trapping, hue error, grayness, efficiency etc. Even if a press operator is knowlegeable enough to perform these calculations, the amount of time required severely handicaps this control method. It is much quicker and easier for the press operators to rely on visual analysis and this is the method utilized by the majority of offset pressmen in the industry.[2]

There is a need for a color control method that can be performed accurately and efficiently via densitometry throughout the press run. This would enable the printer to replace subjective analysis based on the human eye with a more

quantitative measurement of color variation. When the red, green and blue content of the three process inks is monitored, point by point, across the press sheet, maintaining color consistency in the halftone may be possible by maintaining the three filter density values of those points within a narrow range during the run.

FOOTNOTES FOR CHAPTER II

1. Clive Goodacre, "How Brunner Set the Standard," Printing World (reprint), DuPont de Nemours (Deutschland), GmbH, 1981.

2. Miles Southworth, "Tone and Color Analysis" (Lecture Notes, Rochester Institute of Technology, 1984).

CHAPTER III

REVIEW of the LITERATURE

A significant amount of research has been brought to bear on the problem of controlling color variation during four-color offset lithographic press runs. The insistence on the part of many printers, that solid ink densities (SID) must be maintained within a tolerance of plus or minus point zero five to control color variation, has been challenged in various papers. Irving Pobboravsky states that:

> "Although solid ink density is frequently monitored as a control of the printing process, it is possible that the tonal characteristics of a printed image can change even if solid ink density remains constant." [1]

Daniel Lake, in a master's thesis undertaken at the Rochester Institute of Technology (RIT, 1978), determined that variation in color bar solid ink densities did not reflect the direction or magnitude of density variation in halftone overprints. Lake states:

> "It was determined through correlation analysis that solid ink density aids in holding the screened process color densities at approximate inking levels. However, ... the majority of the variation of the screened process colors results from press variables other than solid ink density." [2]

Miles Southworth notes that press operators, comparing color of pulled

sample sheets against an approved OK, are able to maintain consistent hues during the press run by actually varying the solid ink densities.[3] Both printers and customers use overprints hues to compare color, thus it is the overprint hues which provide the best means of controlling color on press.[4] Any change in printing variables such as dot gain or trapping will affect the overprint colors and compensation for such color variation is made by changing ink densities. Thus, hue consistency is maintained by visually comparing the overprint areas and adjusting the appropriate ink settings to compensate for changes in dot gain and/or trapping.

The use of visual comparison of sample sheets to OK sheets or proofs as a method of color control, works, given ideal conditions. However, due to the extremely complex nature of human color perception and the variability introduced by differences in viewing conditions and image color and layout on the press sheet, a number of workers have attempted to make use of instrumentation in monitoring color variation on press.

Chikashi Hashimoto, in his master's thesis (RIT, 1979), investigated the use of densitometry as a control device in monitoring hue consistency of "critical colors" during four-color lithographic press runs. It was hypothesized that a densitometer, which automatically computes hue error and grayness, could be used to measure critical colors and maintain their computed hue consistency. His conclusions showed that there were problems in monitoring hue error and grayness because the calculated values were not always reliable indicators of visual hue consistency. The density values were then used to calculate saturation and hue for plotting on color hexagons, but again there were problems with reliability because the same numeric values could produce

visually different colors.

> "It was suggested that monitoring the three filter density readings of critical colors would be a more reliable control method to maintain the hue consistency of critical colors." [5]

Justification for monitoring three-filter density values in specific areas of the printed sheet is found in the fact that the total red, green and blue content of the process inks is being sampled at that point. When these density values are compared to the readings taken from the same point on the OK sheet, relative changes in the reflectance of red, green and blue light can be monitored during the press run. Miles Southworth notes that in areas of color reproduction where correct color is critical such as trademark colors, pressmen could benefit by using one of the recently developed densitometers that reads all three process color densities at once. Since the three color densities are displayed together, the press operators need only compare densities from the sample press sheet to those on the OK sheet. Any change in the three filter densities during the press run, for whatever reason, would indicate which of the process inks should be adjusted to maintain the correct overprint hue.[6]

During the press run, some of the variation in density values may correlate to process variability (color variability) and thus represents "noise" in the system. At a certain level of density variability however, a change in color appearance will require corrective action to be taken (press adjustment) to ensure that the product remains within specified color tolerances. Robert Loekle, in his 1972 TAGA paper on the use of control charts for printing, recommends charting a response variable that represents a visually significant feature in the process color reproduction.

> "Ink film thickness, and its approximation by color density, is a variable under the pressman's control. The strength to which inks are run largely determines the hue and saturation of the secondary colors. Specifically constructed color bars or targets are not necessary; in some instances the work itself can provide areas for measurement." [7]

The chart provides limits within which the press adjustments should be left alone. If there is a tendency to make adjustments for insignificant changes in densities, this will lead to overcontrol and actually increase variation rather than reduce it.[8]

There is evidence in the literature to indicate that a sensitive control point exists, from which density readings could be taken and charted as a response variable for monitoring color variation.

Franz Sigg, in a TAGA paper (1970) titled, "A New Densitometric Quality Control System for Offset Printing," developed a model of how dot gain affects print density. Using the Yule-Nielsen equation to convert dot areas to print density, Sigg generated theoretical curves indicating that, dot gain caused the greatest change in print density in the three-quarter tones of a halftone image. Figure 1.[9] shows the theoretical curves and the curves he plotted from experimental data leading to the conclusion that:

> "The dot area range between 65 and 85 percent is most sensitive to changes in dot gain, and should therefore be used for control purposes."[10]

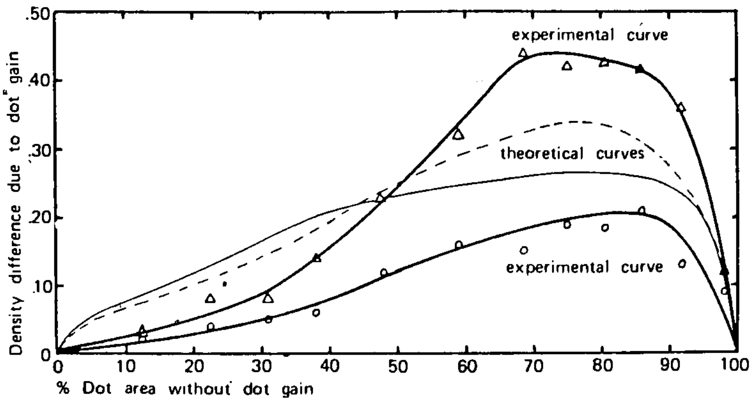


Figure 1.
Density Difference due to Dot Gain

Felix Brunner developed a comprehensive quality control system (System Brunner) that emphasizes measurement and control of dot gain.[11] Brunner states:

> "The main cause of colour variation in multicolour offset printing is uncontrolled halftone dot growth or dot enlargement." [12]

Miles Southworth, about dot gain, writes:

> "Dot gain that varies throughout the press run can severely change color. A pressman prints process color to produce certain overprint colors made up of differing dot sizes of cyan, magenta and yellow. If the dot size of one printer changes in the middletones (such as the magenta 50 percent dot changing to a 60 percent dot), there can be a significant color shift." [13]

Other evidence in the literature indicates that it is important to monitor hue change in three-color overprints of near neutral colors.[14] Glenn Davidson discussed a method of controlling a production press by printing an overprint screen tint of three process colors at the TAGA Color Committee meeting in May 1975.[15] The dot percentages of the three colors were adjusted to achieve neutral gray. Press operators could visually compare the neutral gray tint to an adjacent gray tint of equal visual density produced with black ink.

> "A visual evaluation of the two tints gives the user a good indication of what is happening in the printing by any hue change or visual density change in the overprint tint." 16

Considering the information put forth by these workers, it is plausible that color variation could be monitored by taking three filter density readings from 70 percent overprinted tints during press runs. Using the OK press sheet as a standard, any change in color during the run found in the sample sheet pulls, should also be indicated by a change in three-filter densities.

FOOTNOTES FOR CHAPTER III

1. Milton Pearson, Irving Pobboravsky and Chester Daniels, "Instrumentation for the Measurement of Slur and Fill in on a Lithographic Web Press," TAGA Proceedings, (1979), p. 164.

2. Daniel Lake, "An Investigation into the Interactions of Certain Visual Attributes of a Four-Color Reproduction Produced on a Sheet-Fed Offset Lithographic Printing Press," Gradute Thesis for the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology, (1978), p. 34.

3. Miles Southworth, "Controlling Color on a Printing Press," The Quality Control Scanner, (April, 1983), p. 3.

4. Ibid., p. 1.

5. Chikashi Hashimoto, "Control of a Four-Color Lithographic Press by Monitoring the Hue Consistency of the Reproduction with a Densitometer," Graduate Thesis for the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology, (1979), p. 2.

6. Miles Southworth, "Controlling Color on a Printing Press," The Quality Control Scanner, (April, 1983), p. 2.

7. Robert Loekle, "Control Charts as an Aid to Uniform Quality in Multicolor Presswork," TAGA Proceedings, 1972, p. 6.

8. Ibid., p. 3.

9. Franz Sigg, "A New Densitometric Quality Control System for Offset Printing," TAGA Proceedings, 1970, p. 197-213.

10. Ibid., p. 212.

11. Miles Southworth, "Controlling Color on a Printing Press," The Quality Control Scanner, (April, 1983), p. 4.

12. Felix Brunner, System Brunner, (Locarno, Switzwerland).

13. Miles Southworth, "Dot Gain: Causes and Cures," The Quality Control Scanner, (Sept., 1982), p. 3.

14. John Gaston III, "An Investigation of Solid Ink Density Variation as Determined by Acceptability of Overprints in Process Color Printing," Graduate Thesis for the School of Printing in the College of Graphic Arts and Photography of the Rochester School of Technology, (1979), p. 2.

15. Miles Southworth. "Color Committee," TAGA Proceedings, (1975), p. 380.

16. Ibid., p. 380.

CHAPTER IV

INTRODUCTION TO HYPOTHESES

The purpose of this study is to establish whether a densitometric control method can be used to monitor color strength and hue consistency. It is proposed that, if three-filter densities (taken anywhere in the sheet) can be maintained within specified tolerances during a four color lithographic press run, then color variation may be held within acceptable limits. An accurate and efficient way to monitor color variation requires that certain areas be specified as critical for taking three-filter density readings. Any change in color hue and/or strength of an area on the sample press sheet relative to the same area in the OK press sheet should correlate to a change in three-filter densities values. It is the comparision of an (approved) OK press sheet with a sample press sheet, point by point, that enables the reflection densitometer, equipped with color filters, to perform analysis of changes in color hue and strength.

The modern reflection densitometer measures light that would normally be reflected from a surface, with viewing geometry similar to the human eye.[1] The densitometer does not measure color as seen by the human eye, though it can measure portions of the visible spectrum using red, green and blue filters. Press room quality control is primarily done with reflection densitometers using wide band Wratten gelatin filters, No. 25 red, No. 58 green, No. 47 blue and No.106 visual.

> "While narrowband filters increase the instrument's sensitivity to small variations in density, they are less like the human eye than the wideband filters." [2]

By measuring the amount of red, green and blue light the user can determine the relative (total) amount of a pigment on a surface. It is assumed that the density is an indication of the amount of a certain color light being transmitted, reflected or absorbed by the pigments.

> "The densitometer thereby becomes a process control tool for making certain the total amount of each process ink remains constant throughout a press run." [3]

Although densitometer readings with conventional filters are not suitable for accurate specifications of process ink color [4] (other instruments must be used), densitometry can be used to indicate relative changes in reflectance of red, green and blue during a press run. This assumes that the ink pigment compositions remain constant during the run and only the amount of pigments that are applied to the surface changes. Any change in the three-filter density values taken from an area of the press sheet during the run should indicate the amount of compensation needed in inking to maintain the same red, green and blue reflectance in that area throughout the run.

HYPOTHESES

1. During a four color offset lithographic press run, a change in the three filter densities taken from a specific overprinted tint in sample press sheets will correlate positively to a color hue and strength change of that tint as determined visually.

2. Three filter density values can be established as limits for acceptable color variation in three color overprints when determined visually by a panel of experienced color observers.

3. A 70 percent overprinted tint of cyan, magenta and yellow is a sensitive indicator of color hue and color strength consistency in the printed halftone image lying in line with it on the press sheet, when monitored with three-filter densitometer density readings taken during a four color offset lithographic press run.

FOOTNOTES FOR CHAPTER IV

1. Miles Southworth. "Densitometry," The Quality Control Scanner, (January, 1982), p.1.

2. Ibid., p.2.

3. Ibid., p.2.

4. M.L. Pearsen and J.A.C. Yule. "Conversion of a Densitometer to a Colorimeter," TAGA Proceedings, (1970), p.390.

CHAPTER V
METHODOLOGY

In order to make use of densitometric control of color variation during an offset lithographic press run, two levels of testing were required. The first part of this experimental procedure tested the relationship between, relative change in three-filter density values and a change in color balance of the printed image that can be observed visually in a sequence of press sheet samples taken from a press run. The second part of the experimental procedure required the judgement of a panel of experienced color observers to test whether visual color tolerance limits could be defined for acceptable color variation of the printed image from the sample press sheets. Both of these tests were performed by analysis of sample press sheets after the completion of a single press run. The four-color Goss MGD Commercial 38 inch web offset press located at the Rochester Institute of Technology, was used for generating all the press sheet samples needed for data collection for this thesis in 1984.

Preparation

The 70 percent screen tints and color separations were made on a Hell DC 300 B color scanner using Kodak ES 2587 scanner film (rapid access). This scanner and all other equipment needed for film preparation was also located at the Rochester Institute of Technology. The 70 percent overprint tint bar films were made at a screen ruling of 150 lines per inch at the following screen

angles: Cyan +18°, Magenta -18° and Yellow 0°.

The color separations were scanned at 150 lines per inch from a Kodak Ektachrome transparency (8 x 10). The screen angles used were as follows: Cyan +18°, Magenta -18°, Yellow 0° and Black 45°.

Three sets of color separations were made of the same image with different magnifications and slightly different aim points for highlight, middletone and shadow. Only the image representing the best printed reproduction was used for analysis however. Cromalin proofs were made to ensure acceptable separation positives have been produced on the scanner. The positive separation films were then contacted (dot for dot) using 3-M LOC-4 contacting film.

Both stripping and platemaking operations were performed by the Technical and Education Center (T&E) staff.

Press Run Phase I

All press work was performed by T&E center press men and no special instructions were given to the press crew during the initial stage of the run other than performing normal procedures for printing high quality four-color work. It was the author's responsibility to approve the "OK" press sheet for the run. This OK sheet served as the standard for comparison of successive sample sheets drawn throughout the run by the pressmen. The pressmen were responsible for controlling the press and maintaining color consistency and register in the printed sheets throughout the run. They drew samples for comparison to the OK sheet at their own discretion and made the adjustments necessary to ensure that the press was operating in a stable running condition.

Press Run Phase II

During this phase of the press run, the inking levels were manipulated by the pressmen in order to achieve variations in color balance on the press sheets. The goal of this phase of press work is to obtain a sample population of press sheets that have shifted in color from the color balance previously determined acceptable.

It is known that color variation occurs during offset lithographic press runs because of the effect that changes in printing variables such as dot gain and trapping have on the printed sheet. In order to maintain color balance during the run, the press operators compensate for changes in printing variables by making adjustments to the inking levels.

For this phase of the press run the ink film thicknesses were manipulated, not to compensate for printing variables, but for the sole purpose of causing color variation. The pressmen were instructed to adjust the ink ductor roller sweep controls (ball settings) on the four press units in a certain sequence of combinations. The sequence of changes were specified by the author in order to ensure that the following shifts in color would result in the press sheets:

1. toward cyan
2. toward magenta
3. toward yellow
4. toward red
5. toward green
6. toward blue

Preliminary data secured by this author showed the time necessary for

density to stabilize after a sweep adjustment was made on RIT's Goss MGD web press.It was determined that after a three revolution sweep adjustment on the magenta unit that it took two minutes for density to stabilize in the press sheets sampled.

One hundred percent sampling for this phase of the press run was performed providing a population from which ranked samples were chosen for comparison testing later. In all cases a sample size of twenty press sheets was specified and every second press sheet was analyzed.

Data Retrieval

An X-RITE 348 reflection densitometer was utilized to measure and record density values. Visual (No. 106), red (No. 25), green (No. 58) and blue (No. 47) filter density measurements of specific overprinted tints were made and the values entered into a spreadsheet program for analysis later. Uniformity of the press sheet area chosen for analysis was a primary consideration for establishing continuity of successive measurements taken from specific areas between press sheets. In order to eliminate variability in the placement of the densitometer head with respect to the measuring points effort was made to hold the densitometer at a consistent angle and a registered overlay mask was used. One quarter inch punched holes in the vinyl overlay mask provided windows through which readings were taken thus establishing specific densitometric control points that could be analyzed from sample to sample.The densitometer was calibrated for all four filters on the clean check plaque supplied with the instrument. Before any density values were taken, the densitometer was zeroed

on the press sheet paper.

The Experienced Color Observer

For the purpose of this research, the definition of an experienced color observer was: an individual who is responsible for determining the allowable variation in color of offset lithographic press sheets or pre-press color proofs on a day to day basis. Individuals such as those employed in color quality control work, four-color press operation or as instructors in those areas, fall within the definition of experienced color observers. An attempt was made to secure a balanced population of observers from each of the areas mentioned above.

Paired Comparison Test

The dominant method of controlling color during an offset press run is that of visually comparing specific areas or patches of colors on an OK press sheet to those same patches on a sample sheet. This is essentially a form of paired comparison with which the experienced color observers are quite familiar.

For this research, the two objectives which paired comparison testing has been designed to fulfill are directly related to the first and second hypotheses stated in chapter three. The observers were asked how closely the sample sheet matches the OK sheet (accept or reject) and if the sample differs in color; how did it differ in terms of color strength and hue.

Before testing each individual observer, a check was made to ensure that the viewing conditions met accepted color viewing illumination standards (ANSI).

A standard color viewing booth was used for all subjective testing (5000°K +- 25°). Each observer was tested for defective color vision using the American Optical Company H-R-R Pseudiosochromatic plates. When color deficiencies were detected the test data was eliminated. A specific set of instructions was read to the observers as follows: "You are to compare the sample press sheet image, which I will show you, to the press sheet image that has been specified as the 'OK'. You are to consider these sheets as typical of samples drawn from an 'average' press run. Each sample will be compared to the OK in succession. For each sample, the decision that you are being asked to make is: Do you consider the sample's color to be acceptable or not acceptable for an average press run. If you are undecided about a particular sample, consider it acceptable."

For each acceptance, no further action will be taken. However, if the sample is rejected, then further questions will be asked as follows: "For what reason did you reject the sample? Is a hue shift observable in the sample? Is a color strength difference observable in the sample?" A yes answer to either or both of the last two questions required two further questions to be asked: "Which direction has the hue in the sample shifted from the OK?

1. towards the cyan
2. towards the magenta
3. towards the yellow
4. towards the red
5. towards the green
6. towards the blue

In which direction has the color strength in the sample changed?

1. towards lower strength
2. towards higher strength"

The sample sheets were randomized before each individual observer performed the comparison test. The length of time and positioning of the samples was controlled to remain relatively uniform for each observer. The final part of the test asked each observer to rank a series of five sample sheets that varied in color strength from low to high. Two other sets of five sample sheets that vary in color hue were presented to each color observer who was then asked to rank the samples in an order that varied from one hue (ie blue) to another hue (ie cyan). The rank order chosen by each observer was used for correlation analysis.

Data Analysis

The first part of the paired comparison test established color tolerance levels for acceptable color variation. The values assigned to the limits of acceptance were based upon measured three-filter density differences between the reference standard (OK) and the acceptable sample sheet. Specific overprinted tint areas within the image and points within the 70 percent tint bar were measured for three-filter densities.It was assumed that if the sample sheets presented to the observers differed in sufficiently small increments of density from the OK sheet, then the demarcation between acceptance and rejection could establish tolerance limits precisely defined as density values. The limits of acceptable color variation were defined as that point where seventy percent or

more of the observers accepted the sample. These values were to be used to define the upper and lower control limits for plotting the three filter density values on control charts.

Correlation analysis was used to determine whether there was a relation between visual color strength change and a change in the three-filter densities of the visually ranked samples. Likewise, the correspondence of a change in three-filter density values to a change in color hue as determined visually by the ranking of sample images, was tested by performing correlation analysis. Calculation of correlation coefficients were used to show the degree of similarity between the change in density values of specified areas in the image and points measured in the 70 percent overprint tints controlled by the same ink keys (ie lying in line with one another). It was also expected that the plots of the scatter diagrams for the three-filter densities taken from the specified image areas and points in the 70 percent tint bar will graphically indicate a relationship between changes in the tint bar densities and those measured in the image. These plots of scatter diagrams were also expected to graphically show the relational change of the three filter densities as the color balance changed correlating to the hue shifts observed visually.

CHAPTER 6
EXPERIMENTAL RESULTS

Phase I of the press run was used to establish press operator control over the run, providing stability of process variables and a printed piece that was specified as the OK sheet. No analysis of press sheets from this portion of the run was performed.

Phase II of the press run provided the samples used for densitometric analysis and color viewer response. The sequence of ink adjustments controlling color hue variation during the first half of Phase II (Low Density Series) were as follows:

Period	Inking	Unit	Time	Hue
A.	Decrease	Black	2 minutes	
B.	Decrease	Cyan	4 minutes	Red
C.	Decrease	Yellow	6 minutes	Magenta
D.	Increase	Cyan	8 minutes	Blue
E.	Decrease	Magenta	10 minutes	Cyan
F.	Increase	Yellow	12 minutes	Green
G.	Decrease	Cyan	14 minutes	Yellow
H.	Decrease	Yellow	16 minutes	Neutral

The outcome of the eight inking changes made during this first portion of Phase II, was that an overall reduction of print density resulted. The pressmen were then instructed to balance color at this low density level.

Low Density Series
Hue Correlation

From the Phase II Low Density Series press sheets the experienced observers were asked to rank five samples in ascending order. Samples were selected from period E, which showed a hue shift from blue (end period D) to cyan (end period E).

This hue shift was achieved by reducing the magenta ink density causing the three filter density relationship to change. The relative change of the red, green and blue filter densities becomes apparent when analyzing a hue shift in a series of samples graphically, When the variables; three filter densities and rank order chosen by observers, are plotted in scatter diagrams, the relationship between variables can be assessed.

When the observers ranked the five color hue samples, there was some disagreement between the rank orders chosen. Rank correlation analysis was used to test the hypothesis of independence of the judges. Since the calculated coefficient of rank correlation (rs =.90) was greater than the table value (.87), the hypothesis of independence of judges is rejected (Appendix A). The conclusion therefore is that there was evidence of agreement between judges in the Low Density Series rank order of hue used for analysis.[1]

It can be assumed that the observers were making an overall image comparison when asked to establish a rank order. Overprint tint areas in the printed image, which the author specified as critical were chosen for three filter density analysis and it was these series of values that were correlated to the rank order chosen by the observers.

