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The variability of a web offset newspaper press run as measured by the Eastman Kodak Company's customized color analysis target

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THE VARIABILITY OF A WEB OFFSET NEWSPAPER PRESS RUN AS MEASURED BY THE EASTMAN KODAK COMPANY'S CUSTOMIZED COLOR ANALYSIS TARGET

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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 major in Printing Technology
has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science Degree at the convocation of

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ABSTRACT

The variability of a press run as measured by Eastman Kodak Company's Customized Color Analysis Target was studied and quantified in the areas of Pre-press requirements, Press Performance and Color Measurement.

The test was conducted on a web offset newspaper press maintained to industry standards. The target was printed along with three halftones consisting of high-key, low-key and normal images. The halftone images were be used by the pressman to visually check and evaluate the press sheets during the run to maintain quality. A running color bar was also printed to provide densitometric readings. The test target was be evaluated using a computer controlled spectrophotometer and this information pertained to specific conditions of ink, paper, plates, U.C.R., image type, etc..

The results are presented in the form of time series graphs which show the large degree of variability experienced by this press. The importance of selectivity in choosing a representative sample sheet is emphasized. The various events which can occur during a press run are documented by standard graphic arts variables measured by the test target. A comparison of initial prepress curves and suggested prepress curves is presented, and the effects of a second press run using the suggested prepress curves are predicted. The use of the quantity E as a quality criterion is explored.

Lastly, methods for further study are suggested.

I. INTRODUCTION

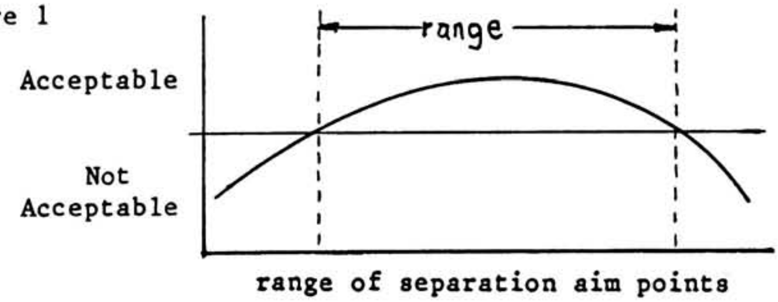
High quality four-color printing has proved an arduous task for many pressmen. Precise reproduction on press depends on accurate color separations from the pre-press. Until recently, the separation process has relied on trial and error which is costly and time consuming. Eastman Kodak Company has developed the Custom Color Analysis System to eliminate this problem.

Custom Color Analysis uses a computer controlled spectrophotometer to analyze a Kodak test target which was developed specifically for this task. The test target is run on a customer's press and the results aid in providing the necessary information on press variables to allow the color separations to be customized for that particular press.

The current procedure for press evaluation consists of running the multipatch color test target under normal shop conditions. The pressman is instructed to monitor the run as if it were a normal job. This can be done with specific densitometric measurements or with comparison of proof to press sheet for included images. The press sheets are visually inspected to determine what is a commercially acceptable result obtainable on that press. This acceptable result could be represented by one press sheet or since some variables follow a periodic pattern, for example dot slur, several consecutive sheets could be checked for agreement. The test target is then evaluated and separation aim points and press performance data are calculated.

The problem which is generated from this application developes in the variability which exists throughout a press run and what is a "commercially acceptable" pictorial image. As it stands, the Custom Color Analysis data provides separation aim curves which pertain to a spec- ific press sheet printed at a specific instant during a press run. This thesis will deal with evaluating the whole of a press run to determine the variability that is measured by the test target. A graphical repre- sentation of the model for this problem would be plotted on an x, y coordinate with acceptability on the y-axis and the range of separation aim points on the x-axis. See Figure 1. Acceptability would be judged subjectively and aim points would be computed spectrophotometrically.