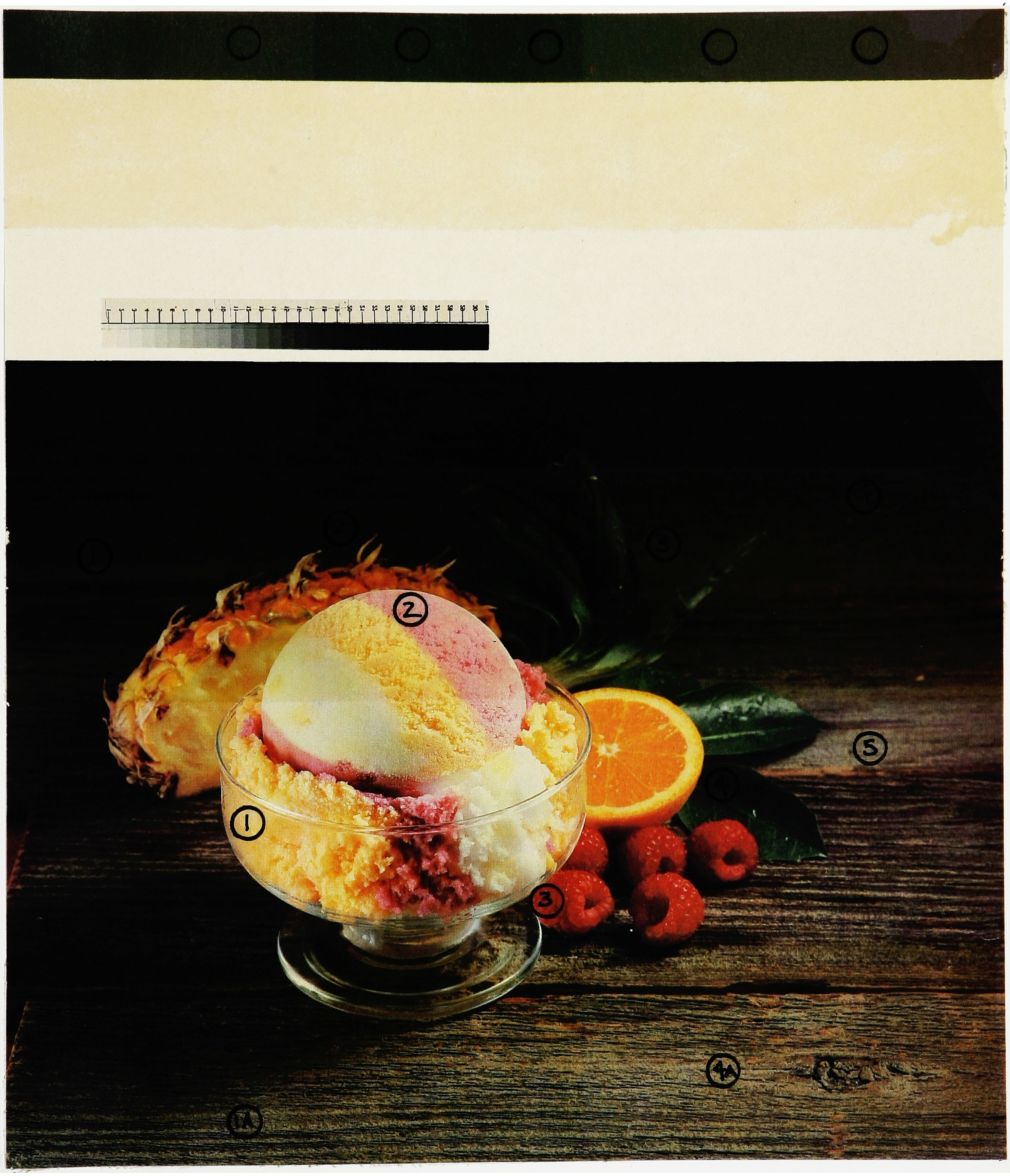
Areas in the printed image (figure 2) were specified as follows:

1. Dark Neutrals - Shadow areas of the gray weathered barnboard (Spots 1-4).

2. Light Neutrals - Midtone areas of the gray weathered barnboard (Spot 1a, 4a, and 5).

2a. Critical Colors - Light pastel colors in the sherbet and fruit colors (Spot 1 orange sherbet, Spot 2 raspberry sherbet, Spot 3 red raspberry, Spot 4 shadow area of green leaf).

Areas in the seventy percent overprint tint bar vertically in line with the image areas were also analyzed and correlated to the rank order chosen by the observers. The plots of scatter diagrams for this low density hue series indicate the change in three filter density relationship as the hue changes from that of blue to that of cyan. The scatter diagrams in figures 3 and 4 show the change in three filter density relationship of the dark neutral image mean spots 1-4 and the corresponding seventy percent mean of spots 1-4. The drop in green filter density throughout the five samples is apparent and corresponds to the expectation of a density change as the hue shifts from blue to that of cyan. The first ranked sample (No.1) shows the dominant density to be that of magenta. The data shows that by rank sample No.3, the decrease in green filter density causes the red filter density to become the dominant of the three filter densities in both the dark neutral spots and the corresponding seventy percent overprint tint spots. Some variation is noticeable in the three filter density relationships when comparing the scatter diagrams in figures 5 and 6 of the dark neutral



Press sheet
Figure 2

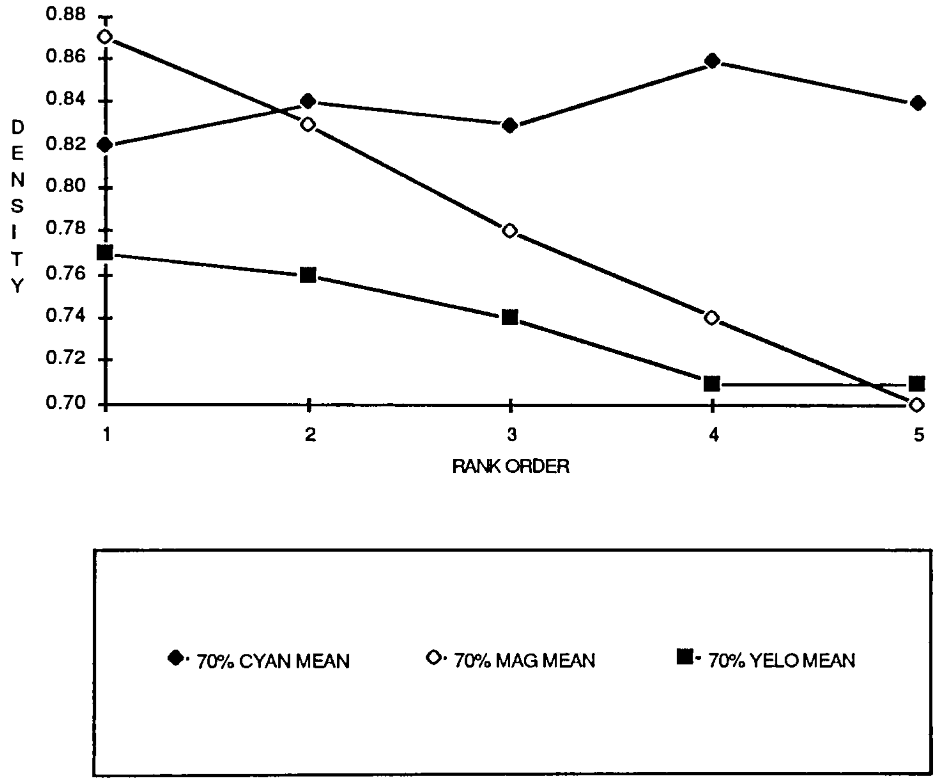


Figure 3
Low Density
Hue correlation of dark neutral
70% Mean

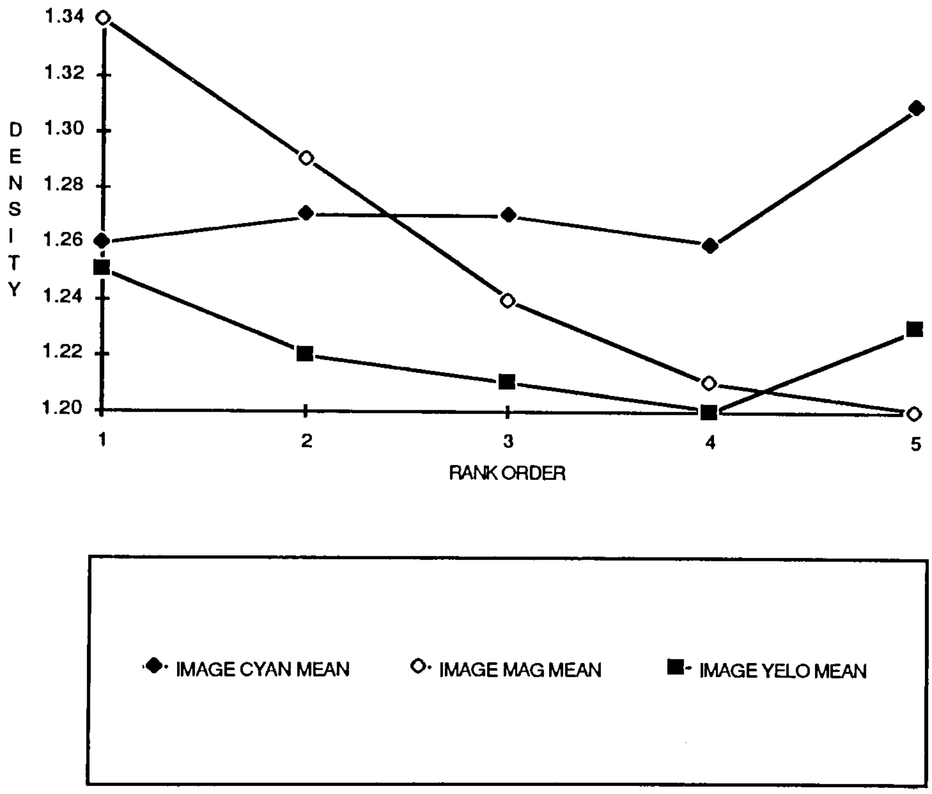


Figure 4
Low Density
Hue correlation of dark neutral
image Mean

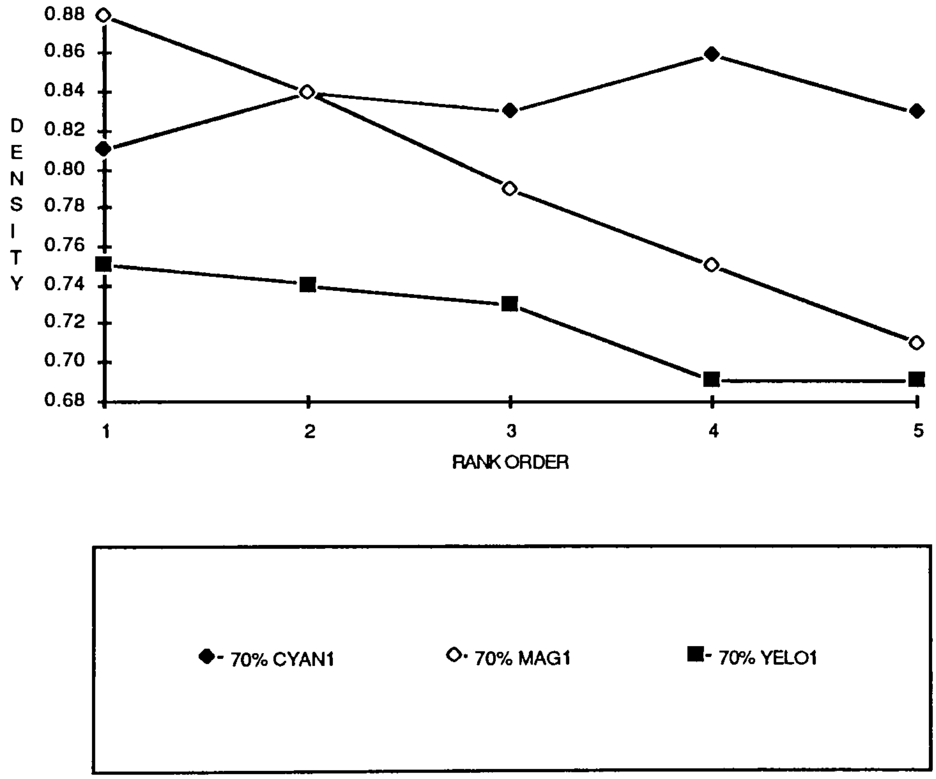


Figure 5
Hue correlation of dark neutral
70% Spot 1

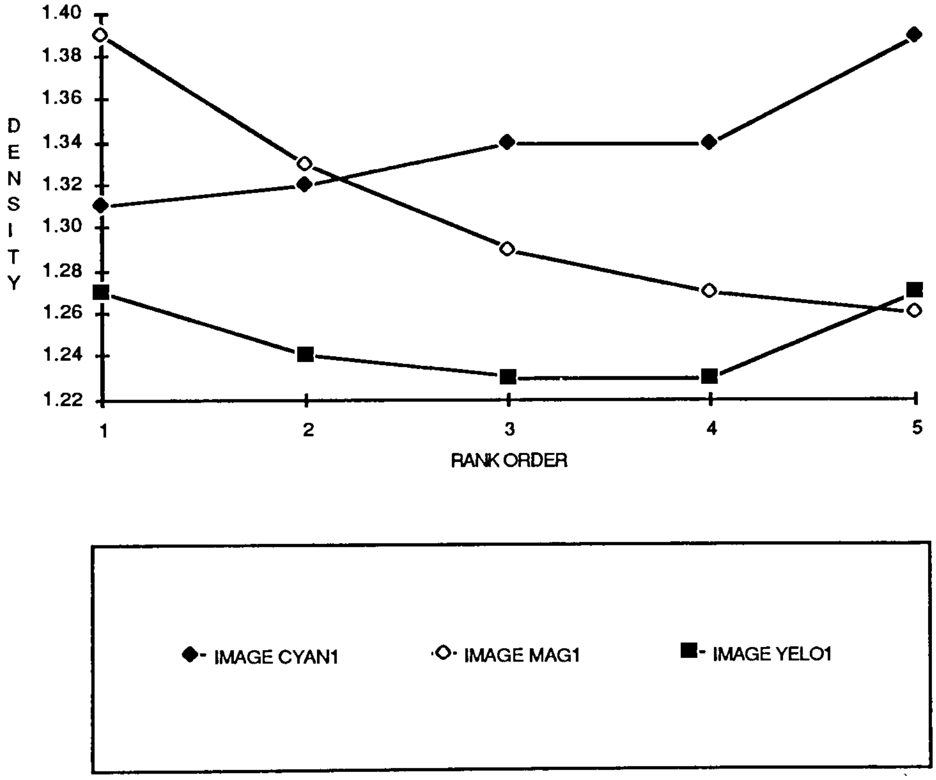


Figure 6
Hue correlation of dark neutral
image Spot 1

image area spot 1 to the corresponding seventy percent overprint tint area spot 1.The correspondence however, of both the dark neutral image three filter density plots and the seventy percent overprint tint area plots to the trend expected with the hue shift ranked by observers, is pronounced.

An examination of the scatter diagrams representing the three filter density data of light neutral and critical color areas shows less of a correspondence to the three filter density relationships expected. It was necessary to analyse each of the spots separately in the light neutral and critical color series due to the difference in image area spots chosen for analysis (figures 7 through 16). The plots of the seventy percent overprint tint spots indicate the same three filter density relationship change as found in the dark neutral series. The slope of the density plots for the light neutral and critical color areas however are less pronounced than the slopes of the seventy percent overprint tint spots lying in line with each of them. The relationship between three filter densities of the image spots is more difficult to analyse and show the correspondence of a hue shift from that of blue to that of cyan, as ranked by the observers. The orange sherbet critical color (spot 1) scatter diagram in figure 7 indicates the trend expected in each of the three filter densities as magenta ink density declines through the series of five samples.The change in density however is minimal and would be difficult to differentiate from density changes due to process variables or measurement inaccuracies (Appendix D).

There was a low correlation of the three filter density relationship expected when the hue shifts from that of blue to that of cyan. In this light orange pastel color, cyan is an undercolor represented by a highlight dot. A dramatic reduction in both yellow and magenta ink densities would be necessary for this critical