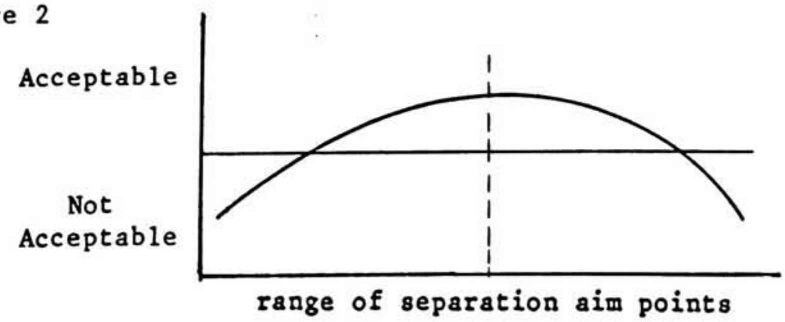
Figure 1



Thesis Model

At this point, color analysis gives not a range of aim points but a specific set of aim points. Therefore, a graphical representation of this situation would contain one straight line only. See Figure 2.

Figure 2



Specific Aim Points of Custom Color Analysis

This technique does not reveal how much leeway there would be before printing becomes unacceptable.

The objective of this thesis is to define the endpoints and the variance that is present in a normal press run. Further studies currently in progress will reveal the correlation between the subjective evaluation of acceptability and the range of data used to produce the images.

HYPOTHESIS

To prepare for subsequent studies of the Custom Color Analysis target, a complete evaluation of the data which are measured for prepress requirements, press performance characteristics and color measurements must be conducted.

By the quantification of press variations throughout an entire press run, the limits, ranges and standard deviations of the following variables could be computed: Halftone Aim Points, Dot Gain, Dot Slur, Percent trap, Solid Ink Density, Hue angle, Chroma and Δ E values.

These statistics can be used to evaluate:

1. The variability in the measured press performance characteristics for the entire press run.
2. The variability in the halftone aim points calculated by Customized Color after acceptable quality was reached.
3. The effect of such press events as a web break, roll change or plate change on the Customized Color Analysis information.

4. The variability of the quantity ΔE from the CIELab color volume for cyan, magenta, yellow, red, green, blue, and three-color.

Furthermore the Custom Color Analysis halftone separation aim points can be compared to the standard aim points used to generate the initial separations to predict the effect of the proposed curves.

II. BACKGROUND

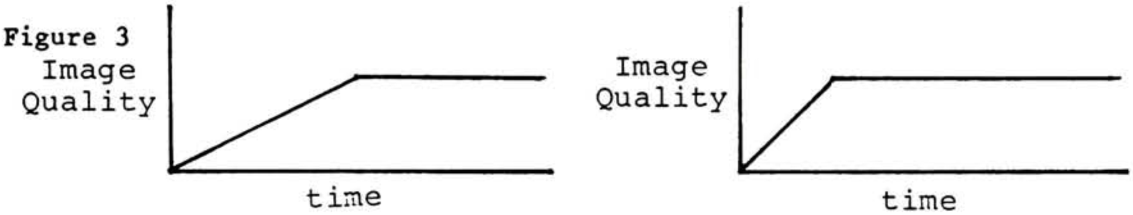
CUSTOM COLOR ANALYSIS

The need to establish a pre-press to press link for maintaining image quality has been a long standing burden to the graphic arts industry. The requirements for achieving optimum quality using a process that undergoes constant variability are seemingly ephemeral at best. Pressmen have been given the impossible task of matching a proof through adjustments to the press. This leads to waste in start up. When separations are received from different suppliers, often a sacrifice must be made in one image to appease another image. A level of diminishing return is encountered which limits the quality of all images and an averaging of color-on-press to the lowest quality denominator occurs. In national magazine publishing, regional plants print editions for distribution. This results in subtle yet discernible variances in color quality. One plant's Coca-Cola red may match another plant's orange sunset. These problems may exist due to the lack of communication between pre-press and press. If the separations are prepared with knowledge of a press' operations, then better quality will be easier to obtain (Hamilton, 1985).

The problems stated above can be better understood by examining the following graphical representations. Start-up waste accounts for a large percentage of costs in the lithographic industry. The pressman pre-sets the inking system by evaluating the image for solids, overprints, design, etc.. From this initial starting point adjustments

are made as the press begins to operate and printed press sheets can be inspected. Separations made without knowledge of the conditions specific for that press can lead to a longer operation time needed to reach acceptable image quality. Customized Color Analysis (CCA) will make quality levels easier to attain by reducing the steps necessary to achieve quality. See Figure 3.

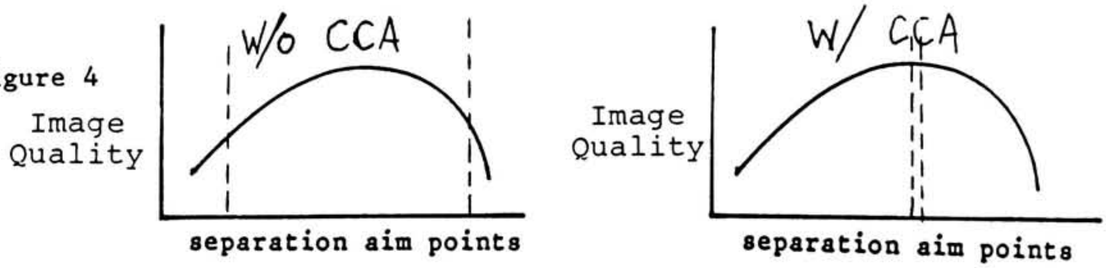
Figure 3



To Lessen Start-up Waste

When a printer receives, from outside his plant, separations which are made to normal industry standards, many times he is frustrated by the lack of consistency that results when the images from different suppliers must be printed in line on the same sheet. One image might have good quality, while another is not acceptable. If adjustments are made to correct the unacceptable image, the quality in the first image is lost. The only solution is an unhappy medium between the two images. Both must suffer to produce an acceptable compromise. This problem can be eliminated by using Customized Color. See Figure 4.

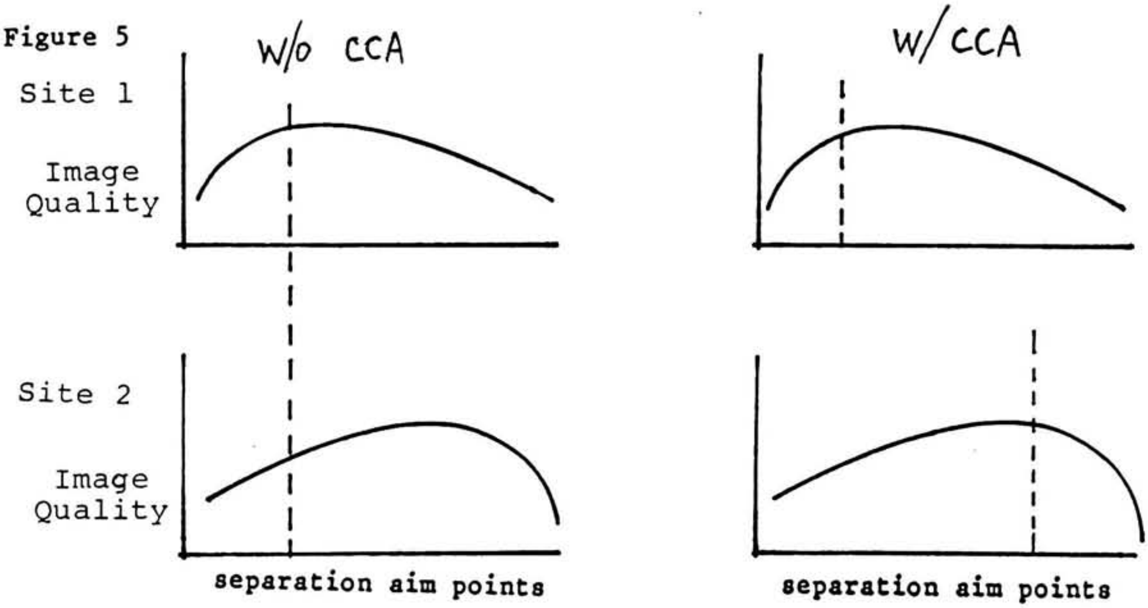
Figure 4



To Eliminate Quality Averaging

The problem of remote site printing is becoming an increasing concern. Many national magazines have eliminated high shipping costs by taking advantage of the advent of electronic communication to transmit information to regional printing sites. These sites then print the regional editions of the magazine. Consistency must be maintained in all copies of the magazine without references to the printing site. If the same separation information is transmitted to all sites, the results will be inconsistent because each press will process that information according to its own capabilities. See Figure 5. The separation aim points must be chosen with the knowledge of the press capabilities. This will make quality easier to obtain by allowing the separations to compensate for the press differences.