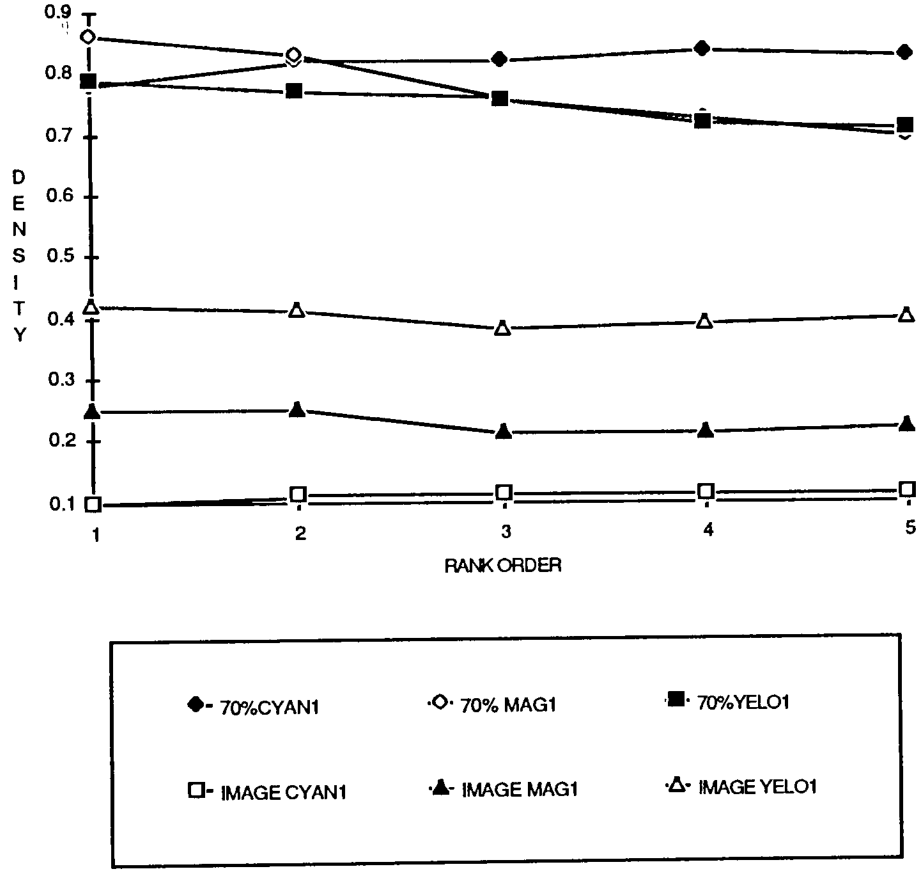


Figure 7
Hue correlation of
critical color Spot 1

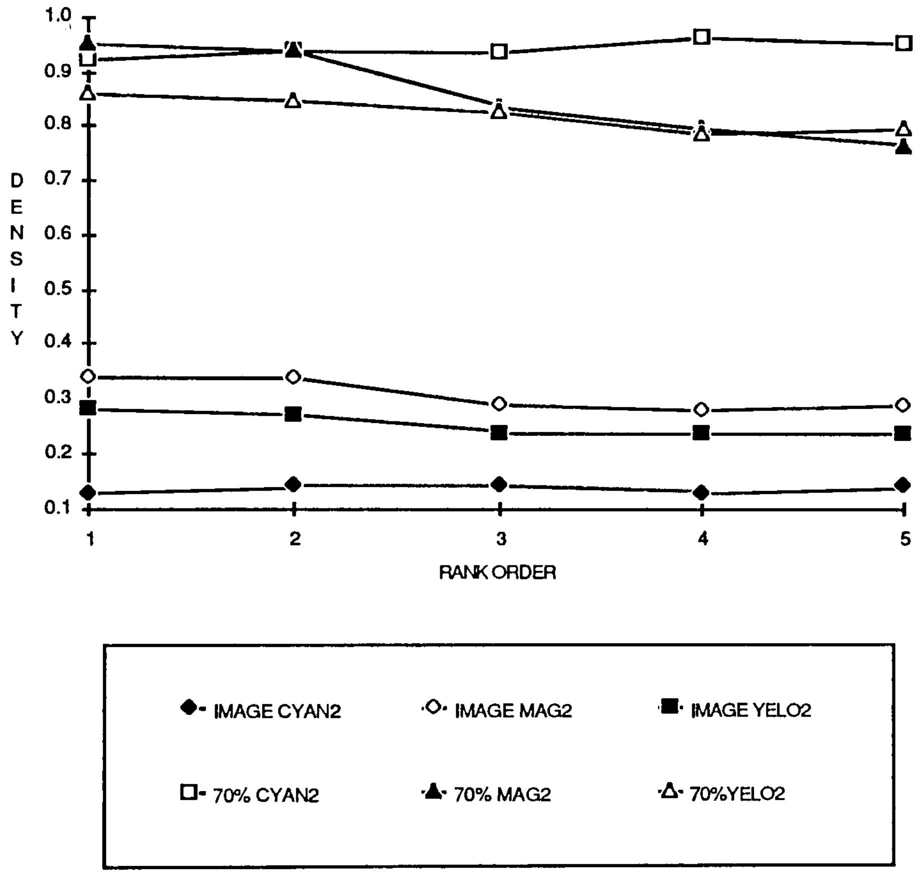


Figure 8
Hue correlation of
critical color Spot 2

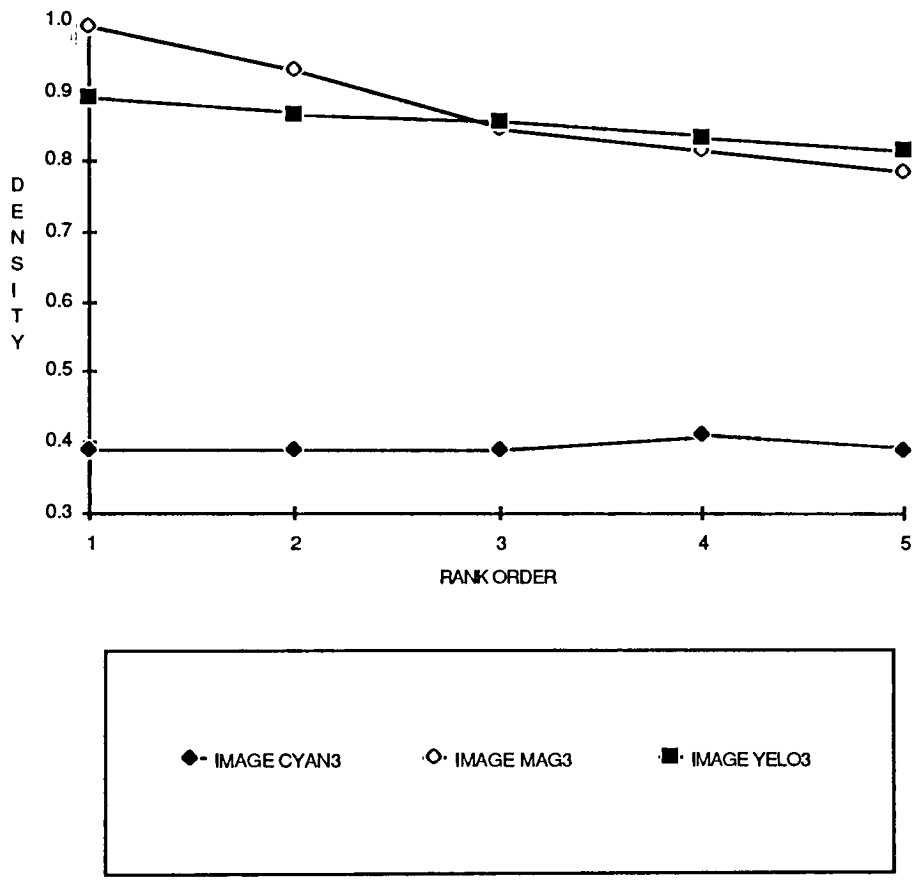


Figure 9
Hue correlation of
critical color image Spot 3

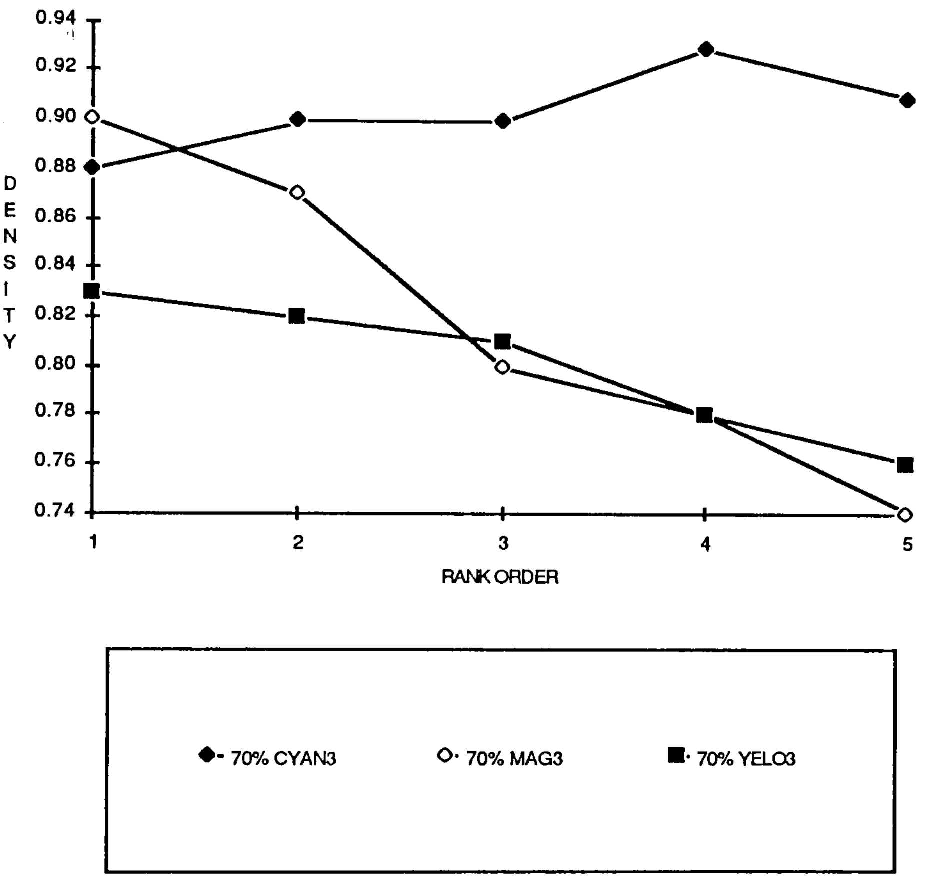


Figure 10
Hue correlation of
critical color 70% Spot 3

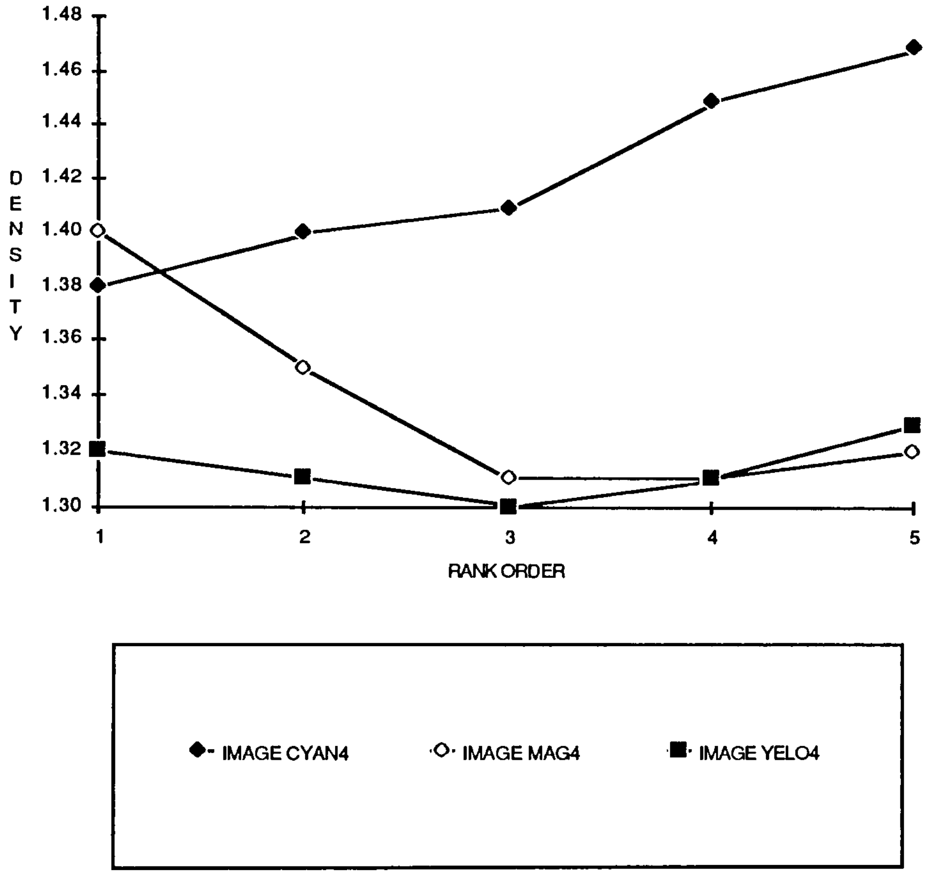


Figure 11
Hue correlation of
critical color image Spot 4

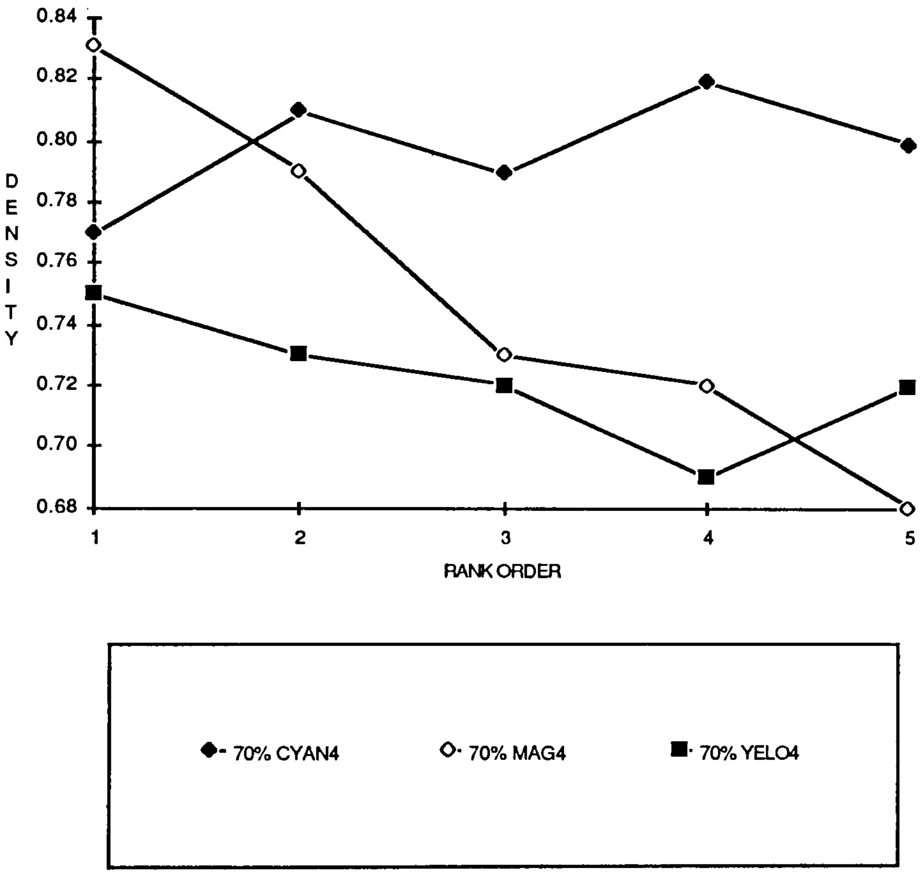


Figure 12
Hue correlation of
critical color 70% Spot 4

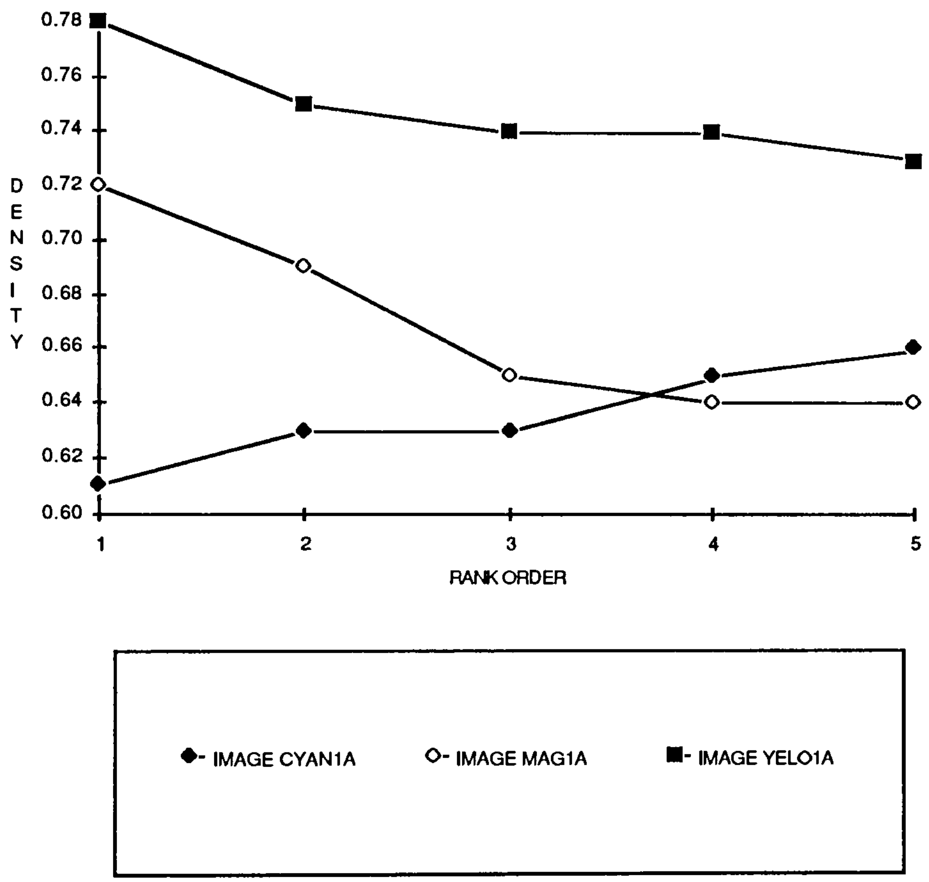


Figure 13
Hue correlation of light neutral
image Spot 1a

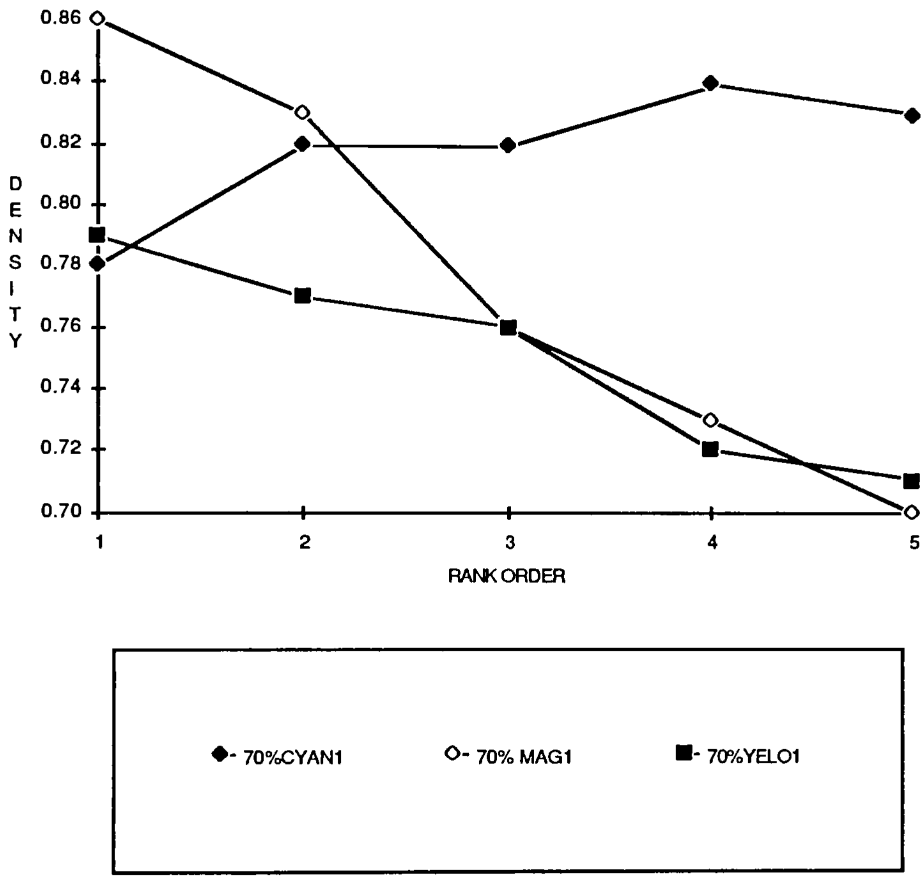


Figure 14
Hue correlation of light neutral
70% Spot 1

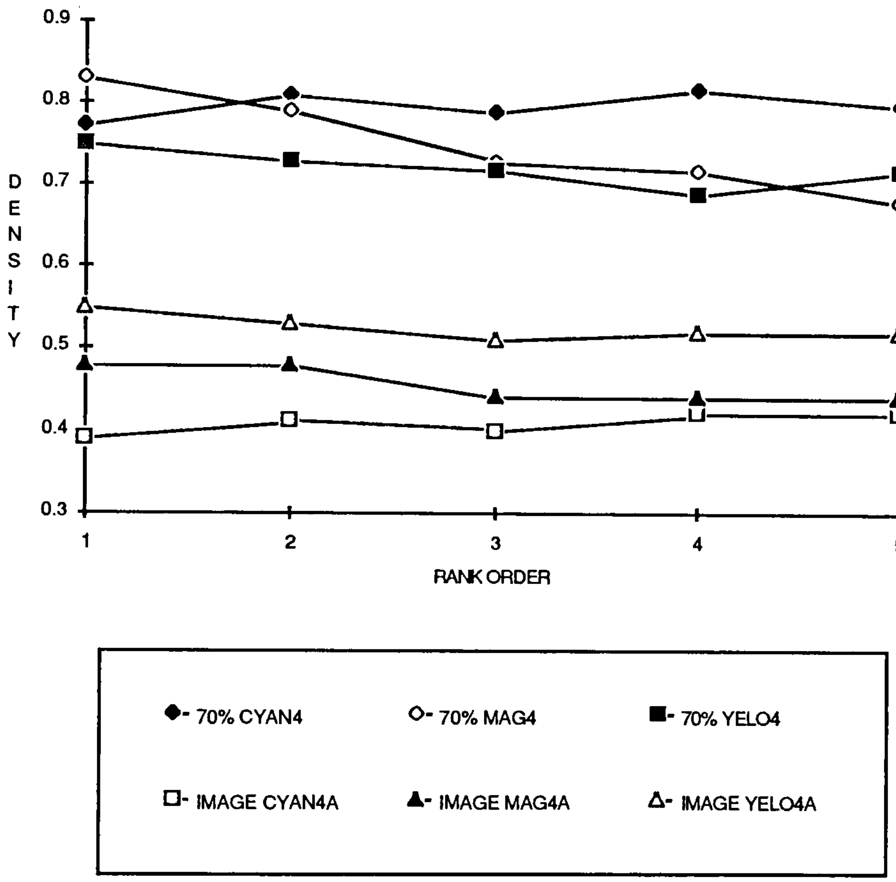


Figure 15
Hue correlation of light neutral
Spot 4a

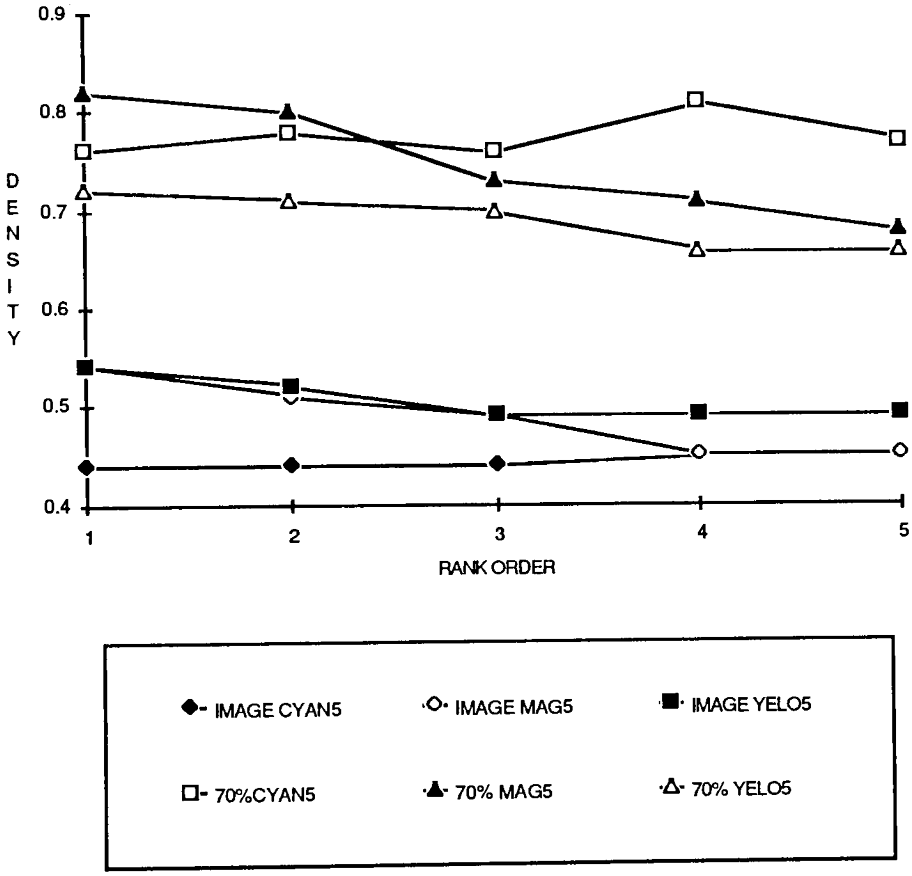


Figure 16
Hue correlation of light neutral
Spot 5

color to shift toward a cyan hue. In Figure 8 the plot of the raspberry sherbet critical color (spot 2) also indicates a low correlation of the three filter density relationship expected from a blue to cyan hue shift. The plot of the red raspberry critical color (spot 3) in figure 9 showed better correspondence to the trend expected from a decrease in magenta ink density. The three filter density relationship however showed a low correlation to what was expected as the hue shifted from that of blue to that of cyan. The critical color in spot 4 was the shadow area of a dark green leaf. The hue of this spot was very similar to those areas specified as dark neutrals and the scatter diagrams in figure 11 show similar slopes and relationship changes of the three filter densities found in the plots of the dark neutral areas. Like the dark neutral plots, there is a pronounced correspondence between spot 4 and the seventy percent overprint tint plots.

The light neutral image areas, spots 1a, 4a and 5, all showed the trend expected with a decrease in magenta ink density (figures 13 - 16). As indicated in the plots of image areas 1a and 4a in figures 13 and 15, there is a low correlation to the three filter density relationship one would expect with a hue shift from blue to cyan. In each of these plots the blue filter density remains the dominant of the three filter densities. A shift toward a cyan hue would not be predicted from the change in magenta and cyan densities in these light neutral areas. Only image spot 5 shows the change in relationship of the three filter densities that indicates a hue shift toward cyan.

Calculation of correlation coefficients (r) were inconclusive when attempting to find correlation of the hue shift as ranked by the observers to the three filter density values. For a small sample size ($n = 5$), it was necessary to test the hypothesis of the significance of r. Since ($v = n-2$) the correlation coefficient r

must exceed the table value (.878) for there to be a real correlation to exist .[2] Above this value we ran a risk of error (x risk) of less than five percent if we assume that a real correlation exists.

Within the dark neutral series a correlation can be assumed to exist with ninety five percent confidence, between the variables, rank order and magenta ink density value. Both the image and the seventy percent overprint tint spots exhibited a high negative correlation between the rank order chosen by the observers and the green filter density value. The correlation coefficient for seventy percent magenta mean density was (-.999). The correlation coefficient for the image areas magenta mean density was (-.972). These high values of negative correlation between the cyan hue rank order and the decreasing magenta ink density reflect the correspondence of both visual analysis and densitometric analysis. Thus as magenta ink density decreased in the ranked samples the hue shifted from that of blue to that of cyan. This was reflected in both the dark neutral image areas and in the seventy percent overprint tint bar.

Within the light neutral and critical color series a similar high value of negative correlation between the rank order and magenta ink existed in the seventy percent mean overprint tint bar (r = -.986). There were also high values of negative correlation found in the correlation coefficients calculated for image spot 3 (r = -.979) (red raspberry) and in image spots 1a (r = -.932) and 5 (r = -.973) of the light neutrals for the magenta ink density (Appendix B).

The data shows this correlation between a reduction of magenta ink density and an increase in cyan hue. It is notable that there was also a high negative correlation coefficient calculated for the yellow ink densities in both the dark neutral series seventy percent tint bar (r = -.969) and in the light neutral and

critical color series seventy percent tint bar (r = -.969). Because the 3-filter density readings were taken in the overprint tints, the total absorption of all three process colors was included in the measurements. Therefore the blue filter density of the three color overprint included the primary influence of the yellow ink plus the added blue filter density of the magenta and cyan inks which although unwanted, contribute to the total blue filter density. Because the primary density comes from the magenta ink, when magenta ink (green filter density) decreases the unwanted blue filter density also decreases, giving the impression of a decrease in yellow ink density

The correlation coefficients were inadequate when attempting to find the correlation between a relational change in three filter density values and a hue shift of a rank order series determined by a panel of judges. Graphical correlation analysis was more valuable when a relational change in three filter densities needed to be analyzed. Appendix D includes the data tables for the low density hue correlation series.

High Density Series

Hue Correlation

The second part of Phase II of the press run provided the high density samples necessary to correlate viewer response to density changes in a series of ranked samples. The sequence of ink adjustments controlling color hue variation during this high density series of the press run were as follows:

Period	Inking	Press	Time	Hue
A.	Increase	Black	2 minutes	
B.	Increase	Cyan	4 minutes	Cyan
C.	Increase	Yellow	6 minutes	Green
D.	Decrease	Cyan	8 minutes	Yellow
E.	Increase	Magenta	10 minutes	Red
F.	Decrease	Yellow	12 minutes	Magenta
G.	Increase	Cyan	14 minutes	Blue
H.	Increase	Yellow	16 minutes	Neutral

For this portion of the press run the outcome of the eight ink adjustments made over sixteen minutes was an overall increase in print density. The last ink adjustment culminated in a balanced level of inking at high density from which the pressmen were instructed to bring color into balance at this high level.

From the Phase II High Density Series press sheets, five samples were selected from period B. The experienced color observers were asked to rank the samples in ascending order based on a shift in hue. Rank one was a sample taken from the period before Phase II High Density series, when the pressmen had brought the press into neutral color balance at a normal level of density. Sample ranks two through five represent the hue shift toward a cyan hue as the cyan ink density was increased. The relative change of the red, green and blue

filter densities as the hue shifted from that of neutral to that of cyan were analyzed in scatter diagrams.

Again there was disagreement between the judges when establishing the rank order based upon this high density hue shift series. Three color observers chose rank orders that differed from the majority of judges. Rank correlation analysis tested the hypothesis of independence among judges (Appendix A). In all three cases the calculated coefficient of rank correlation was greater than the table value (.87). The conclusion therefore is that there is evidence of agreement between judges establishing the rank order based upon hue shift.[3] It can be assumed that an overall image comparison was made by the viewers when asked to rank the samples in order.

To test which portion of the printed image best correlated to the viewers chosen rank order, specific overprint tint areas in the image were used for analysis. The printed sample in figure 2 indicates the dark neutral, light neutral and critical, color areas chosen for three filter density analysis. The same sampling masks used for the low density hue analysis were used for the high density hue analysis as well as the color strength analysis that will follow.

In the scatter diagram (figure 17), the dark neutral image area mean densities of spots 1 through 4 of the five samples are plotted against the rank order chosen by the judges. The red filter density reflects the increase in the cyan ink density that occurred during period B as the hue was observed to shift from neutral to cyan. The red, green and blue filter densities increase initially from the neutral sample, rank one to rank two. The three filter density relationship however, does not change and this may account for the discrepancy in viewer response when assigning a consistent rank order to the first three

ranks. The three filter density relationship in ranks four and five changes with the red filter density becoming the dominant or highest density. Areas in the seventy percent overprint tint bar vertically in line with the dark neutral image area spots were correlated to the rank order chosen by the color observers. The scatter diagram in figure 18 shows the change in relationship of the three filter densities through the rank order. The increase in red filter density contrasting with the level slope of the green and blue filter density plots corresponds to the expected hue shift toward cyan as ranked by the viewers.

When comparing the dark neutral image area means to the corresponding mean densities in the seventy percent overprint spots in figures 17 and 18, there is a good correspondence of the red filter density increase. The relationship of the three filter densities although similar, is not the same. However, both scatter diagrams reflect the shift in hue that was ranked by the observers. As with the Low Density Series, the seventy percent overprint tint in this High Density Series appears to show a better indication of the hue shift as ranked by the panel of viewers.