Figure 5



To Eliminate Differences in Remote Site Presses

Customized Color Analysis joins the pre-press input with the press conditions to establish a continuity for image reproduction. A computer controlled spectrophotometer is used to scan the analysis target and data

is transmitted to a central computer unit which records the press functions, calculates the halftone separation aim points and provides color measurements for quality control.

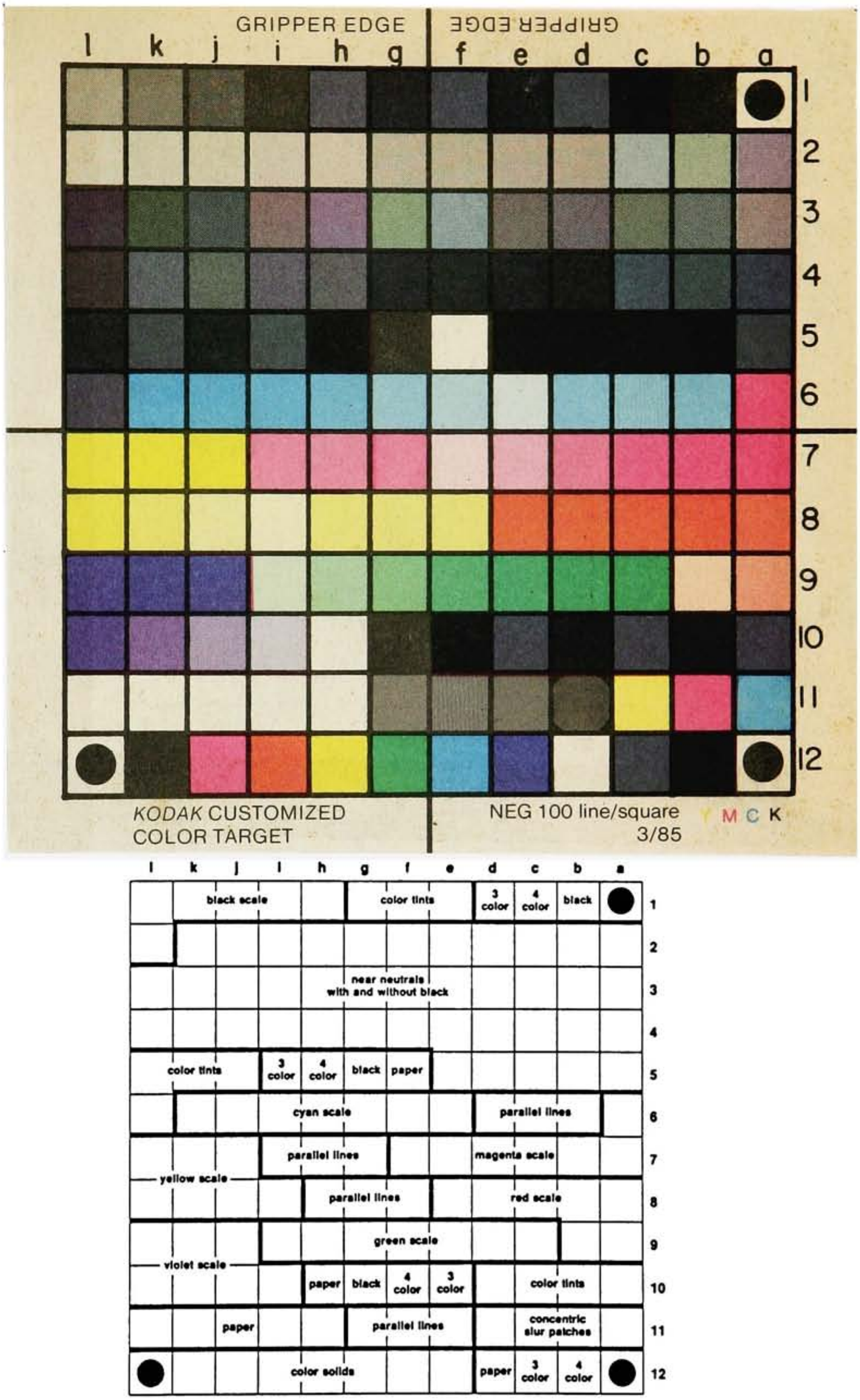
The analysis target consists of nine types of testing configurations which provide corresponding information (Maurer, 1982). See Figure 6 on Page 9.