It is difficult to assess which of the scatter diagrams most closely represents the hue shift observed. The dark neutral image spot three filter densities show a change in relationship through the rank order. If the dark neutral areas sampled had a tighter grouping of the three filter densities, more like that of the seventy percent overprint tint areas, then their scatter diagrams would be similar. There is a discrepancy between rank one (neutral) and rank two when comparing the seventy percent mean scatter diagram to that of the dark neutral image areas (figures 17 & 18). The initial increase in green filter and blue filter density in the dark neutral image areas does not correlate to the decrease in these densities in

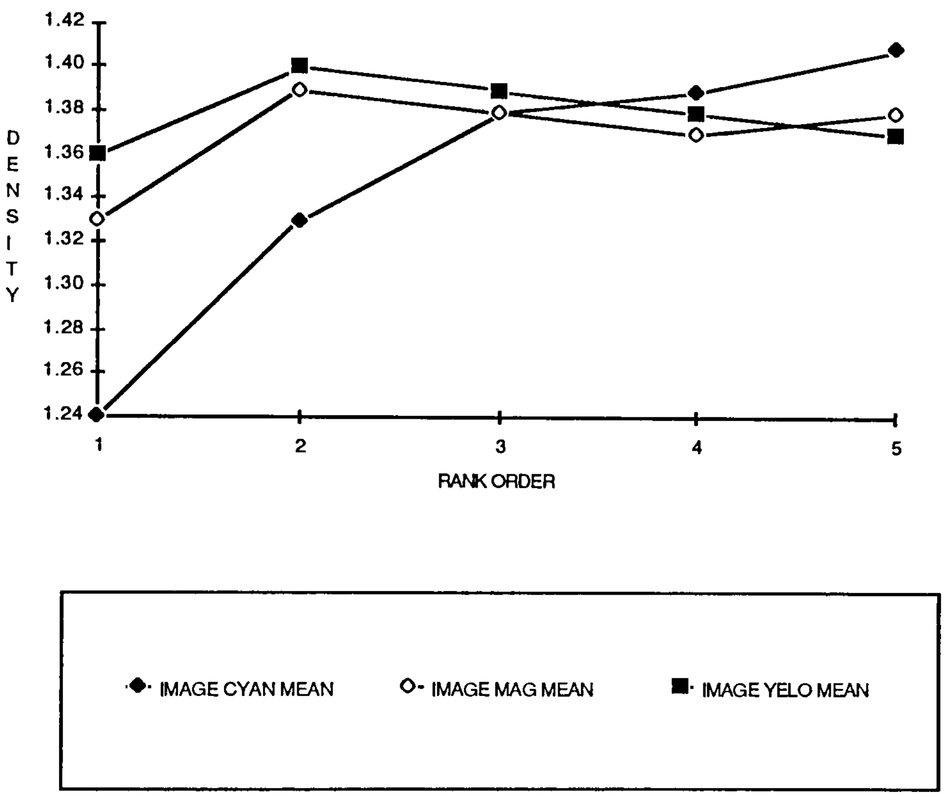


Figure 17
High density Hue correlation
of dark neutral image Mean

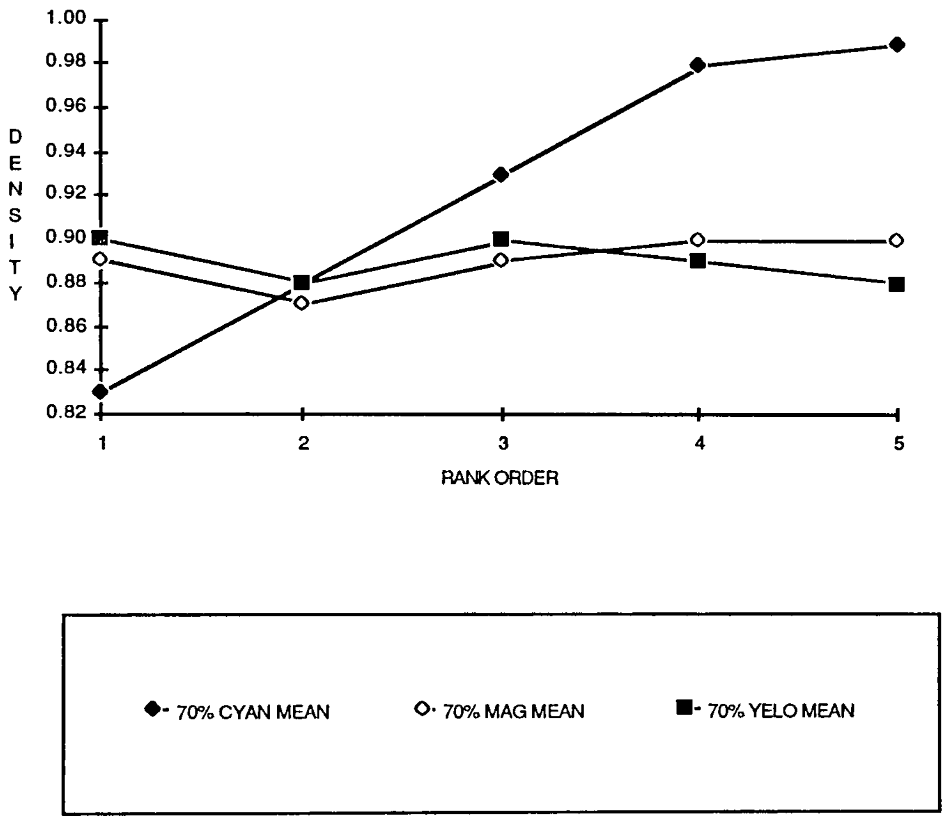


Figure 18
High density Hue correlation
of dark neutral 70% Mean

the seventy percent overprint tint. This may be explained by the fact that during period A, the black ink density was increased and is reflected in rank two by the increase in green and blue filter densities. The rank one sample was selected from the normal balanced color portion of the press run prior to period A. The seventy percent overprint tint did not include a black separation and does not reflect this increase in black density. This observation of parallelism between magenta and yellow ink density, with a change in black ink density, was noted in another study[4] and plots of spots 1-4 indicating this are shown in Appendix C (figures 40 - 47). The elimination of the black ink component from the seventy percent three color overprint tint likely aids in densitometric analysis of the hue shift in the samples ranked by observers.

Scatter diagrams representing plots of light neutral areas and critical colors in the image and their corresponding seventy percent overprint tint plots for the High Density Hue series are found in figures 19-27. Here as in the Low Density Series each point must be analyzed separately. In the light orange sherbet represented by image spot one (figure 19), no increase in red filter density is observed showing little correspondence to the trend expected with a hue shift from neutral to cyan through the rank order. The three filter density relationship also does not change, showing a low correlation to the hue shift observed. Likewise the raspberry sherbet (spot 2, figure 20) and the red raspberry (spot 3, figure 21) critical colors indicate a low correlation when three filter density change and relationship are compared to a hue shift from neutral to cyan. The scatter diagram for the spot four critical color (the dark green leaf, figure 23) showed the same similarity to the plot of the dark neutral image area means (figures 17-18) as was seen in the Low Density Series.

The light neutral image mean areas representing spots 1A, 4A and 5 in Figure 25 showed the trend expected graphically, an increase in red filter density. The three filter density relationship however showed no correlation to the hue shift of ranked samples.

For the calculation of correlation coefficients to be meaningful, because of the small sample size (n = 5), the calculated value of (r) had to be greater than the table value of .878. Above this value there is a ninety five percent chance that a true correlation exists.[5] The correlation coefficient for the seventy percent overprint mean densities vs rank order were: cyan (red filter density) r = .982, magenta (green filter density) r = .645 and yellow (blue filter density) r = .474. The corresponding dark neutral image area mean density correlation coefficients were: cyan (red filter density) r = .927, magenta (green filter density) r = .539 and yellow (blue filter density) r = .000. These correlation coefficients indicate a positive correlation between the cyan hue rank order determined by the observers and the increase in red filter density values in both the dark neutrals and seventy percent overprint area. Thus as the cyan ink density increased in the ranked samples, the hue shifted from that of neutral to cyan.

In the data representing light neutral and critical colors of the High Density Hue Series, there were a few areas of the press sheet where density changes correspond to the hue shift towards cyan. A high correlation coefficient value (r = .982) was calculated for the red filter density in the seventy percent overprint tint area mean as was determined in the same area from the dark neutral data. The light neutral areas also indicated a correspondence between an increase in red filter density and increase in cyan hue as observed and ranked by the viewers. Light neutral image areas had red filter density vs rank order correlation

coefficients as follows: Spot 1A (r = .936), Spot 4A (r= .969) and Spot 5 (r = .983) (Appendix B).

This data shows a correlation to the hue shift ranked by observers only in the simplest form. The correlation coefficients indicate only that a correlation exists between the two variables; red filter density and hue shift toward cyan. When attempting to associate three filter density values with a visual change in the printed image, it is the change in relationship of the three filter densities and the magnitude of that change in scatter diagrams that is indicative of the association. Of the critical colors, only the image spot 4 (dark green leaf, figure 23) shows a correlation to the hue shift from neutral to cyan as ranked by observers. This shadow area of a dark green leaf includes a significant amount of black and was similar in three filter density relationship to the dark neutral image areas analyzed previously. An examination of the scatter diagram shows the same green filter and blue filter density increases as found in the dark neutral image areas (figure 17) between rank number one and rank number two. The scatter diagram for the seventy percent overprint area in figure 24, like that in figure 18, does not show this same increase in density. Again, parallelism of the green filter and the blue filter density with an increase in black ink density could be the cause.

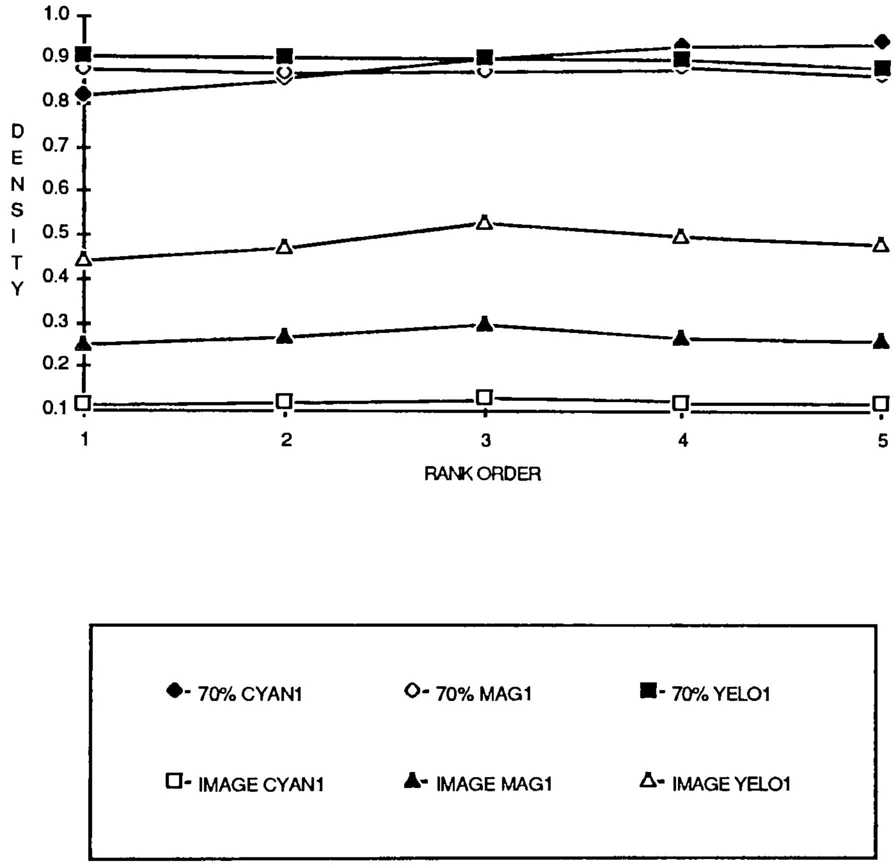


Figure 19
Hue correlation of critical color Spot 1

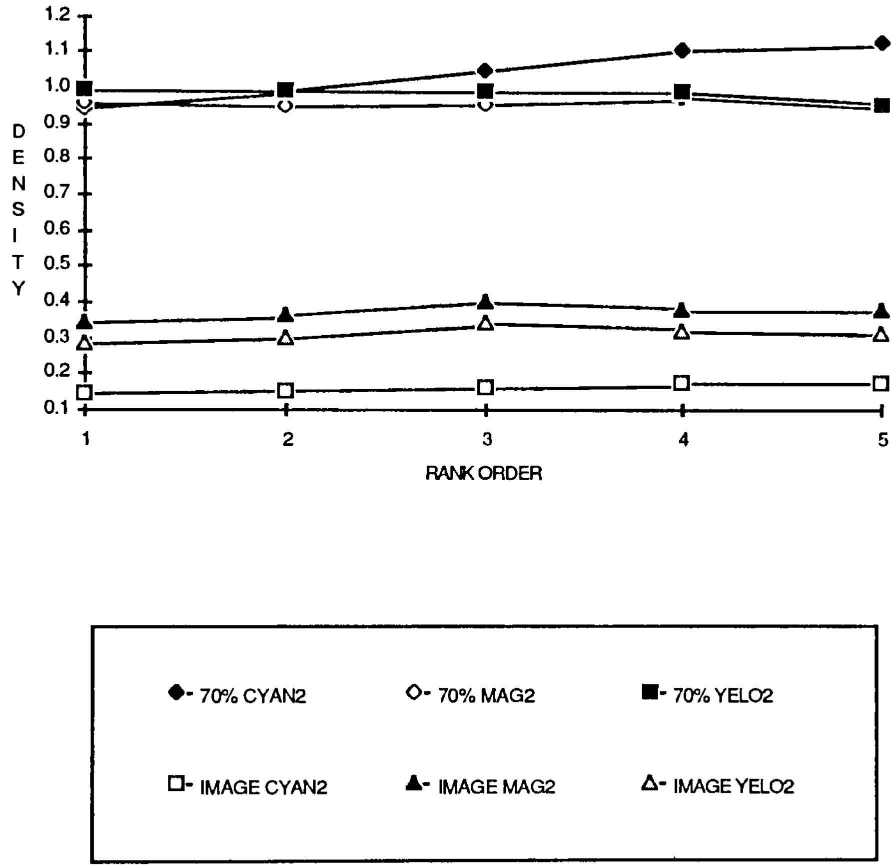


Figure 20
Hue correlation of critical color Spot 2

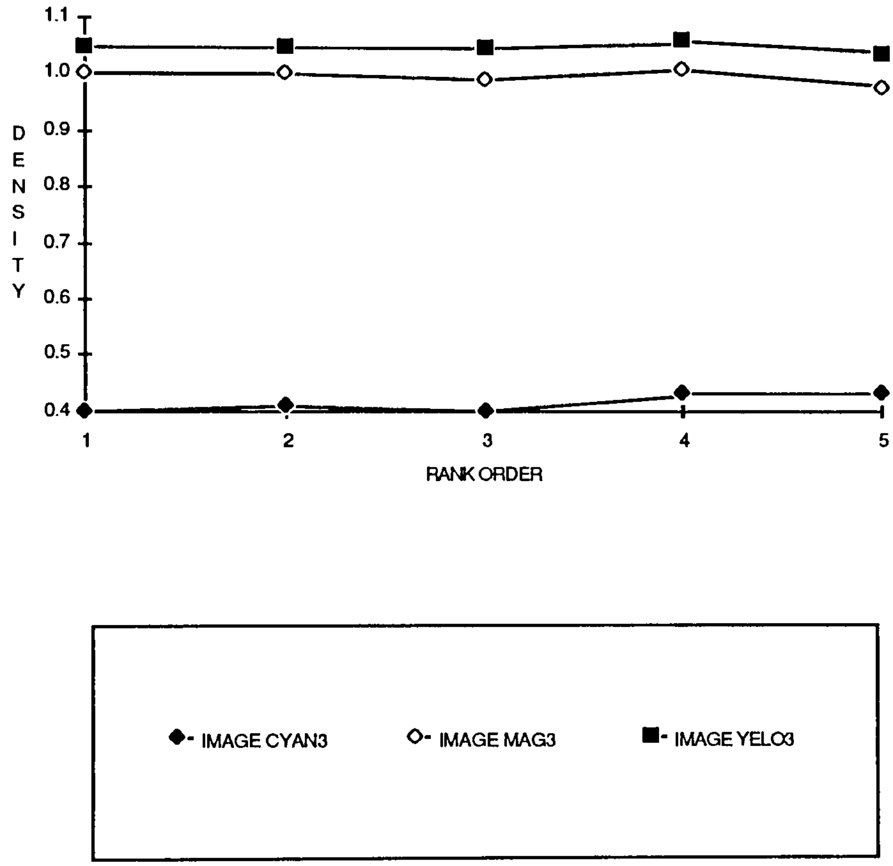


Figure 21
Hue correlation of critical color
image Spot 3

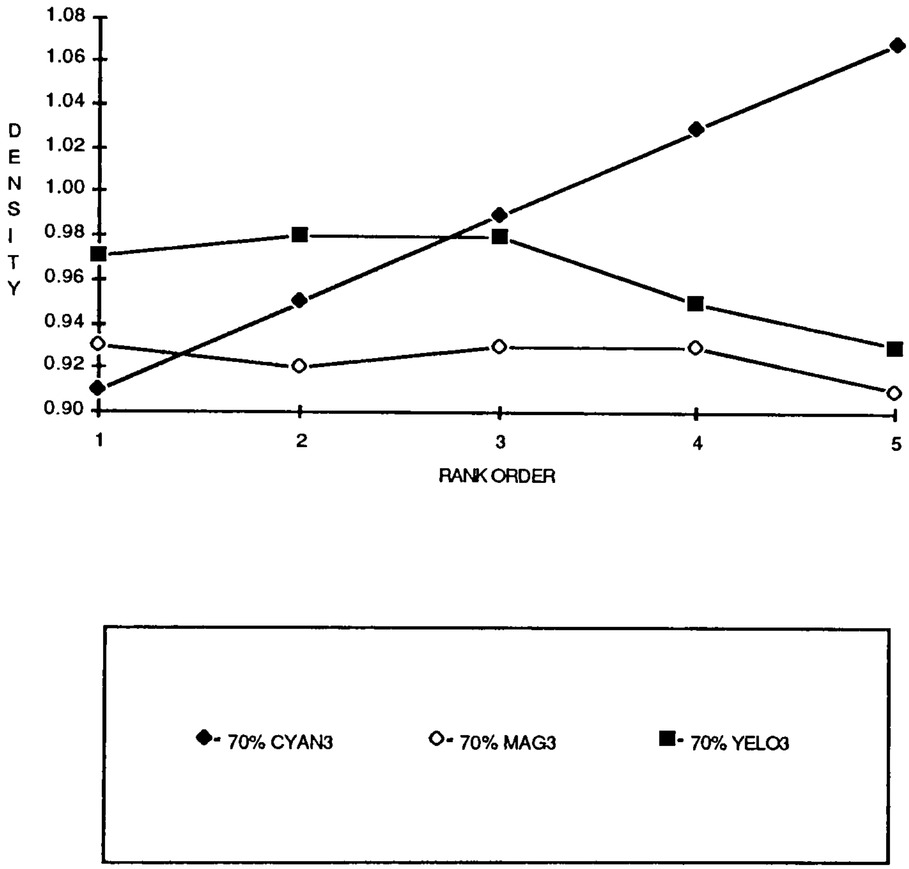


Figure 22
Hue correlation of critical color
70% Spot 3

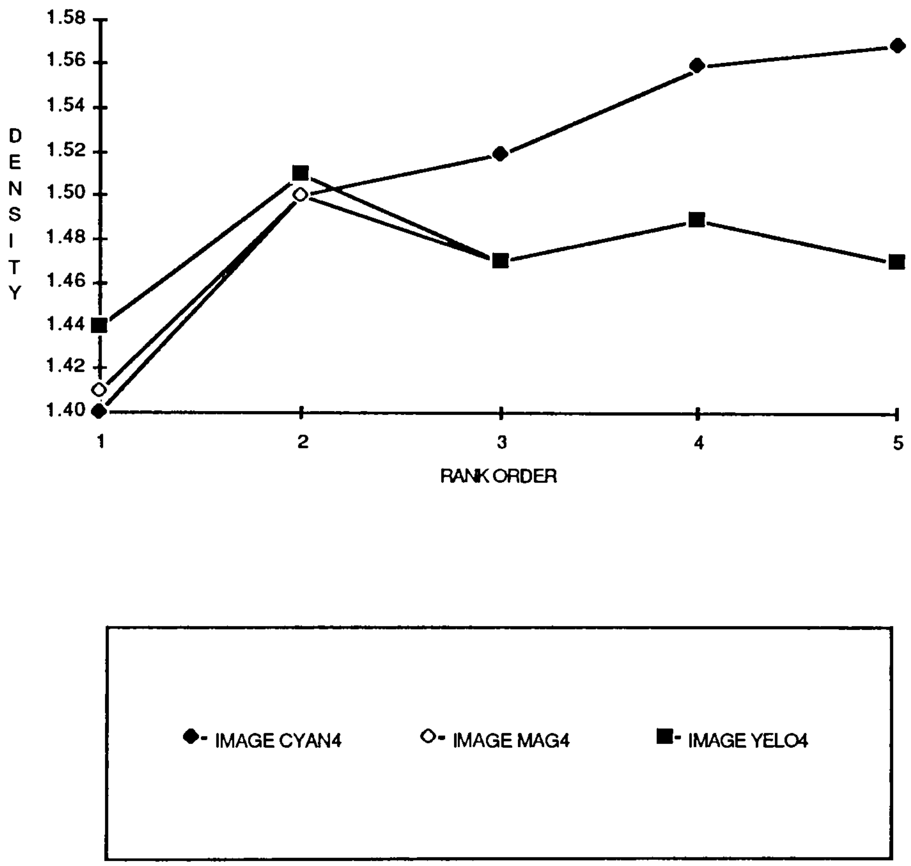


Figure 23
Hue correlation of critical color
image Spot 4

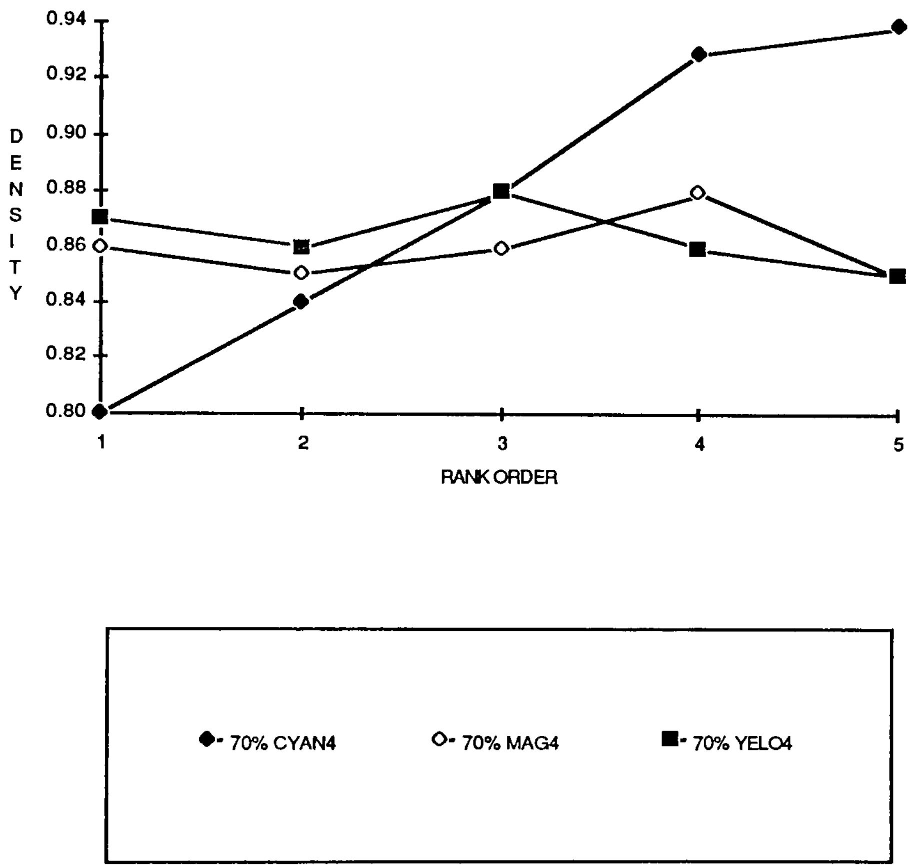


Figure 24
Hue correlation of critical color
70% Spot 4

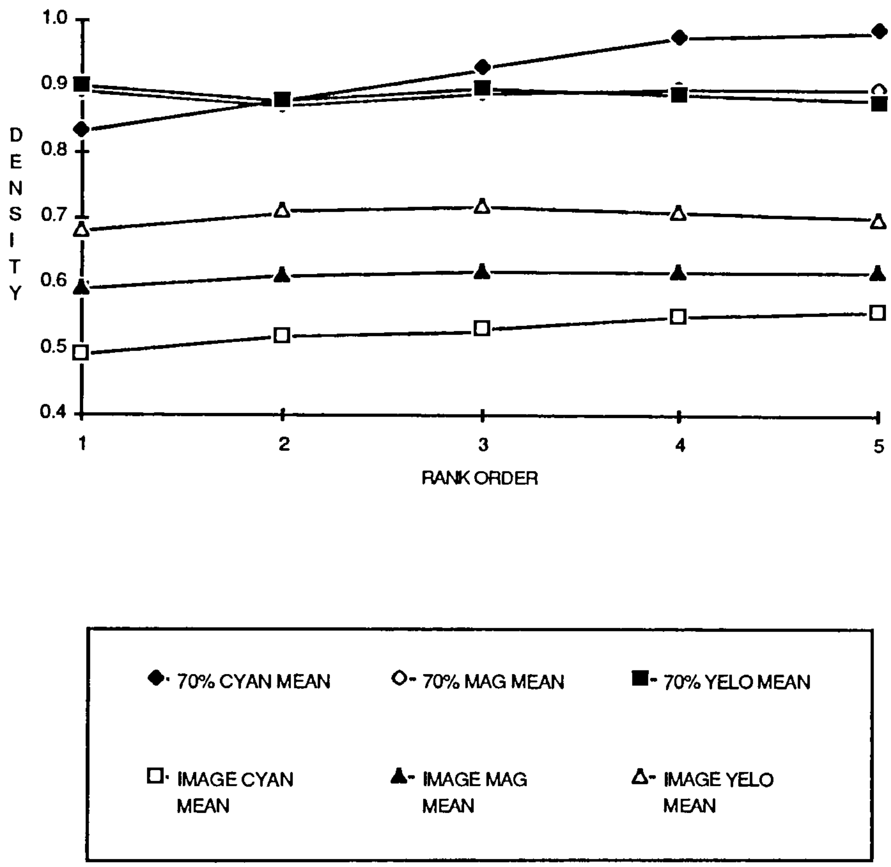


Figure 25
Hue correlation of Light neutral color Mean

Color Strength Series

This series was generated at the end of the press run as the ink feeds were shut down, prior to stopping the press. Sampling consisted of pulling thirty consecutive sheets that appeared to be showing a decrease in color strength. A sample of every other sheet was selected of the first twenty sheets and it was from this group of ten sheets that the five samples were selected for rank order analysis.

Most of the experienced color observers noted a change in hue while they ranked the five samples in order of increasing color strength. There was complete agreement between judges when ranking the color strength series and the assumption was again made that an overall image comparison was being made as the observers ranked samples. The same dark neutral, light neutral and critical color masks were used to sample densities as in the preceding color hue analysis. Three filter density values were then correlated to the rank order specified by the color observers.