1. Black Circles - Registration
2. Color Solids - Solid ink densities, Spectrophotometric curves, Dot Gain, Trapping and color space measurement.
3. 3-color and 4-color - Maximum printing density and tone reproduction.
4. Near Neutrals - Gray balance, tone reproduction and effective black.
5. Color Scales - Dot gain and color rendition.
6. Black Scales - Effective black.
7. Color Tints - Color rendition.
8. Parallel Lines - Slur measurements.
9. Concentric Circles - Visual slur assessment.

This information is derived in accordance with specifications lating to the desired production routine. These specifications include:

1. Scanner or photographic process
2. Negative or positive halftone
3. Copy mode: Transparent or reflective
4. Aim points: AMB or HPS/TR
5. Tone reproduction: Average, high or low key

Figure 6



Kodak Customized Color Target and Schematic of Patch Location

6. Undercolor removal: Amount
7. Black printer: Starting point on original scale above highlight and percent dot area in the shadow step.

At present this system is designed as a central service operation because of hardware requirements. This necessitates the use of a large target (4 1/2 square inches). The size of the current target limits its use to special test runs, and prevents the system from becoming an in-plant monitoring device. The prohibitive cost of space and time available to a commercial printer also restricts the number of targets run.

STUDY OF WEB OFFSET VARIABILITY

The Graphic Communications Association has conducted a study of variability in web offset color advertising reproduction. Twenty-eight U.S. publication printers were involved (Scharpf, 1983). Through analysis of the information provided from Phase I of this program, Publication Advertising Reproduction (PAR) curves were generated. PAR curves represented the average printing conditions for all the participating printers. These separation curves were based on a SWOP standard 280% maximum total printing dot area and a skeleton black. There were many "ad hoc" provisions to this test which must be taken into consideration. Most important is the fact that the presses did not represent a scientific sampling.

Phase II of the test program included four images that were separated to the PAR curves and to conventional standards. The color

control that was provided by the PAR curves resulted in improved printing and confirmed the value of choosing the correct tone reproduction curve and mid-tone dot gain value.

Norman W. Sharpf, G.C.A. president, stated that "... the PAR curve in all cases resulted in a more appealing image than was produced by the conventional curve, was better matched to the proofs and produced greater uniformity between sites." (Scharpf, 1983). G.C.A. indicates that a narrow range of dot gain on press is essential if the PAR curve concept is to prove relevant.

FOOTNOTES FOR CHAPTER II

Hamilton, John 1986 — Private Communication

Maurer, R.E. 1982 — "Customized-Color Computer Printing Analysis", TAGA Proceedings, pp. 518-550.

Scharpf, Norman 1983 — "Further Analysis of Factors Contributing to Variability in Web Offset Color Advertising Reproduction", TAGA Proceedings, pp. 65-77.

III. INK PRESS PERFORMANCE VARIABLES

Dot Gain is the percentage increase of dot size between the halftone film and the substrate. The reflection density of a tint is compared with its corresponding solid ink density using the Yule-Nielson equation (Equation 1). The optical dot gain is compensated for by using an "n" factor > 1.0 suggested by Pearson as being "... an optimum for effective compromise between convenience and accuracy." (Pearson, 1980).

Equation 1

$$\text{dot area} = \frac{1 - 10^{-Dt/n}}{1 - 10^{-Ds/n}}$$

Dt = Density of tint

Ds = Density of solid

The use of n=1.0 will yield the Murray-Davies equation which calculates the physical dot gain. By indicating the type of paper used, the "n" factor will be designated as follows: Coated stock 1.5, uncoated stock 1.9 and newpaper 1.5.

Optical dot gain is caused by the multiple internal reflections which trap some light beneath the dot, within the substrate. Physical dot gain is the symetrical enlargement of the dot caused by cylinder pressure and ink spread in the substrate. Slur, the distortion of a dot shape caused by tensions and the multiple impressions of dot doubling, is also a factor in physical dot gain. The combination of all three factors contributes to what is called visual dot gain. References to physical dot gain simply eliminates optical dot gain influences.