The plots of scatter diagrams for the dark neutral image area means (figure 26) indicate that all three filter densities correlate to the color strength increase ranked by the viewers. In figure 27, the plot of the seventy percent overprint tint area mean densities shows a strong correlation to both the rank order chosen by the viewers and to the dark neutral image area means plotted in figure 26. The slopes of the red filter, green filter and blue filter densities differ from one another which lead to the viewer response of the hue shifting as well as the color strength increasing. The data shows that as the color strength increased throughout the ranked samples, so too did the three filter density values in both

the dark neutral image areas and the seventy percent overprint bar. Correlation coefficients based on rank order, the three filter density of the dark neutral image mean areas and the seventy percent overprint means confirm this. Dark neutral correlation coefficients were as follows: red filter density r = .997, green filter density r = .972 and blue filter density r = .959. Calculation of the seventy percent overprint correlation coefficients were as follows: red filter density r = .993, green filter density r = .979 and blue filter density r = .990.

The three filter densities for light neutral areas in the image also show a correlation to the rank order chosen by the viewers. The three light neutral image area spots were combined for color strength analysis as was done for the dark neutral image areas in the previous two color hue series.

Comparison of the light neutral image mean scatter diagram to that of the seventy percent overprint tint mean plot indicates that a simple correlation coefficient calculation would be inadequate for analysis (figures 28 & 29).

There was a hue shift in rank 4 and 5 indicated by eighty percent of the observers when ranking the samples for color strength. A corresponding change in the three filter density relationship through the rank order is observable in the seventy percent overprint mean scatter diagram, but not in the scatter diagram of the light neutral image area means. This relational density change, where the red filter density transitions from the lowest position of the three filter densities in rank one, to the highest density position in rank 5 is not indicated in the light neutral image mean plot (figure 28). While the observers were ranking the samples according to an increase in color strength, they were also cognizant of the hue shifting toward green and cyan. The scatter diagram (figure 26) representing the dark neutral image area mean densities also indicates this

change in three filter density relationship. This data is significant because it verifies the assumption that by monitoring three filter densities in certain overprint tints, both color hue and color strength variation through a press run can be monitored by densitometry. An examination of scatter diagrams representing the four critical color image area spots demonstrate the need to analyse sensitive control points on the press sheet in order to monitor color hue and strength variation densitometrically. Critical color spot 1 (orange sherbet, figure 30) indicates a low correlation to the change in color strength as ranked by viewers. Correlation coefficients representing this critical color were too low to show a positive correlation with the rank order and are as follows: red filter density r = .000, green filter density r = .834, blue filter density r =.868. Critical color spot 2 (raspberry sherbet, figure 32) correlation coefficients showed a positive correlation between density and color strength rank order only with magenta and yellow as follows: red filter density r = .791, green filter density r = .971, blue filter density r =.904. Critical colors spot 3 (red raspberry, figure 34) and spot 4 (dark green leaf, figure 36) demonstrate the problem with indicating a positive correlation between three filter density and color strength.. Both areas showed positive correlation to an increase in color strength as follows: Spot 3 - red filter density r = .912, green filter density r = .971, blue filter density r = .974 ; spot 4 - red filter density r = .981, green filter density r = .989, blue filter density r = .967 (Appendix B).

When analyzing which areas of the press sheet indicate both and increase in color strength and the hue shift noted in ranks four and five (toward cyan), only the critical color in spot 4 and the seventy percent overprint tint area three filter densities support this viewer response. The three filter density relationship

change that correlates positively to the color hue and strength change as ranked by observers is consistently found in: A) the seventy percent overprint tint areas (figures 27,29,31,33,35,37), B) dark neutral image areas (figure 26) and C) critical color spot 4 (figure 36), (similar in density to the image areas specified as dark neutral).

A review of the scatter diagrams representing the dark neutral image areas and the seventy percent overprint areas shows the similarity between the two areas of the press sheet. Data plotted from the color strength series indicate that a pronounced correspondence exists between the dark neutral image areas and the seventy percent overprint tint areas lying vertically in line with them on the press sheet. Scatter diagrams and correlation coefficients comparing each of the three filter densities of the dark neutral image spot 1 (figures 38 & 39 and Appendix B) to the corresponding seventy percent overprint spot support this conclusion. Correlation coefficients alone however only indicate that a change in one variable correlates to a change in another variable. More complete data analysis requires the support of both correlation coefficients - showing the correlation of color strength between the image area and the corresponding seventy percent overprint area - as well as three filter density relationship plots, indicating a change in color hue. The comparison of data and three filter density relationships for the dark neutral image areas and then the seventy percent overprint areas indicates that a pronounced association exists between the two press sheet areas. A much weaker association exists between other image areas and the seventy percent overprint tint when data and plots of three filter densities are compared. This is the case for example in comparing critical color spot three to its corresponding seventy percent overprint tint. Correlation

coefficients indicate a correlation exists between these two areas of the press sheet and the color strength rank chosen by the viewers (image red filter density r = .981, image green filter density r= .989, image blue filter density r= 967) (70% red filter density r = .992, 70% green filter density r= .986, 70% blue filter density r= 971). The plots of three filter density relationships for critical color spot three and the seventy percent overprint tint show a lack of correspondence relating to color hue however (figures 34 & 35).

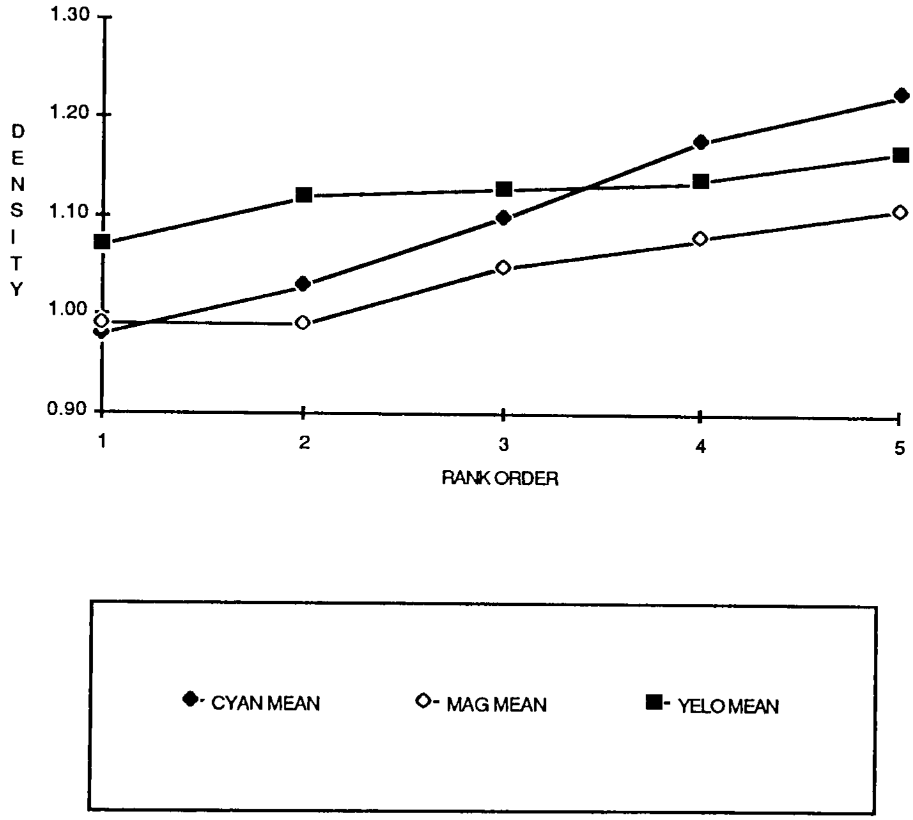


Figure 26

Image Mean Density
dark neutral colors

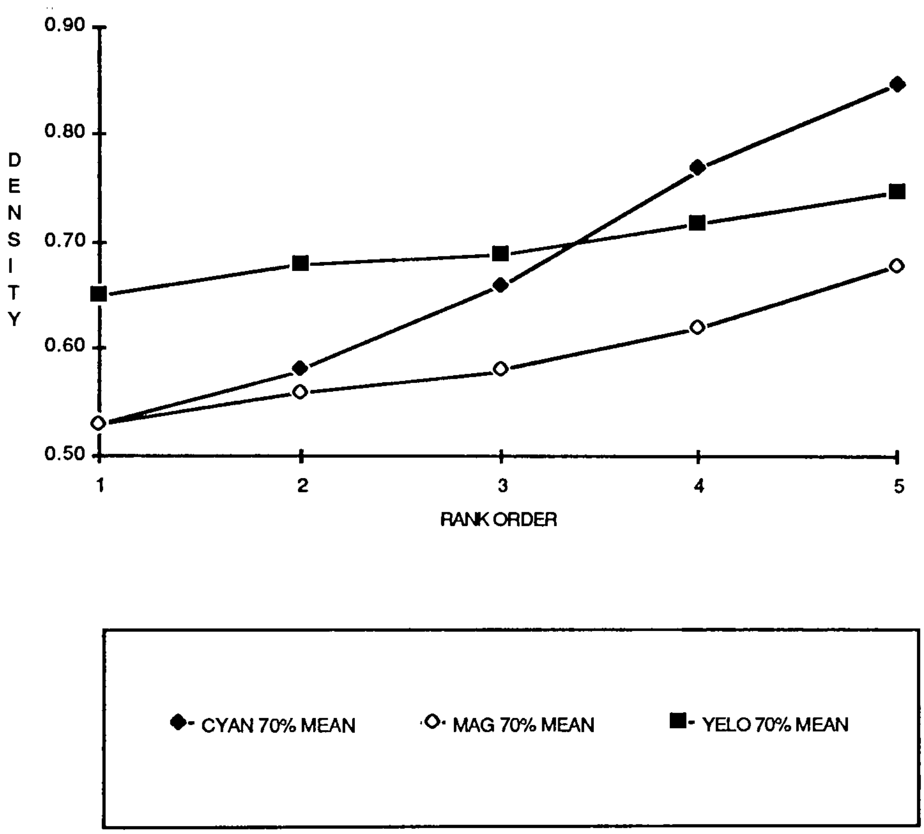


Figure 27

70% Mean Density
dark neutral colors

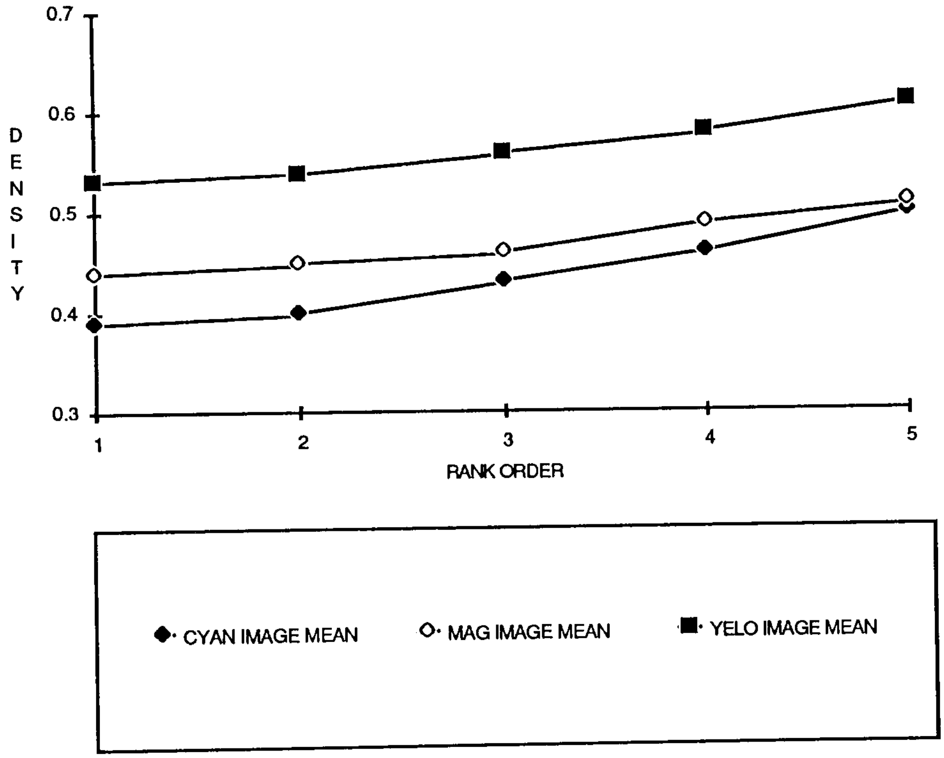


Figure 28

Image Mean Density
light neutral colors

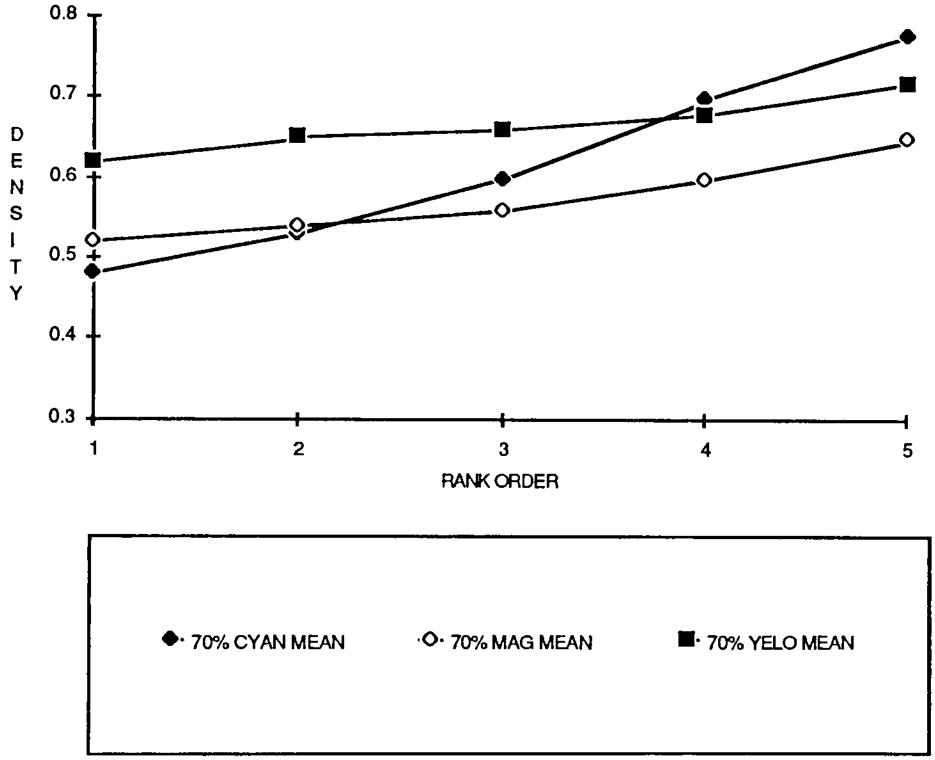


Figure 29

70% Mean Density
light neutral colors

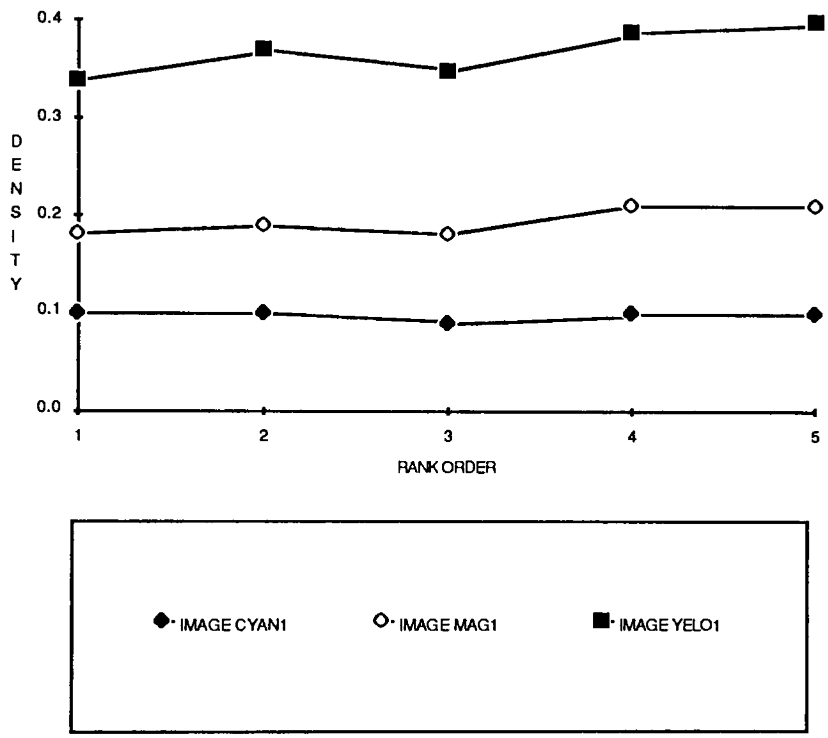


Figure 30

Image Spot 1
critical color

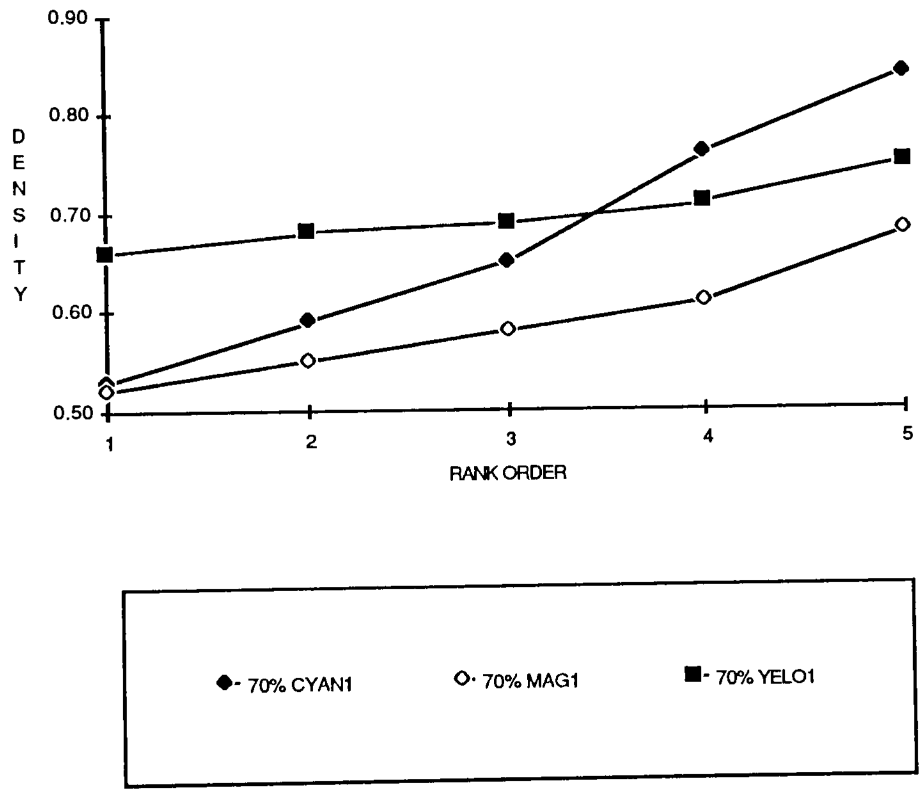


Figure 31

70% Spot 1
critical color

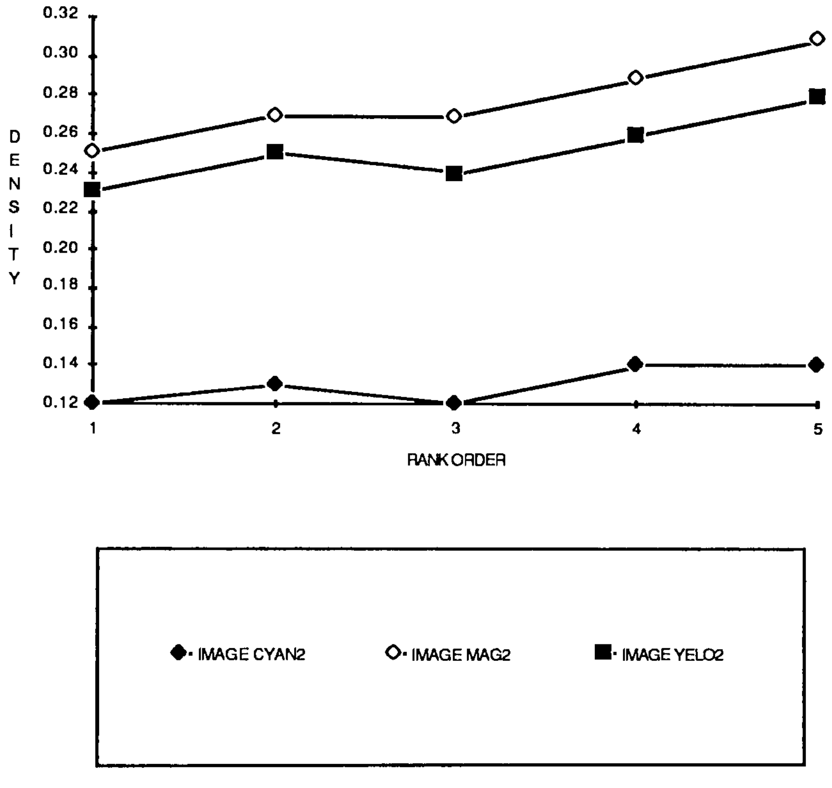


Figure 32

Image Spot 2
critical color

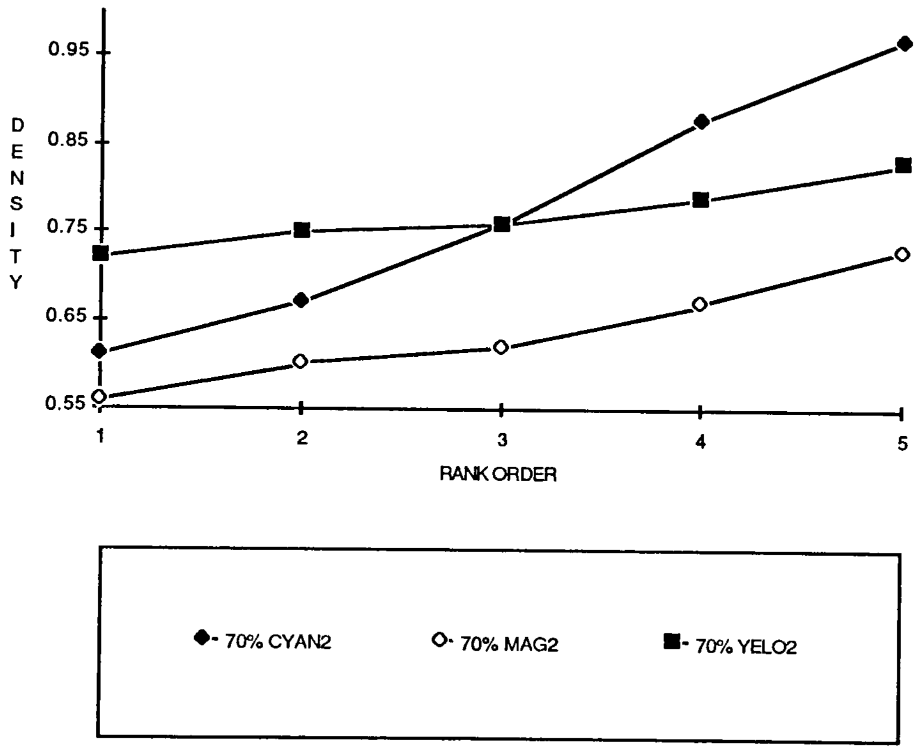


Figure 33

70% Spot 2
critical color

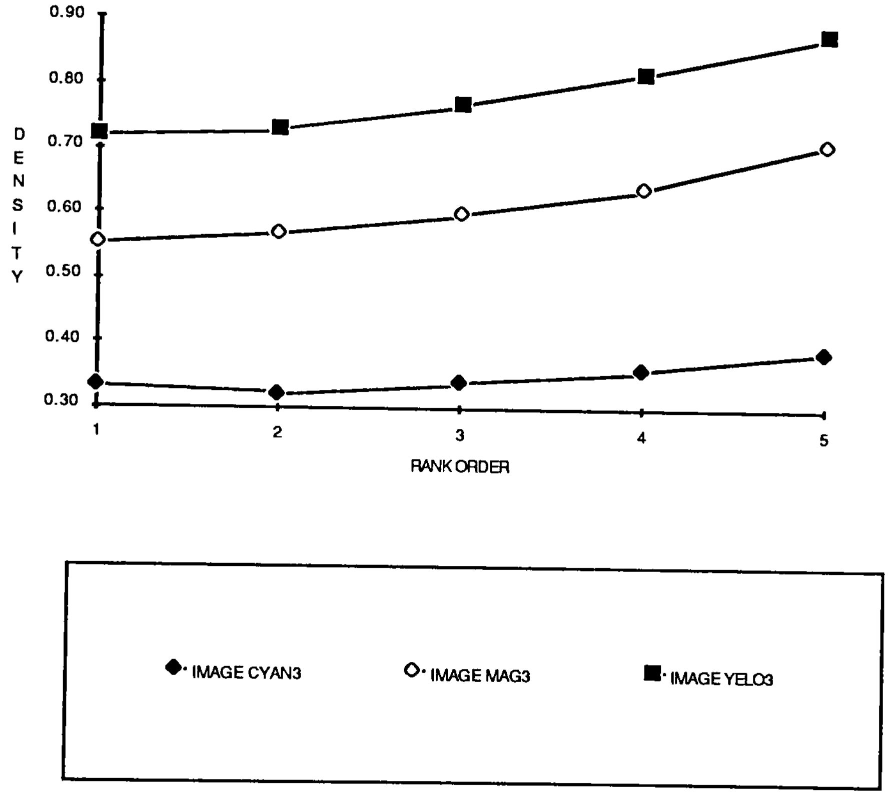


Figure 34

Image Spot 3
critical color

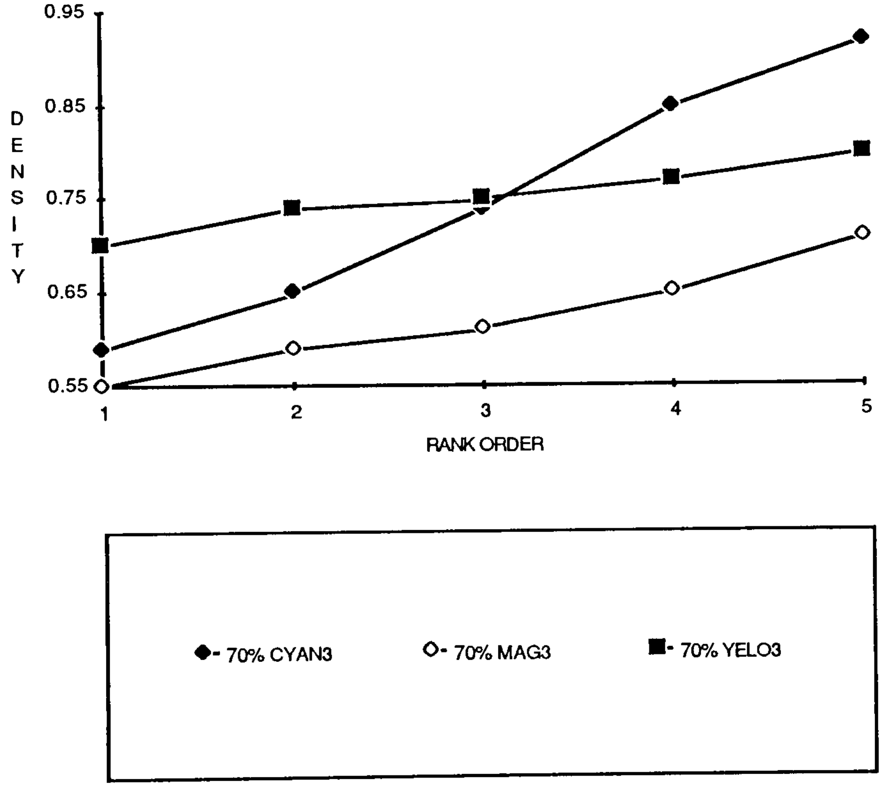


Figure 35

70% Spot 3
critical color

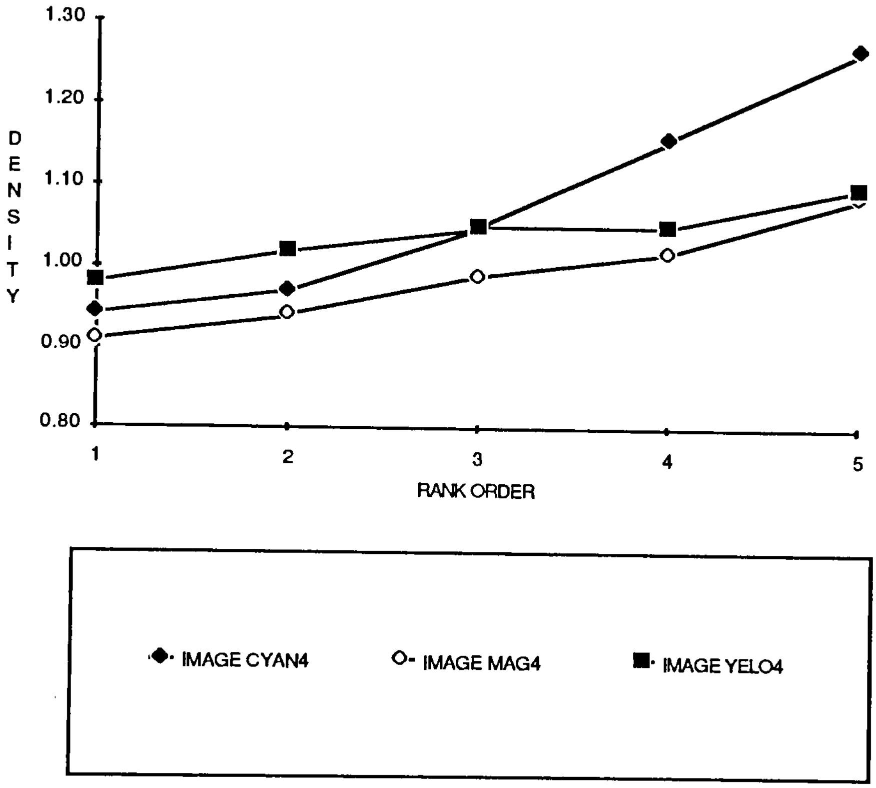


Figure 36

Image Spot 4
critical color

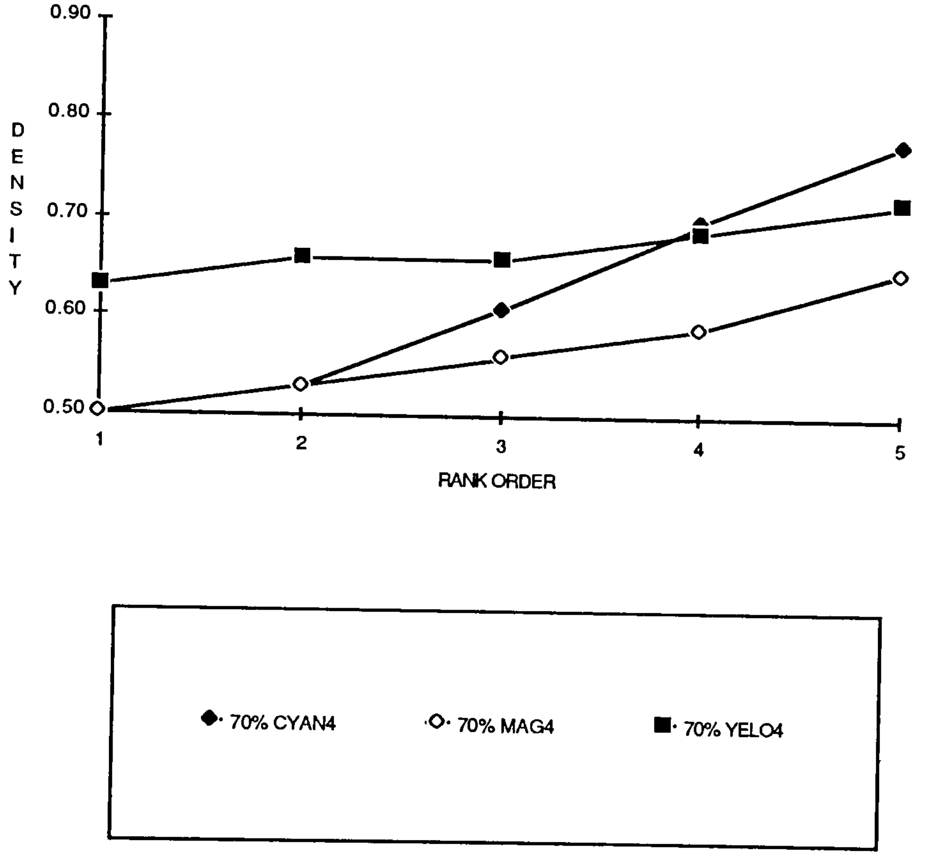


Figure 37

70% Spot 4
critical color

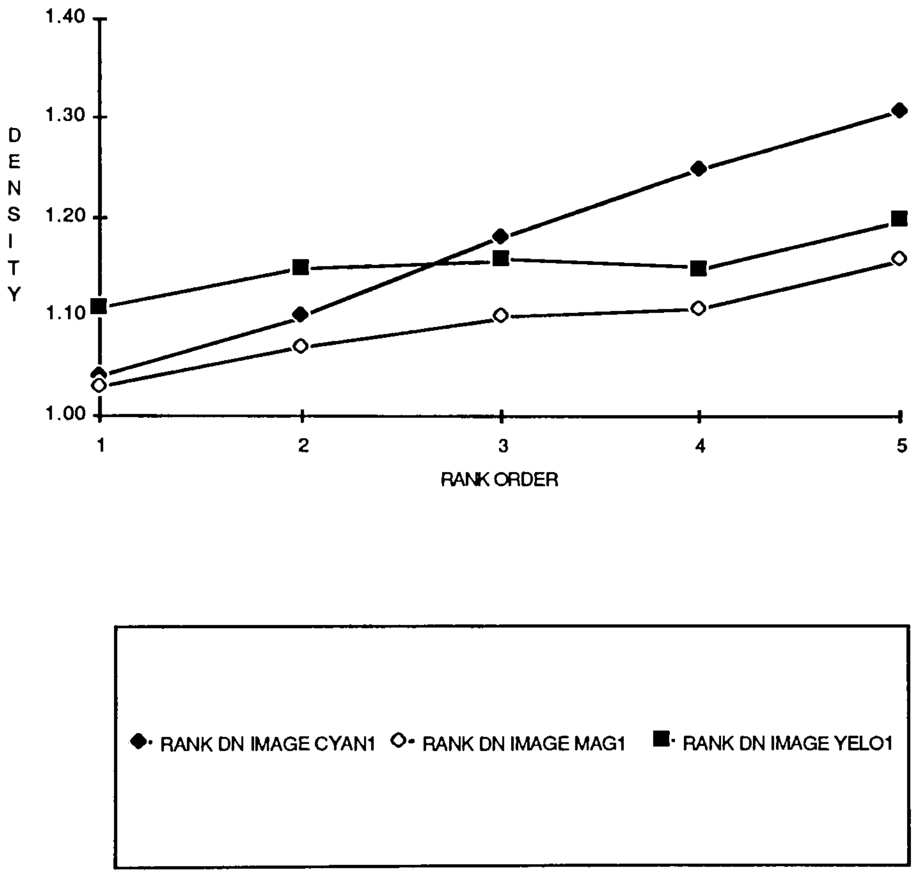


Figure 38

Image Spot 1
Dark neutrals

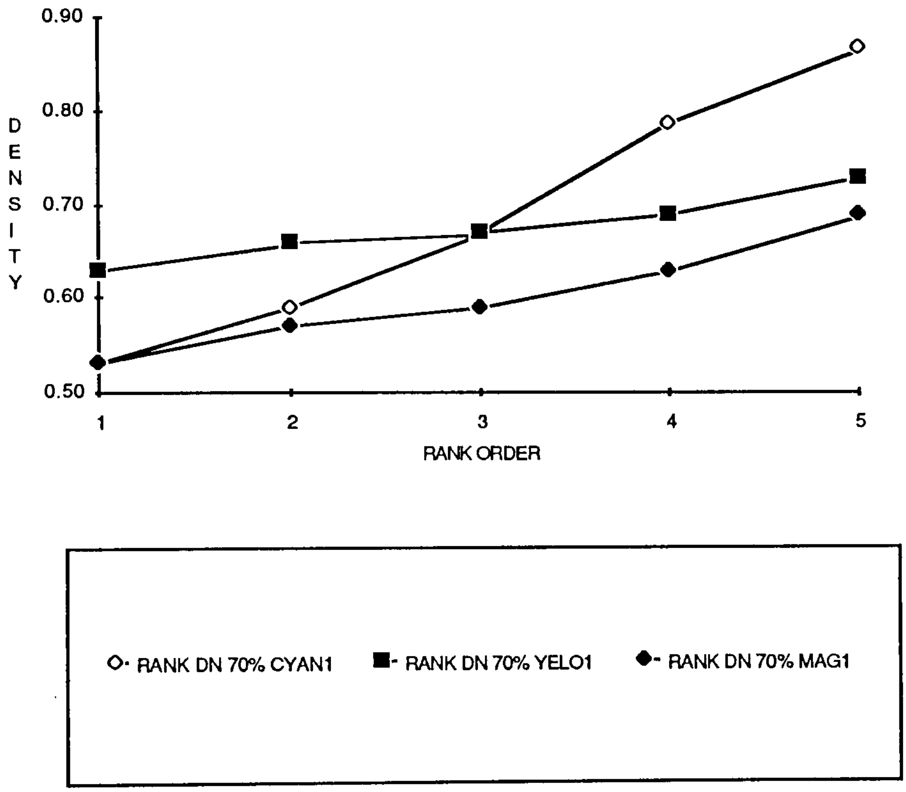


Figure 39

70% Spot 1
Dark neutrals

Color Tolerance Limits

Data taken from each of the three series of the press run phase II (low density, high density and color strength) indicated a significant problem existed with regard to establishing color tolerance limits. It had been assumed that if a series of samples presented to a panel of judges had differed in color hue and strength, in small increments, that a limit of acceptance could be established. The viewers would either accept or reject the sample and three filter density values representing the demarcation from acceptance to rejection would establish a tolerance limit. This demarcation would be defined as that point where seventy five percent of the viewers accepted the sample. Data taken from the low density color series was inconclusive because none of the samples presented were accepted by seventy five percent of the viewers.

Data obtained from the high density color series presented a different problem with setting color tolerance limits based upon three density filters values of the samples accepted by the judges. It is assumed that the color observers were judging color based upon the change in the total amount of red, green and blue light reflecting from the press sheet. Using period B of the high density color hue series as an example (see rank charts in figures 19 & 20) the demarcation between acceptance and rejection occurred between rank order four and five. Eighty percent of the viewers accepted rank four and only sixty percent of the viewers accepted rank five. It was clear from viewer response that rejection was based upon a shift in hue (represented a change in red, green and blue reflectance). It was unclear however which, if any of the three filter densities alone, was responsible for indicating the change red, green and blue reflectance

from the image.

The dominant density change was the increase in the red filter density between rank four and five. Between the two samples the green filter density did not change and the blue filter density decreased. Undoubtedly it was the total change in red, green and blue reflectance that caused the viewers to reject rank sample five after accepting sample four. It is the relationship as well as the level of the each of the three filter densities that is a measurement of the total red, green and blue reflectance from each area of the press sheet. Because of this it was not possible to set a tolerance limit at a specific set of numerical density values which would reflect the judge's acceptance or rejection.

The experimental design developed for this thesis utilized a series of ink manipulations that provided samples for viewer ranking. Because of this, color observers were performing paired comparisons of samples derived from an unstable process. In order to assign tolerance limits to control charts it would have been necessary to select samples from a stable press run for viewer response.

FOOTNOTES FOR CHAPTER VI

1. Albert D. Rickmers and Hollis N. Todd. Statistics: An Introduction, New York: McGraw Hill, 1967, pp. 397-398, 570.

2. Ibid., p. 563.

3. Ibid., p. 570.

4. Robert P. Mason. "Color Control by Image Color Measurement (A Progress Report)," TAGA Proceedings, (1987), p. 32.

5. Albert D. Rickmers and Hollis N. Todd. Statistics: An Introduction, New York: McGraw Hill, 1967, p. 563.

CHAPTER 7

SUMMARY AND CONCLUSIONS

This study investigated the use of densitometry as a tool in monitoring color hue and color strength change of the printed images taken from an offset lithographic press run. By analyzing which areas of the press sheet would be useful for monitoring red, green and blue filter density change, specific control points were proposed. These overprint tint areas indicated correspondence to the color hue and color strength change that was determined visually by a group of experienced color observers. Correlation analysis was performed to determined the degree of association between changes in three filter density values of the overprint areas of the press sheet and color variation as ranked by the viewers.

It was determined that dark neutral image areas were the most color hue and strength sensitive points in the press sheet image for monitoring changes in three filter densities. This was a significant result because it had been assumed that three filter density analysis could be performed in any image area of the press sheet and a change in red, green and blue filter density would correspond to a visual color hue and strength change of the press sheet overall. Image areas such as critical colors and light neutrals were determined to be less sensitive control points to monitor the change in relationship of three filter densities as color hue shifted. It is the relationship between the red, green and blue filter densities that changes in response to a variation in color hue thus it is

necessary to be able to monitor the relational change of the three filter densities. Critical colors such as the pastels of orange and raspberry sherbet were composed of halftone dots in highlight and quartertone region of the tonal range. Plots of three filter density change, reflecting a hue shift caused by inking manipulation, indicated that highlight and quartertones showed very slight density change.

Correlation analysis in graphical form showed that there was a significant correspondence between the color hue and strength change determined visually and the change in three filter density relationship of the seventy percent overprint tint bar. The fact that there were only three process colors, cyan, magenta and yellow used to make up the seventy percent overprint bar eliminated the variable of how a change in the black ink density might affect the three filter density relationship. The dark neutral image areas included a significant amount of black and this study found that an increase in black ink density caused a parallel increase in the green and blue filter density values of these overprint image areas supporting similar observations made in other research.[1] Thus if monitoring three filter density for change in image color hue, it is suggested that a seventy percent three color overprint bar should be placed in line with the image and monitored densitometrically. This near neutral control point reflects color hue and strength changes and provides a control bar that is sensitive to color variation throughout a press run. Monitoring this seventy percent overprint for relational change in three filter densities could provide the data necessary to control color during offset press runs.

FOOTNOTES FOR CHAPTER VII

1. Robert P. Mason. "Color Control by Image Color Measurement (A Progress Report)," TAGA Proceedings, (1987), p. 32.

CHAPTER 8

RECOMMENDATIONS FOR FURTHER INVESTIGATION

It had been hypothesized that data secured by acceptance or rejection of sample press sheets would enable establishment of tolerance limits for color variability based on density values. This goal however was not achieveable because the samples secured from the press run represented a high degree of color variation. Many of the samples demonstrating these gross changes in color hue were rejected by the observers as being out of tolerance for an average production press run. It was also determined that assignment of tolerance limits based on independent numerical values for each of the three filter densities would be insufficient in terms of determining limits for color variability. A complex interrelationship exists between three filter density values taken from an overprint area of a printed image. The data secured by this study proved to be insufficient to analyse this type of dynamic change. Color hue and strength differences in the print area are indications of a change in red, green and blue reflectance. What this work demonstrates to the industry is that specific areas of the press sheet need to be monitored if three filter density analysis is to be of use in controlling color variation during offset lithographic press runs. The three filter density values taken from a specific overprint area throughout a press run will reflect the change in red, green and blue reflectance. There could be a continual change in relationship of the three filter densities representing a

constantly changing print hue and strength. With the OK press sheet defined as the nullpoint, away from which the red, green and blue filter density values would move, another study might determine the acceptable range of this movement in density. Such a study would require careful planning to ensure that data secured could contribute to the specific objective of determining tolerance limits.

If three filter density values are monitored and color variation is a function of the change in relationship of these three variables then an analysis of the relational change of the variables is necessary. Other research done in the area of press sheet image densitometric and colorimetric analysis have made use of control charts to monitor color variation. Individual three filter density control chart plots indicate the change in density values throughout a press run as color moves away from the OK sheet. Placement of the upper and lower control limits for each of the three filter density values however would be insufficient because the limits for color variation need to address the changing relationship of the three variables. This indicates that further research in this area will require a narrowly defined set of hypotheses in order to establish limits to color variation defined by a group of experienced color viewers. A study that looks at specific color hue shifts would address both a simplified experimental design and data analysis as well as take into account the color response of the human visual system.

The outcome of work with densitometery used to scan plates for presetting ink fountain keys has provided the offset printer with a starting point for the press run. The press operator then takes control of fine tuning the press for inking adjustment and register. It seems likely that a scanning densitometer interfaced to a computer will soon be able to monitor color variation during a press run and

through a feedback loop reset inking controls to compensate for hue shifts in the press sheet. The fine inking adjustments will likely be accomplished by the press operator for some time however, because of the efficiency of the human eye and brain in responding to color variation while also taking into account the quality level expected by the printing customer.

APPENDICES

APPENDIX A

TABLE 1
Low Density Series

Judge A	Judge B	di	di^2
1	2	1	1
2	1	1	1
3	3	0	0
4	4	0	0
5	5	0	0
		Total	2

Results of Ranking

Coefficient of Rank Correlation

$$rs = 1 - \frac{6\Sigma di^2}{n(n^2-1)}$$

$$rs = .90$$

Since the calculated rs(.90) is greater than the table value (.87) then we reject the hypothesis of independence of judges and conclude that there is evidence of agreement between them.

TABLE 2
High Density Series

Judge A	Judge B	di	di2
1	2	1	1
2	1	1	1
3	3	0	0
4	4	0	0
5	5	0	0
		Total	2

Results of Ranking

Coefficient of Rank Correlation

$$rs = 1 - \frac{6\Sigma di^2}{n(n^2-1)}$$

rs = .90

Judge A	Judge C	di	di2
1	1	0	0
2	3	1	1
3	2	1	1
4	4	0	0
5	5	0	0
		Total	2

TABLE 2 (continued)

Results of Ranking

Coefficient of Rank Correlation

$$rs = 1 - \frac{6\Sigma di^2}{n(n^2-1)}$$

rs = .90

Judge A	Judge D	di	di2
1	2	1	1
2	1	1	1
3	3	0	0
4	4	0	0
5	5	0	0
		Total	2

Results of Ranking

Coefficient of Rank Correlation

$$rs = 1 - \frac{6\Sigma di^2}{n(n^2-1)}$$

rs = .90

TABLE 2 (continued)

In each of the three High density cases the calculated rs(.90) is greater than the table value (.87) and we reject the hypothesis of independence of judges and conclude that there is evidence of agreement between them.