This method of calculating dot gain makes several assumptions. (Maurer, 1982)

a) Inks are perfectly transparent.

b) Density of halftone dots are perfectly uniform and equal to the solid ink density.

c) The "n" factor involved in the Yule-Nielson equation is correct. With materials that exhibit large light-scattering properties, physical dot gain can be low while visual dot gain will be high.

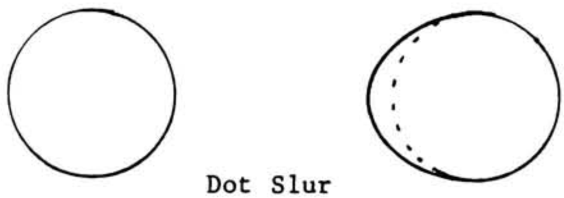
d) Dot area is constant between the halftone films and the printing plates.

The percentage of dot gain is calculated for the following dot areas: 10%, 30%, 50%, 70% and 90%. In many tests such as the Graphic Communication Association SPECTRUM program, dot gain has been identified as a major variable producing variation in printing results (Scharpf, 1983). Dot gain can be the major cause of loss of contrast and depth, halftone screen plug-up, and drastic color changes. Dot gain has the greatest influence on color variations which can lead to waste factors as high as 15-20%. With caveats such as these, dot gain will be subjected to close scrutiny.

Dot Slur, although it is a contributor to dot gain, can be measured and quantified separately. Slur is caused by incorrect cylinder pressures or misregister of sequential printing units. It appears as a distortion of the dot shape (Figure 7). This distortion is measured in percent slur and angle of direction. Percent slur will

indicate if an observed hue shift might occur. A percentage higher than 5% will effect a hue shift (Maurer, 1982). The direction of slur will pinpoint mechanical adjustments that may be needed.

Figure 7



Dot Slur

Slur is measured by comparing the densities of the 30°, 90°, and 120° parallel line patches for each ink. The line angles refer to orientations to the gripper bar. Any density difference can be attributed to slur since dot gain, discounting slur, would be constant for all three angles.

<u>S.I.D.</u>, solid ink density, is any measured amount of ink that can be applied to a substrate. Ideally this amount would maintain quality. These measurements aid in quality control comparisons between the analysis target and control bars. The spectrophotometric readings are analogous to the standards for narrow-band densitometry. Before we proceed further, an explanation of narrow-band densitometry is in order

Densitometers are used to measure two variables associated with a given area; how much the area will vary the light it reflects (transmits) and the amount of specific primary color present. The quantities are attained by measurement in the first case and by computations in the second.

Reproducability between densitometers is a major problem. Variations associated with light sources, sensors and filters all

contribute to incongruent readings between like instruments. Wide-band filters allow these factors to affect readings while narrow-band filters do not (McCamy, 1977). Wide-band filters measure half bandwidths of 50-70 nanometers. Narrow-band filter measuring widths are 20 nanometers. The term bandwidth refers to the red, green and blue bands which are approximately 120nm in width. By restricting the measuring response to a narrow range, variations in spectral emissions in the light source and in the sensitivity of the photodetector are greatly reduced.

The reproducability provided by narrow-width filters is desirable for several reasons. Communication between remote sites can be standardized where density readings from one site will agree with readings from another site. Many times a specific density is requested by a client. If a densitometer is damaged and must be replaced, readings must be reproducible. To maintain quality control densitometers must be able to function in this manner.

The optimum center wavelength of the narrow-band filter range of 20nm has been found to be 432nm for the blue, 536nm for the green and 624nm for the red (Kishner, 1981). These are the figures used in Custom Color Analysis. Wide-band filter readings are also supplied using filters of 40nm width and solid ink patches from the target are available to relate the data to available equipment readings. The difference in the readings of the narrow versus the wide band filters is minimal for the red and green but is significant for the blue (Southworth, 1982). Wide-band readings generate yellow densities of approximately 0.98 while narrow-band yellow readings are 1.30. One must be aware of this fact when comparing readings for density, hue error and gray content.