APPENDIX B

TABLE 3

LOW DENSITY SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Dark Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.522	-0.999	-0.95
2	0.945	-0.998	-0.985
3	0.577	-0.998	-0.93
4	0.516	-0.991	-0.999
MEAN	0.64	-0.999	-0.969

Rank Order vs Image Dark Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.923	-0.953	0.077
2	0.866	-0.978	-0.674
3	0.423	-0.967	-0.73
4	0.453	-0.974	-0.577
MEAN	0.686	-0.972	-0.493

TABLE 4

LOW DENSITY SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Critical Colors Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.832	-0.987	-0.979
2	0.892	-0.969	-0.933
3	0.783	-0.986	-0.976
4	0.575	-0.982	-0.729
MEAN	0.696	-0.986	-0.969

Rank Order vs Image Critical Color Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.707	-0.772	-0.6
2	0.289	-0.858	-0.892
3	0.354	-0.979	-0.995
4	0.983	-0.825	0.277
MEAN	na	na	na

TABLE 5

LOW DENSITY SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Light Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.832	-0.987	-0.979
4	0.575	-0.982	-0.729
5	0.381	-0.979	-0.95

Rank Order vs Image Light Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1a	0.973	-0.932	-0.904
4a	0.849	-0.866	-0.73
5	0.866	-0.973	-0.893

TABLE 6

HIGH DENSITY SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Dark Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.984	0.707	-0.395
2	0.974	0.364	-0.832
3	0.986	0.832	-0.277
4	0.979	0.756	-0.606
MEAN	0.982	0.645	-0.474

Rank Order vs Image Dark Neutrals Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.921	0.811	0.082
2	0.936	0.728	0.138
3	0.92	0.373	0.061
4	0.943	0.481	-0.289
MEAN	0.927	0.539	0

TABLE 7

HIGH DENSITY SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Critical Color Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.977	0	-0.707
2	0.99	0.129	-0.707
3	1	-0.53	-0.802
4	0.986	0.129	-0.555
MEAN	0.982	0.645	-0.474

Rank Order vs Image Critical Color Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.447	0.169	0.517
2	0.97	0.693	0.566
3	0.834	-0.416	-0.224
4	0.932	0.497	0.243
MEAN	na	na	na

TABLE 8

HIGH DENSITY SERIES
Correlation Coefficients

Rank vs Seventy Percent Light Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.977	0	-0.707
4	0.986	0.129	-0.555
5	0.985	0	-0.472
MEAN	0.982	0.645	-0.474

Rank Order vs Image Light Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1a	0.936	0.73	0.606
4a	0.969	0.728	0.487
5	0.983	0.73	0.348
MEAN	0.981	0.848	0.417

TABLE 9

COLOR STRENGTH SERIES
Correlation Coefficients

Rank vs Seventy Percent Dark Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.993	0.985	0.979
2	0.994	0.987	0.994
3	0.992	0.985	0.971
4	0.993	0.979	0.962
MEAN	0.993	0.979	0.99

Rank Order vs Image Dark Neutrals Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.999	0.983	0.887
2	0.988	0.998	0.956
3	0.998	0.982	0.964
4	0.991	0.998	0.974
MEAN	0.997	0.972	0.954

TABLE 10

COLOR STRENGTH SERIES
Correlation Coefficients

Rank Order vs Seventy Percent Critical Color Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0.993	0.979	0.971
2	0.994	0.985	0.983
3	0.996	0.985	0.985
4	0.992	0.986	0.971
MEAN	0.994	0.979	0.991

Rank Order vs Image Critical Color Areas

SPOT	CYAN	MAGENTA	YELLOW
1	0	0.834	0.868
2	0.791	0.971	0.904
3	0.912	0.971	0.974
4	0.981	0.989	0.967
MEAN	0.884	0.949	0.957

Rank Order vs 70% & Image Light Neutral Areas

SPOT	CYAN	MAGENTA	YELLOW
70% MEAN	0.993	0.977	0.979
IMAGE MEAN	0.982	0.976	0.985

APPENDIX C

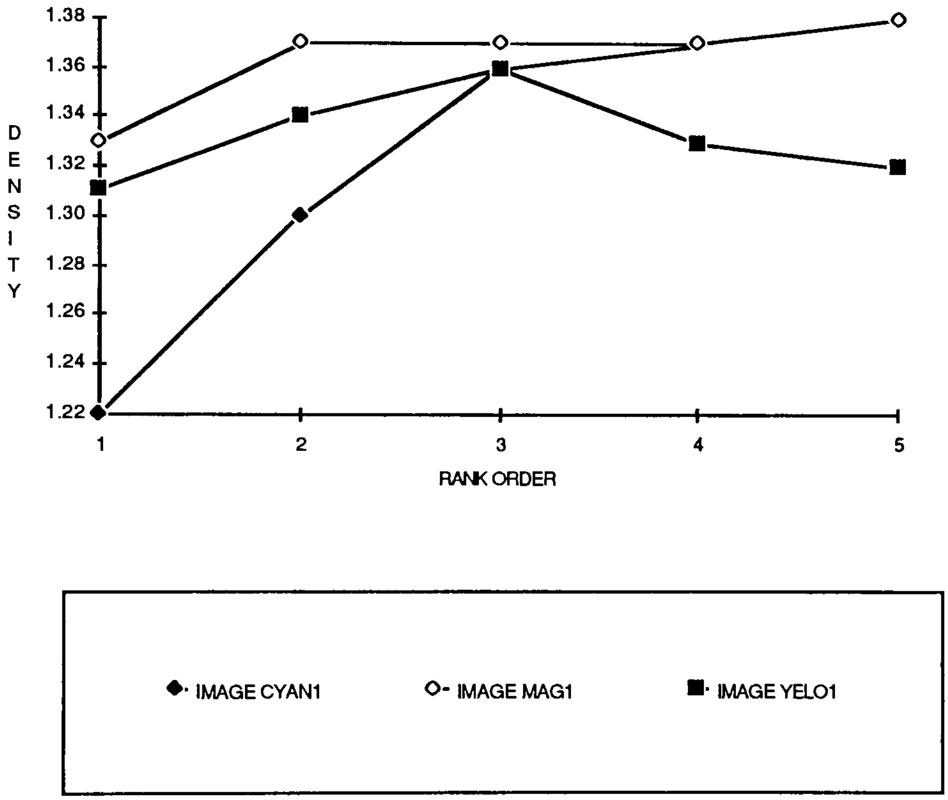


Figure 40
High density Hue correlation
of dark neutral image Spot 1

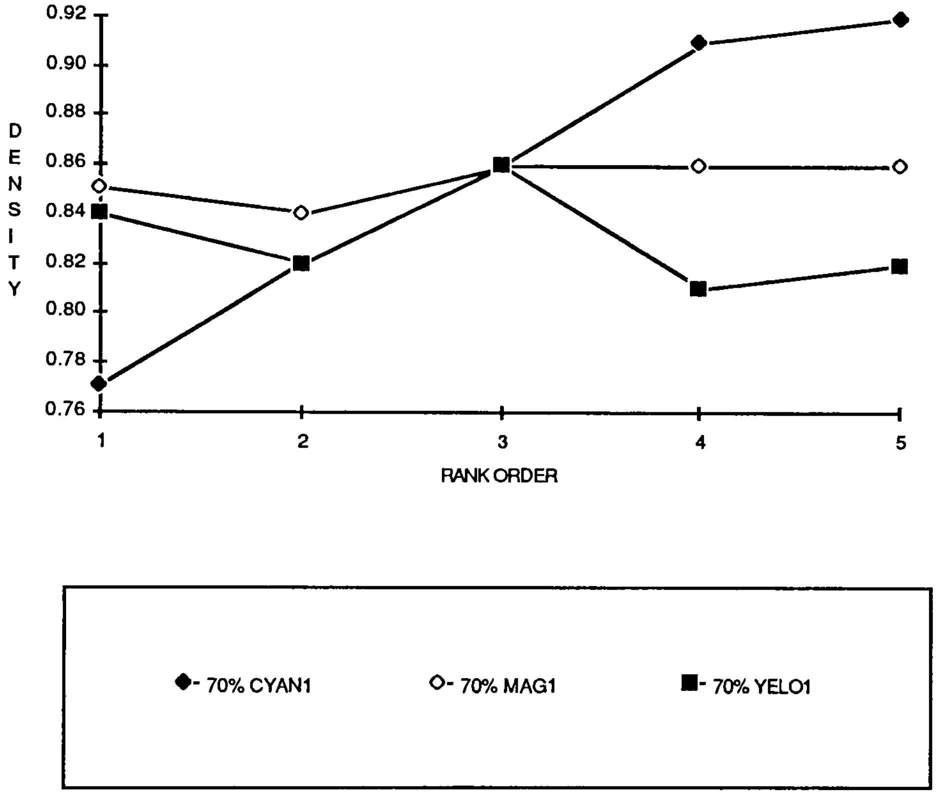


Figure 41
High density Hue correlation
of dark neutral 70% Spot 1

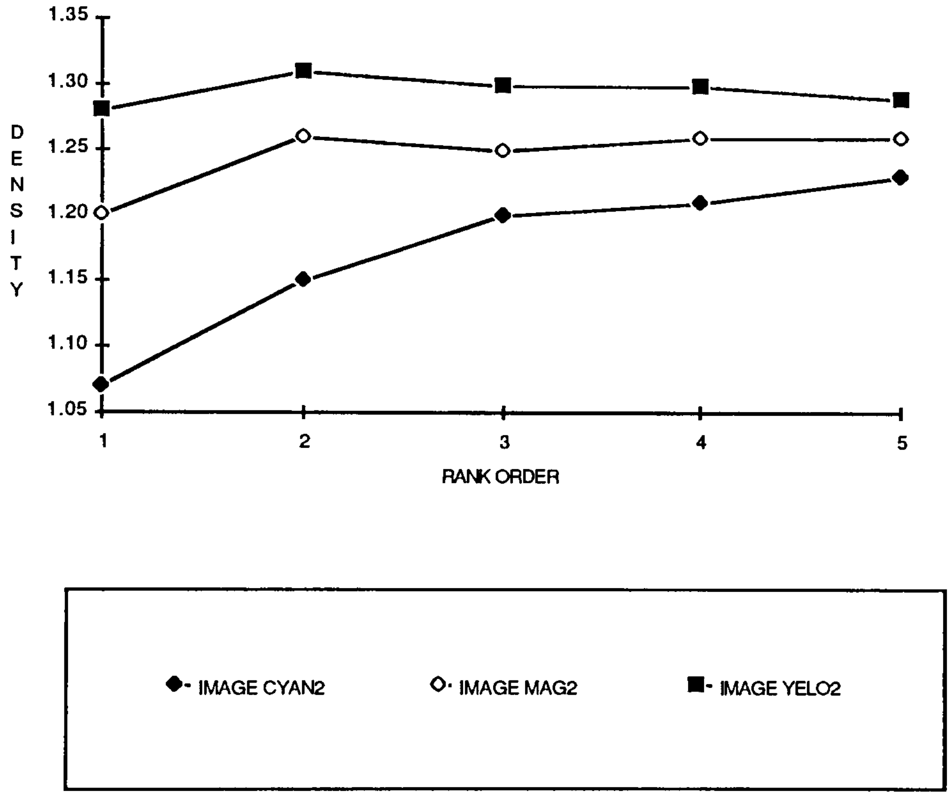


Figure 42
High density Hue correlation
of dark neutral image Spot 2

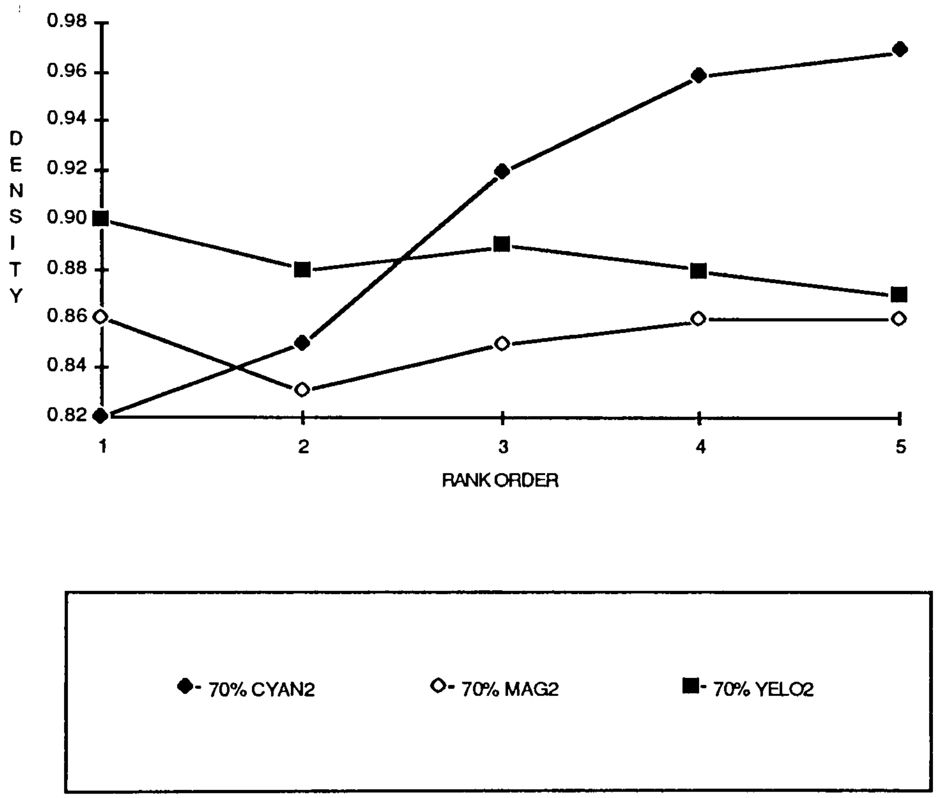


Figure 43
High density Hue correlation
of dark neutral 70% Spot 2

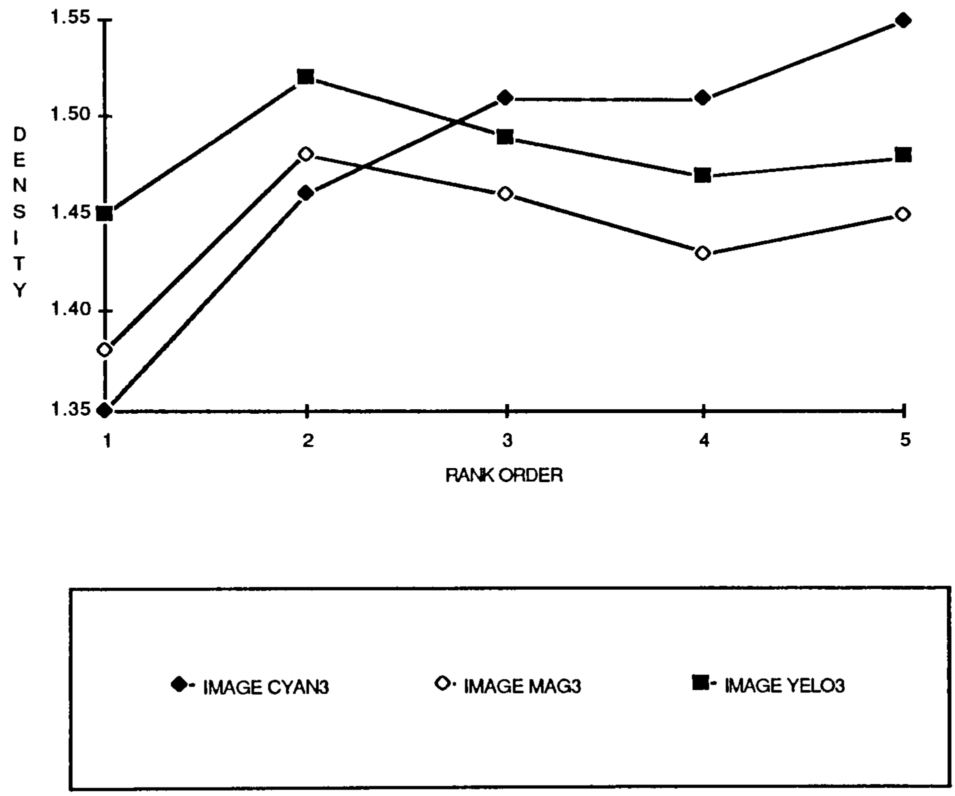


Figure 44
High density Hue correlation
of dark neutral image Spot 3

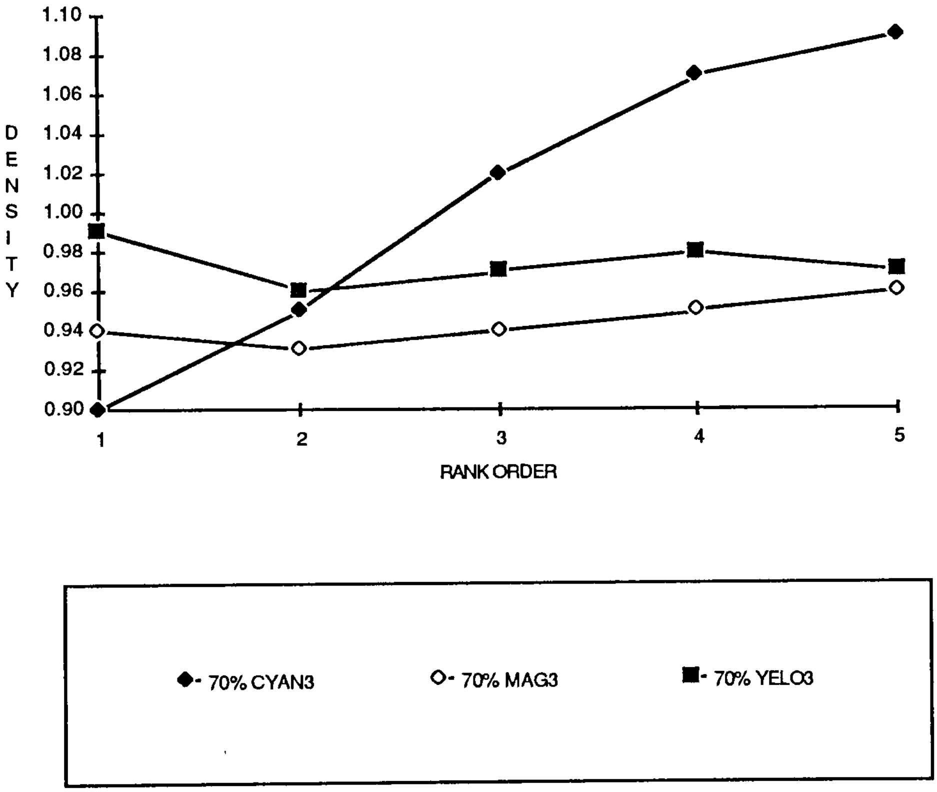


Figure 45
High density Hue correlation
of dark neutral 70% Spot 3

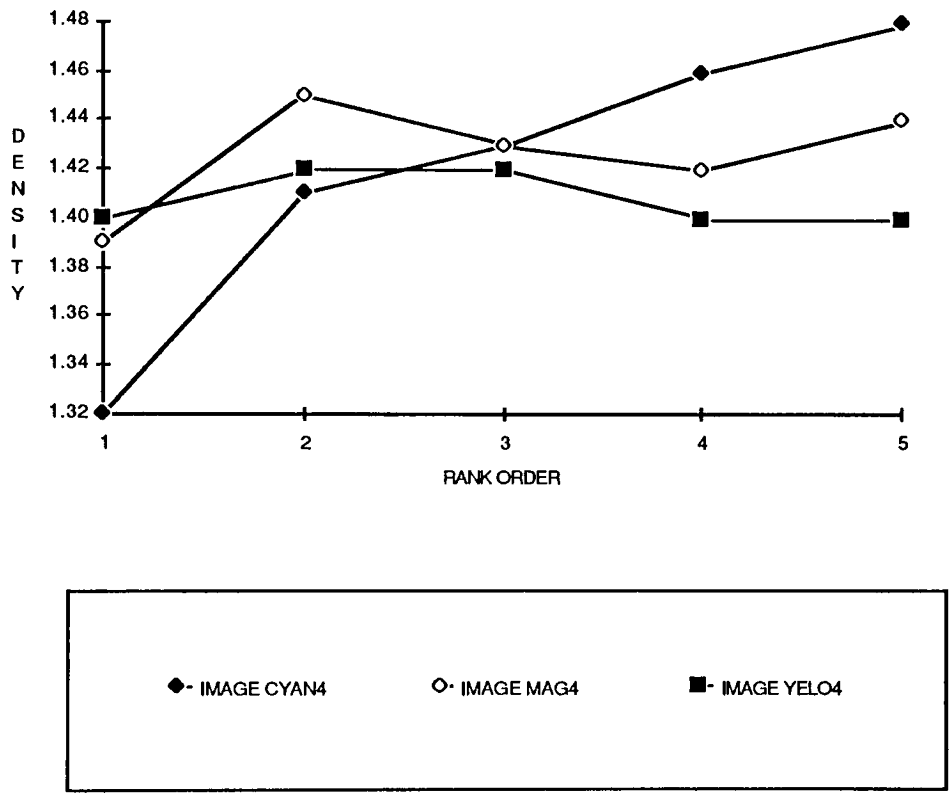


Figure 46
High density Hue correlation
of dark neutral image Spot 4

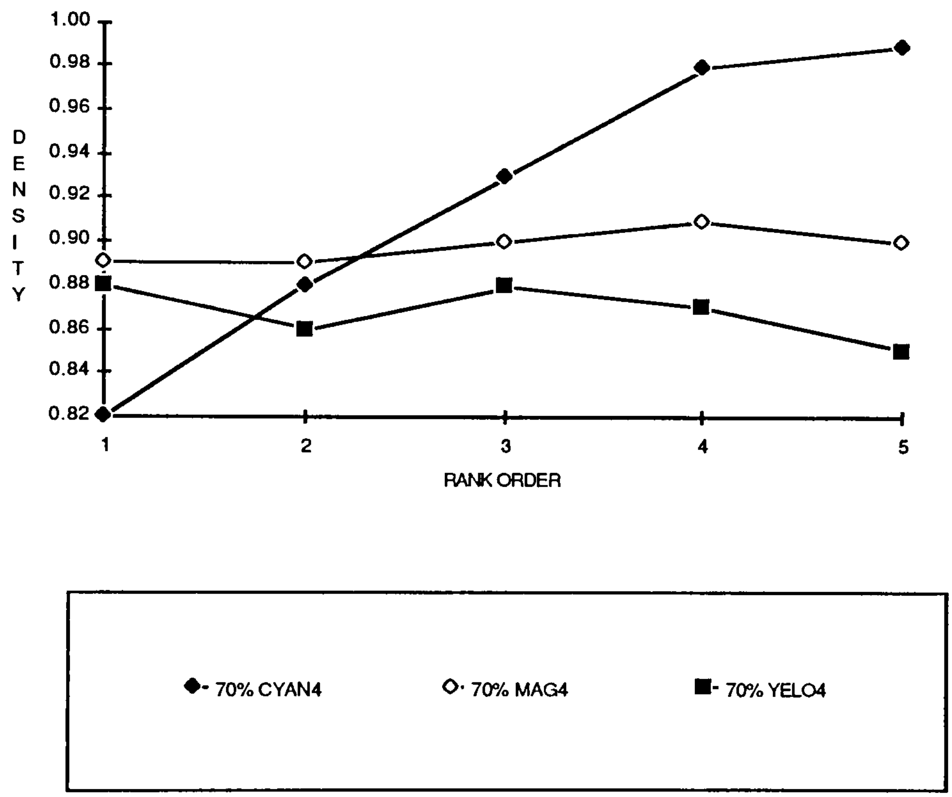


Figure 47
High density Hue correlation
of dark neutral 70% Spot 4

APPENDIX D

Table 11

LOW DENSITY CYAN

DARK NEUTRALS

70% TINT

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
CK	0.83	0.90	0.89
1	0.82	0.89	0.75
2	0.85	0.90	0.77
3	0.84	0.87	0.75
4	0.84	0.84	0.74
5	0.83	0.79	0.73
6	0.85	0.75	0.70
7	0.86	0.75	0.69
8	0.83	0.73	0.70
9	0.85	0.72	0.69
10	0.83	0.71	0.69

LOW DENSITY CYAN

DARK NEUTRALS

IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
CK	1.29	1.36	1.38
1	1.34	1.41	1.28
2	1.35	1.40	1.29
3	1.34	1.38	1.27
4	1.32	1.33	1.24
5	1.34	1.29	1.23
6	1.33	1.26	1.23
7	1.34	1.27	1.23
8	1.35	1.26	1.23
9	1.35	1.23	1.22
10	1.39	1.26	1.27

Table 12
LOW DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
CK	0.90	0.94	0.99
1	0.91	0.93	0.84
2	0.93	0.93	0.86
3	0.92	0.93	0.85
4	0.91	0.89	0.84
5	0.91	0.83	0.81
6	0.92	0.79	0.78
7	0.93	0.79	0.79
8	0.91	0.78	0.80
9	0.93	0.76	0.78
10	0.93	0.74	0.78

LOW DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
CK	1.36	1.40	1.46
1	1.41	1.44	1.34
2	1.43	1.44	1.36
3	1.44	1.46	1.37
4	1.41	1.39	1.33
5	1.42	1.34	1.32
6	1.41	1.30	1.31
7	1.41	1.31	1.32
8	1.42	1.32	1.32
9	1.43	1.28	1.32
10	1.45	1.29	1.33

Table 13
LOW DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
CK	0.82	0.85	0.90
1	0.81	0.84	0.77
2	0.84	0.85	0.77
3	0.82	0.83	0.76
4	0.82	0.80	0.75
5	0.82	0.75	0.73
6	0.82	0.71	0.71
7	0.84	0.71	0.70
8	0.82	0.70	0.71
9	0.85	0.69	0.71
10	0.82	0.67	0.71

LOW DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
CK	1.07	1.19	1.25
1	1.09	1.21	1.14
2	1.11	1.21	1.13
3	1.10	1.20	1.13
4	1.09	1.15	1.12
5	1.07	1.09	1.12
6	1.08	1.06	1.11
7	1.08	1.07	1.11
8	1.10	1.08	1.10
9	1.10	1.06	1.10
10	1.12	1.05	1.12

Table 14
LOW DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	0.77	0.85	0.85
1	0.76	0.84	0.72
2	0.79	0.84	0.74
3	0.77	0.82	0.71
4	0.77	0.79	0.70
5	0.76	0.73	0.70
6	0.79	0.71	0.68
7	0.79	0.71	0.66
8	0.77	0.69	0.67
9	0.79	0.68	0.66
10	0.77	0.66	0.66

LOW DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	1.22	1.33	1.32
1	1.23	1.32	1.20
2	1.26	1.32	1.20
3	1.25	1.31	1.20
4	1.24	1.28	1.19
5	1.24	1.24	1.18
6	1.25	1.20	1.17
7	1.22	1.19	1.15
8	1.24	1.19	1.15
9	1.25	1.16	1.14
10	1.28	1.19	1.19

Table 15
LOW DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
CK	0.83	0.89	0.91
1	0.83	0.88	0.77
2	0.85	0.88	0.79
3	0.84	0.86	0.77
4	0.84	0.83	0.76
5	0.83	0.78	0.74
6	0.85	0.74	0.72
7	0.86	0.74	0.71
8	0.83	0.73	0.72
9	0.86	0.71	0.71
10	0.84	0.70	0.71

LOW DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
CK	1.24	1.32	1.35
1	1.27	1.35	1.24
2	1.29	1.34	1.25
3	1.28	1.34	1.24
4	1.27	1.29	1.22
5	1.27	1.24	1.21
6	1.27	1.21	1.21
7	1.26	1.21	1.20
8	1.28	1.21	1.20
9	1.28	1.18	1.20
10	1.31	1.20	1.23

Table 16
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.82	0.88	0.92
1	0.81	0.87	0.77
2	0.83	0.87	0.79
3	0.83	0.86	0.79
4	0.82	0.83	0.77
5	0.82	0.76	0.76
6	0.82	0.73	0.72
7	0.84	0.73	0.72
8	0.81	0.72	0.74
9	0.83	0.71	0.72
10	0.83	0.70	0.71

LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.11	0.26	0.47
1	0.11	0.25	0.40
2	0.11	0.26	0.42
3	0.11	0.27	0.42
4	0.11	0.25	0.41
5	0.11	0.21	0.38
6	0.11	0.21	0.38
7	0.11	0.21	0.39
8	0.11	0.22	0.41
9	0.12	0.22	0.39
10	0.11	0.22	0.40

Table 17
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	0.94	0.96	1.00
1	0.93	0.94	0.84
2	0.95	0.96	0.87
3	0.95	0.94	0.85
4	0.94	0.90	0.85
5	0.94	0.84	0.83
6	0.96	0.80	0.79
7	0.97	0.80	0.79
8	0.95	0.79	0.81
9	0.96	0.78	0.79
10	0.96	0.77	0.80

LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	0.14	0.35	0.30
1	0.13	0.35	0.27
2	0.14	0.37	0.29
3	0.15	0.39	0.29
4	0.14	0.34	0.27
5	0.14	0.29	0.24
6	0.14	0.28	0.24
7	0.13	0.28	0.24
8	0.14	0.30	0.26
9	0.14	0.29	0.24
10	0.14	0.29	0.24

Table 18
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	0.90	0.92	0.97
1	0.89	0.92	0.83
2	0.92	0.93	0.84
3	0.91	0.91	0.82
4	0.90	0.87	0.82
5	0.90	0.80	0.81
6	0.93	0.77	0.77
7	0.93	0.78	0.78
8	0.91	0.76	0.79
9	0.94	0.74	0.76
10	0.91	0.74	0.76

LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	0.39	0.98	1.04
1	0.40	1.00	0.89
2	0.40	0.99	0.89
3	0.40	0.98	0.88
4	0.39	0.93	0.87
5	0.39	0.85	0.86
6	0.38	0.82	0.85
7	0.41	0.82	0.84
8	0.39	0.82	0.85
9	0.39	0.79	0.83
10	0.39	0.79	0.82

Table 19
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	0.81	0.86	0.87
1	0.79	0.84	0.75
2	0.82	0.85	0.76
3	0.80	0.84	0.75
4	0.81	0.79	0.73
5	0.79	0.73	0.72
6	0.80	0.70	0.70
7	0.82	0.72	0.69
8	0.80	0.70	0.69
9	0.82	0.69	0.69
10	0.80	0.68	0.72

LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	1.40	1.39	1.41
1	1.41	1.41	1.32
2	1.44	1.43	1.33
3	1.40	1.40	1.32
4	1.40	1.35	1.31
5	1.41	1.31	1.30
6	1.43	1.33	1.33
7	1.45	1.31	1.31
8	1.44	1.33	1.32
9	1.44	1.26	1.27
10	1.47	1.32	1.33

Table 20
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 5	MAGENTA 5	YELLOW 5
OK	0.78	0.87	0.85
1	0.77	0.84	0.71
2	0.79	0.85	0.74
3	0.78	0.83	0.72
4	0.78	0.80	0.71
5	0.76	0.73	0.70
6	0.79	0.71	0.67
7	0.81	0.71	0.66
8	0.79	0.70	0.66
9	0.80	0.69	0.65
10	0.77	0.68	0.66

LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 5	MAGENTA 5	YELLOW 5
OK	0.44	0.52	0.59
1	0.45	0.52	0.54
2	0.46	0.53	0.54
3	0.45	0.52	0.53
4	0.44	0.49	0.52
5	0.44	0.45	0.49
6	0.44	0.44	0.48
7	0.45	0.45	0.49
8	0.46	0.46	0.51
9	0.46	0.45	0.49
10	0.45	0.45	0.49

Table 21
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
CK	0.85	0.90	0.92
1	0.84	0.88	0.78
2	0.86	0.89	0.80
3	0.85	0.88	0.79
4	0.85	0.84	0.78
5	0.84	0.77	0.76
6	0.86	0.74	0.73
7	0.87	0.75	0.73
8	0.85	0.73	0.74
9	0.87	0.72	0.72
10	0.85	0.71	0.73

Table 22
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.64	0.76	0.85
1	0.63	0.72	0.77
2	0.62	0.74	0.77
3	0.62	0.74	0.78
4	0.63	0.69	0.75
5	0.63	0.65	0.74
6	0.63	0.64	0.73
7	0.65	0.64	0.74
8	0.63	0.64	0.76
9	0.62	0.62	0.73
10	0.66	0.64	0.73

Table 23
LOW DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 4a	MAGENTA 4a	YELLOW 4a
OK	0.41	0.52	0.61
1	0.41	0.50	0.56
2	0.40	0.51	0.56
3	0.40	0.50	0.55
4	0.41	0.48	0.53
5	0.40	0.44	0.51
6	0.40	0.44	0.51
7	0.42	0.44	0.52
8	0.41	0.44	0.54
9	0.40	0.42	0.51
10	0.42	0.44	0.52

Table 24
HIGH DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.97	0.90	0.90
1	0.78	0.86	0.85
2	0.80	0.86	0.85
3	0.82	0.84	0.82
4	0.84	0.87	0.85
5	0.86	0.86	0.86
6	0.90	0.87	0.83
7	0.91	0.86	0.81
8	0.94	0.88	0.82
9	0.89	0.87	0.84
10	0.89	0.88	0.84

HIGH DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	1.46	1.41	1.43
1	1.27	1.38	1.35
2	1.29	1.37	1.35
3	1.30	1.37	1.34
4	1.33	1.37	1.36
5	1.36	1.37	1.36
6	1.34	1.37	1.32
7	1.37	1.37	1.33
8	1.38	1.40	1.34
9	1.38	1.38	1.35
10	1.38	1.39	1.36

Table 25
HIGH DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	1.08	0.91	1.00
1	0.82	0.85	0.90
2	0.84	0.85	0.90
3	0.85	0.83	0.88
4	0.87	0.85	0.89
5	0.92	0.85	0.89
6	0.94	0.87	0.88
7	0.96	0.86	0.88
8	0.99	0.88	0.88
9	0.94	0.85	0.88
10	0.94	0.88	0.91

HIGH DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	1.53	1.39	1.48
1	1.13	1.26	1.32
2	1.14	1.24	1.30
3	1.15	1.26	1.31
4	1.18	1.25	1.30
5	1.20	1.25	1.30
6	1.17	1.25	1.28
7	1.21	1.26	1.30
8	1.23	1.29	1.29
9	1.23	1.27	1.32
10	1.22	1.27	1.32

Table 26
HIGH DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	0.96	0.84	0.93
1	0.92	0.95	0.99
2	0.93	0.94	0.99
3	0.95	0.93	0.96
4	0.99	0.94	0.98
5	1.02	0.94	0.97
6	1.03	0.96	0.97
7	1.07	0.95	0.98
8	1.05	0.97	0.98
9	1.05	0.96	0.98
10	1.04	0.96	0.99

HIGH DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	1.20	1.23	1.33
1	1.44	1.47	1.50
2	1.45	1.45	1.49
3	1.46	1.48	1.52
4	1.48	1.45	1.50
5	1.51	1.46	1.49
6	1.49	1.46	1.48
7	1.51	1.43	1.47
8	1.53	1.49	1.49
9	1.55	1.47	1.50
10	1.55	1.47	1.49

Table 27
HIGH DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	0.91	0.88	0.89
1	0.85	0.90	0.88
2	0.85	0.90	0.88
3	0.88	0.89	0.86
4	0.90	0.92	0.89
5	0.93	0.90	0.88
6	0.95	0.92	0.87
7	0.98	0.91	0.87
8	0.98	0.92	0.87
9	0.95	0.91	0.88
10	0.96	0.92	0.89

HIGH DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	1.35	1.36	1.39
1	1.40	1.46	1.42
2	1.40	1.44	1.43
3	1.41	1.45	1.42
4	1.41	1.42	1.42
5	1.43	1.43	1.42
6	1.44	1.43	1.40
7	1.46	1.42	1.40
8	1.46	1.45	1.40
9	1.48	1.45	1.43
10	1.47	1.46	1.42

Table 28
HIGH DENSITY CYAN
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
OK	0.98	0.88	0.93
1	0.84	0.89	0.91
2	0.86	0.89	0.91
3	0.88	0.87	0.88
4	0.90	0.90	0.90
5	0.93	0.89	0.90
6	0.96	0.91	0.89
7	0.98	0.90	0.89
8	0.99	0.91	0.89
9	0.96	0.90	0.90
10	0.96	0.91	0.91

HIGH DENSITY CYAN
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
OK	1.39	1.35	1.41
1	1.31	1.39	1.40
2	1.32	1.38	1.39
3	1.33	1.39	1.40
4	1.35	1.37	1.40
5	1.38	1.38	1.39
6	1.36	1.38	1.37
7	1.39	1.37	1.38
8	1.40	1.41	1.38
9	1.41	1.39	1.40
10	1.41	1.40	1.40

Table 29
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.96	0.86	0.94
1	0.82	0.87	0.91
2	0.84	0.89	0.93
3	0.86	0.87	0.91
4	0.88	0.89	0.92
5	0.91	0.88	0.91
6	0.92	0.91	0.91
7	0.94	0.89	0.91
8	0.94	0.92	0.91
9	0.92	0.90	0.92
10	0.93	0.91	0.93

HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	0.13	0.27	0.53
1	0.12	0.25	0.47
2	0.12	0.26	0.47
3	0.12	0.27	0.47
4	0.14	0.30	0.52
5	0.13	0.30	0.53
6	0.12	0.26	0.46
7	0.12	0.27	0.50
8	0.12	0.28	0.50
9	0.12	0.28	0.49
10	0.12	0.27	0.47

Table 30
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	1.12	0.92	1.02
1	0.96	0.96	1.02
2	0.99	0.97	1.01
3	0.99	0.95	0.99
4	1.03	0.98	1.02
5	1.05	0.96	0.99
6	1.07	0.98	0.99
7	1.11	0.98	0.99
8	1.11	0.99	0.99
9	1.09	0.98	0.99
10	1.08	0.98	1.00

HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
OK	0.17	0.38	0.34
1	0.14	0.35	0.30
2	0.16	0.36	0.31
3	0.15	0.36	0.30
4	0.16	0.39	0.33
5	0.16	0.40	0.34
6	0.15	0.35	0.29
7	0.17	0.38	0.32
8	0.16	0.38	0.32
9	0.16	0.37	0.31
10	0.15	0.36	0.30

Table 31
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	1.06	0.90	1.00
1	0.91	0.93	0.99
2	0.93	0.92	0.98
3	0.95	0.92	0.98
4	0.98	0.93	0.97
5	0.99	0.93	0.98
6	1.02	0.94	0.96
7	1.03	0.93	0.95
8	1.07	0.95	0.96
9	1.03	0.94	0.97
10	1.02	0.95	0.97

HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
OK	0.43	0.96	1.10
1	0.40	1.01	1.07
2	0.40	0.99	1.06
3	0.41	1.00	1.05
4	0.42	0.98	1.06
5	0.40	0.99	1.05
6	0.44	1.02	1.05
7	0.43	1.01	1.06
8	0.43	1.02	1.04
9	0.42	1.00	1.05
10	0.42	1.00	1.05

Table 32
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	0.94	0.85	0.92
1	0.81	0.87	0.90
2	0.83	0.85	0.88
3	0.84	0.85	0.86
4	0.87	0.87	0.89
5	0.88	0.86	0.88
6	0.91	0.89	0.86
7	0.93	0.88	0.86
8	0.96	0.90	0.86
9	0.92	0.87	0.87
10	0.90	0.88	0.89

HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
OK	1.55	1.44	1.52
1	1.50	1.50	1.52
2	1.48	1.48	1.49
3	1.50	1.50	1.51
4	1.51	1.46	1.49
5	1.52	1.47	1.47
6	1.55	1.50	1.49
7	1.56	1.49	1.49
8	1.60	1.51	1.48
9	1.56	1.48	1.47
10	1.57	1.49	1.49

Table 33
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN 5	MAGENTA 5	YELLOW 5
OK	0.92	0.89	0.89
1	0.79	0.87	0.86
2	0.81	0.87	0.85
3	0.84	0.86	0.83
4	0.85	0.88	0.85
5	0.86	0.88	0.86
6	0.90	0.89	0.84
7	0.91	0.88	0.82
8	0.94	0.89	0.82
9	0.90	0.88	0.83
10	0.89	0.89	0.85

HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 5	MAGENTA 5	YELLOW 5
OK	0.51	0.57	0.65
1	0.45	0.53	0.61
2	0.46	0.53	0.61
3	0.46	0.54	0.61
4	0.49	0.56	0.63
5	0.49	0.56	0.63
6	0.48	0.54	0.59
7	0.50	0.55	0.61
8	0.50	0.56	0.61
9	0.49	0.56	0.62
10	0.48	0.55	0.61

Table 34
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
70% TINT

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
OK	1.00	0.88	0.95
1	0.86	0.90	0.94
2	0.88	0.90	0.93
3	0.90	0.89	0.91
4	0.92	0.91	0.93
5	0.94	0.90	0.92
6	0.96	0.92	0.91
7	0.98	0.91	0.91
8	1.00	0.93	0.91
9	0.97	0.91	0.92
10	0.96	0.92	0.93

Table 35
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 1a	MAGENTA 1a	YELLOW 1a
OK	0.69	0.76	0.90
1	0.66	0.76	0.89
2	0.66	0.75	0.89
3	0.67	0.77	0.89
4	0.68	0.78	0.89
5	0.66	0.77	0.89
6	0.69	0.75	0.87
7	0.70	0.78	0.88
8	0.68	0.77	0.89
9	0.70	0.79	0.90
10	0.69	0.77	0.88

Table 36
HIGH DENSITY CYAN
LIGHT NEUTRALS & CRITICAL COLORS
IMAGE

SHEET SEQ	CYAN 4a	MAGENTA 4a	YELLOW 4a
OK	0.45	0.52	0.66
1	0.42	0.52	0.63
2	0.43	0.52	0.63
3	0.43	0.52	0.62
4	0.45	0.55	0.65
5	0.44	0.54	0.65
6	0.45	0.53	0.61
7	0.46	0.54	0.64
8	0.45	0.54	0.63
9	0.44	0.54	0.63
10	0.45	0.54	0.62

Table 37
COLOR STRENGTH SERIES
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
CK	0.98	0.89	0.89
1	0.94	0.84	0.89
2	0.93	0.82	0.90
3	0.92	0.82	0.87
4	0.91	0.82	0.89
5	0.92	0.80	0.88
6	0.90	0.79	0.86
7	0.89	0.79	0.84
8	0.91	0.78	0.80
9	0.90	0.77	0.77
10	0.90	0.72	0.75
11	0.87	0.69	0.73
12	0.87	0.65	0.69
13	0.79	0.63	0.69
14	0.71	0.62	0.70
15	0.67	0.59	0.67
16	0.62	0.58	0.66
17	0.59	0.57	0.66
18	0.55	0.54	0.64
19	0.53	0.53	0.63
20	0.52	0.53	0.61
21	0.52	0.53	0.60
22	0.50	0.51	0.58
23	0.50	0.51	0.57
24	0.48	0.50	0.56
25	0.48	0.50	0.55
26	0.47	0.47	0.55
27	0.47	0.47	0.54
28	0.47	0.47	0.53
29	0.46	0.47	0.53
30	0.44	0.46	0.52

Table 38
COLOR STRENGTH SERIES
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
CK	1.09	0.92	1.00
1	1.03	0.88	1.00
2	1.02	0.86	0.99
3	1.01	0.86	0.97
4	1.00	0.85	0.97
5	1.00	0.84	0.99
6	0.98	0.84	0.99
7	0.96	0.82	0.94
8	0.98	0.81	0.88
9	0.97	0.82	0.89
10	0.98	0.76	0.85
11	0.94	0.72	0.82
12	0.94	0.67	0.77
13	0.86	0.66	0.79
14	0.79	0.65	0.78
15	0.73	0.62	0.76
16	0.69	0.61	0.75
17	0.65	0.59	0.74
18	0.60	0.57	0.72
19	0.58	0.56	0.72
20	0.56	0.56	0.69
21	0.57	0.55	0.68
22	0.54	0.54	0.66
23	0.56	0.54	0.64
24	0.53	0.52	0.63
25	0.52	0.52	0.63
26	0.50	0.50	0.62
27	0.50	0.49	0.61
28	0.51	0.49	0.60
29	0.50	0.49	0.58
30	0.49	0.48	0.58

Table 39
COLOR STRENGTH SERIES
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
CK	0.97	0.83	0.92
1	0.91	0.79	0.91
2	0.90	0.78	0.90
3	0.90	0.78	0.89
4	0.89	0.78	0.90
5	0.89	0.77	0.91
6	0.89	0.76	0.89
7	0.86	0.75	0.86
8	0.88	0.75	0.82
9	0.85	0.73	0.79
10	0.86	0.67	0.76
11	0.82	0.66	0.76
12	0.82	0.62	0.71
13	0.75	0.61	0.72
14	0.68	0.58	0.71
15	0.65	0.56	0.68
16	0.59	0.55	0.69
17	0.56	0.54	0.68
18	0.53	0.52	0.66
19	0.52	0.51	0.64
20	0.50	0.50	0.62
21	0.49	0.50	0.62
22	0.47	0.49	0.60
23	0.46	0.49	0.58
24	0.45	0.47	0.57
25	0.45	0.48	0.57
26	0.44	0.45	0.56
27	0.45	0.45	0.55
28	0.45	0.45	0.55
29	0.44	0.45	0.54
30	0.42	0.44	0.54

Table 40
COLOR STRENGTH SERIES
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
CK	0.92	0.85	0.86
1	0.86	0.78	0.85
2	0.84	0.78	0.85
3	0.83	0.78	0.84
4	0.82	0.77	0.84
5	0.83	0.75	0.84
6	0.81	0.74	0.82
7	0.79	0.74	0.81
8	0.80	0.74	0.77
9	0.77	0.72	0.73
10	0.78	0.67	0.72
11	0.75	0.65	0.70
12	0.75	0.61	0.67
13	0.68	0.59	0.66
14	0.63	0.57	0.66
15	0.59	0.55	0.63
16	0.54	0.54	0.64
17	0.52	0.53	0.63
18	0.49	0.51	0.61
19	0.48	0.50	0.60
20	0.47	0.50	0.57
21	0.47	0.49	0.57
22	0.45	0.48	0.55
23	0.45	0.48	0.55
24	0.43	0.47	0.54
25	0.43	0.47	0.54
26	0.43	0.45	0.53
27	0.43	0.46	0.52
28	0.42	0.44	0.51
29	0.41	0.44	0.50
30	0.39	0.43	0.50

Table 41
COLOR STRENGTH SERIES
DARK NEUTRALS
70% TINT

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
CK	0.99	0.87	0.92
1	0.94	0.82	0.91
2	0.92	0.81	0.91
3	0.92	0.81	0.89
4	0.91	0.81	0.90
5	0.91	0.79	0.91
6	0.90	0.78	0.89
7	0.88	0.78	0.86
8	0.89	0.77	0.82
9	0.87	0.76	0.80
10	0.88	0.71	0.77
11	0.85	0.68	0.75
12	0.85	0.64	0.71
13	0.77	0.62	0.72
14	0.70	0.61	0.71
15	0.66	0.58	0.69
16	0.61	0.57	0.69
17	0.58	0.56	0.68
18	0.54	0.54	0.66
19	0.53	0.53	0.65
20	0.51	0.52	0.62
21	0.51	0.52	0.62
22	0.49	0.51	0.60
23	0.49	0.51	0.59
24	0.47	0.49	0.58
25	0.47	0.49	0.57
26	0.46	0.47	0.57
27	0.46	0.47	0.56
28	0.46	0.46	0.55
29	0.45	0.46	0.54
30	0.44	0.45	0.54

Table 42
COLOR STRENGTH SERIES
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 1	MAGENTA 1	YELLOW 1
OK	1.47	1.40	1.41
1	1.44	1.36	1.40
2	1.43	1.36	1.42
3	1.39	1.32	1.38
4	1.40	1.33	1.38
5	1.38	1.29	1.33
6	1.32	1.24	1.29
7	1.34	1.27	1.29
8	1.34	1.25	1.26
9	1.37	1.26	1.25
10	1.34	1.18	1.19
11	1.31	1.16	1.20
12	1.33	1.15	1.20
13	1.25	1.11	1.15
14	1.22	1.12	1.18
15	1.18	1.10	1.16
16	1.12	1.08	1.16
17	1.10	1.07	1.15
18	1.06	1.05	1.14
19	1.04	1.03	1.11
20	1.03	1.02	1.10
21	1.04	1.03	1.09
22	1.01	1.01	1.06
23	1.00	1.00	1.03
24	0.98	0.98	1.04
25	1.00	0.99	1.02
26	0.96	0.95	1.00
27	0.97	0.95	1.02
28	0.96	0.95	1.02
29	0.97	0.96	1.01
30	0.95	0.95	0.99

Table 43
COLOR STRENGTH SERIES
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 2	MAGENTA 2	YELLOW 2
CK	1.56	1.41	1.48
1	1.52	1.39	1.49
2	1.49	1.39	1.50
3	1.47	1.36	1.47
4	1.46	1.35	1.45
5	1.46	1.34	1.44
6	1.42	1.29	1.41
7	1.42	1.32	1.39
8	1.42	1.30	1.35
9	1.43	1.31	1.34
10	1.42	1.24	1.30
11	1.39	1.20	1.28
12	1.41	1.20	1.28
13	1.34	1.18	1.26
14	1.31	1.19	1.29
15	1.23	1.15	1.26
16	1.20	1.14	1.27
17	1.16	1.13	1.24
18	1.13	1.10	1.22
19	1.12	1.10	1.21
20	1.10	1.07	1.18
21	1.10	1.08	1.18
22	1.08	1.06	1.15
23	1.08	1.07	1.13
24	1.03	1.05	1.13
25	1.06	1.06	1.11
26	1.03	1.01	1.09
27	1.03	1.01	1.09
28	1.01	0.99	1.09
29	1.03	1.02	1.08
30	1.01	1.00	1.06

Table 44
COLOR STRENGTH SERIES
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 3	MAGENTA 3	YELLOW 3
CK	1.23	1.22	1.32
1	1.19	1.16	1.25
2	1.17	1.15	1.24
3	1.15	1.14	1.23
4	1.14	1.12	1.21
5	1.14	1.11	1.21
6	1.09	1.07	1.17
7	1.10	1.09	1.15
8	1.10	1.07	1.13
9	1.10	1.08	1.12
10	1.09	1.01	1.09
11	1.05	0.98	1.06
12	1.08	0.99	1.07
13	1.01	0.96	1.05
14	1.00	0.96	1.06
15	0.96	0.92	1.02
16	0.92	0.92	1.02
17	0.90	0.91	1.01
18	0.85	0.87	0.97
19	0.85	0.86	0.96
20	0.84	0.86	0.95
21	0.85	0.86	0.94
22	0.81	0.84	0.91
23	0.81	0.84	0.92
24	0.79	0.82	0.90
25	0.79	0.82	0.89
26	0.77	0.80	0.89
27	0.78	0.79	0.88
28	0.78	0.78	0.86
29	0.78	0.79	0.87
30	0.75	0.78	0.86

Table 45
COLOR STRENGTH SERIES
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN 4	MAGENTA 4	YELLOW 4
CK	1.37	1.34	1.37
1	1.31	1.28	1.32
2	1.29	1.28	1.33
3	1.27	1.25	1.31
4	1.24	1.23	1.29
5	1.27	1.24	1.28
6	1.22	1.19	1.24
7	1.19	1.19	1.22
8	1.21	1.20	1.22
9	1.22	1.19	1.19
10	1.21	1.13	1.15
11	1.15	1.08	1.12
12	1.17	1.08	1.12
13	1.10	1.05	1.10
14	1.09	1.06	1.11
15	1.01	1.02	1.08
16	0.99	1.00	1.08
17	0.96	0.99	1.06
18	0.93	0.97	1.04
19	0.92	0.95	1.01
20	0.90	0.94	0.99
21	0.89	0.95	0.99
22	0.86	0.92	0.96
23	0.89	0.94	0.98
24	0.86	0.91	0.96
25	0.86	0.91	0.96
26	0.84	0.89	0.93
27	0.84	0.88	0.92
28	0.83	0.88	0.92
29	0.82	0.86	0.92
30	0.82	0.87	0.93

Table 46
COLOR STRENGTH SERIES
DARK NEUTRALS
IMAGE

SHEET SEQ	CYAN MEAN	MAG MEAN	YELO MEAN
CK	1.41	1.34	1.40
1	1.37	1.30	1.37
2	1.35	1.30	1.37
3	1.32	1.27	1.35
4	1.31	1.26	1.33
5	1.31	1.25	1.32
6	1.26	1.20	1.28
7	1.26	1.22	1.26
8	1.27	1.21	1.24
9	1.28	1.21	1.23
10	1.27	1.14	1.18
11	1.23	1.11	1.17
12	1.25	1.11	1.17
13	1.18	1.08	1.14
14	1.16	1.08	1.16
15	1.10	1.05	1.13
16	1.06	1.04	1.13
17	1.03	1.03	1.12
18	0.99	1.00	1.09
19	0.98	0.99	1.07
20	0.97	0.97	1.06
21	0.97	0.98	1.05
22	0.94	0.96	1.02
23	0.95	0.96	1.02
24	0.92	0.94	1.01
25	0.93	0.95	1.00
26	0.90	0.91	0.98
27	0.91	0.91	0.98
28	0.90	0.90	0.97
29	0.90	0.91	0.97
30	0.88	0.90	0.96

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