S.I.D. measurements can be used to determine if the ink levels are correct by using the Graphic Arts Technical Foundation (GATF) formulas (Elyjiw, Preucil, 1964). Yellow S.I.D. can be read directly. The yellow density should be near 1.00 if the ink set has a bluish magenta and near 0.80 if a reddish magenta is used. The difference compensates for the yellow "contamination" in reddish magenta. Magenta and cyan S.I.D.'s should fall in the following ranges using Equations 2 and 3 below. The magenta is read from the red patch (magenta over yellow) while the cyan is read from the green patch (cyan over yellow).

Equation 2 $$\frac{Drb}{Drg} \times 100 = \text{Percentage between 85 and 100}$$

Equation 3 $$\frac{Dgb}{Dgr} \times 100 = \text{Percentage between 90 and 100}$$

Where for Dxy: D = Density
x = Patch color
y = Filter color

The densities read through the three filters are also used to produce spectrophotometric curves which reveal the spectral quality of the inks and overprints. These will be discussed later.

% Ink Trap is derived from the S.I.D. readings and the overprint densities (Jorgensen, 1983). Trap is the degree of ink transfer onto wet ink films already present on the substrate. It is expressed as the percentage of ink film thickness on an overprint in relation to the ink

film thickness on the substrate alone. There is no direct way to measure ink film thickness, therefore it must be calculated from indirect measurements such as density by using Equation 4.

Equation 4

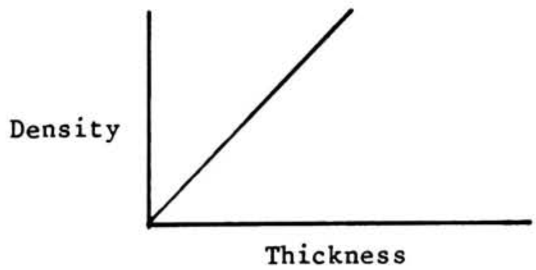
$$\% \text{ Trap} = \frac{Dop - D1}{D2 - Ds} \times 100$$

Where D1 = Density of first down ink
D2 = Density of second down ink
Dop = Density of the overprint
Ds = Density of substrate alone

All readings are taken with the filter which corresponds to the color of the second down ink. Preucil called this percent trap "apparent trap" (Preucil, 1958). Optical and physical properties both contribute to percent trap. Optical, in that the ink is not totally transparent and the gloss of the ink is changed, and physical in that the second ink does not adhere as well to the first ink as to paper. Density measurements can only approximate the human visual response, thus the term apparent trap.

Preucil's equation uses density measurements to compute % trap. Thus a change in ink film thickness (D2) will effect a linear change in density as in Figure 8.

Figure 8



Linearity of the Preucil Ink Trap Equation

The assumption is made that densities are additive in such a way that

the total density of two ink layers combined will equal the sum of their individual densities. This additive rule fails for several reasons as described by Yule and Clapper (1956). For substrates which have low maximum printable densities such as newsprint, the additive failure causes a large descrepancy between the trap calculations from Equation 4 and real percent trap.

There have been other suggestions for ink trap formulea such as the Childers Equation and the Brunner Equation. These were shown to have inaccuracies when tested by both Elyjiw and Field (1985). These inaccuracies are caused by the lack of an agreed upon definition of ink trap (Hamilton, 1985). Childers' definition is stated in Equation 5.

Equation 5

$$\%\ \text{Trap} = 100 \times \frac{\text{Expected Reflectance of Two-color Patch}}{\text{Observed Reflectance of Two-color Patch}}$$

Brunner's definition is stated as in Equation 6.

Equation 6

$$\%\ \text{Trap} = 100 \times \frac{\text{Observed Absorption of the Two-color Patch}}{\text{Expected Absorption of the Two-color Patch}}$$

Preucil's definition is stated as in Equation 7.

Equation 7

$$\%\ \text{Trap} = 100 \times \frac{\text{Observed Ink Layer Thickness of Second Ink}}{\text{Expected Ink Layer Thickness of Second Ink}}$$

A new ink trap equation has been proposed by Hamilton (1986) which makes use of the term maximum printable density (MPD). The assumption

of additive densities is again made with the addition of the MPD term. See Equation 8.

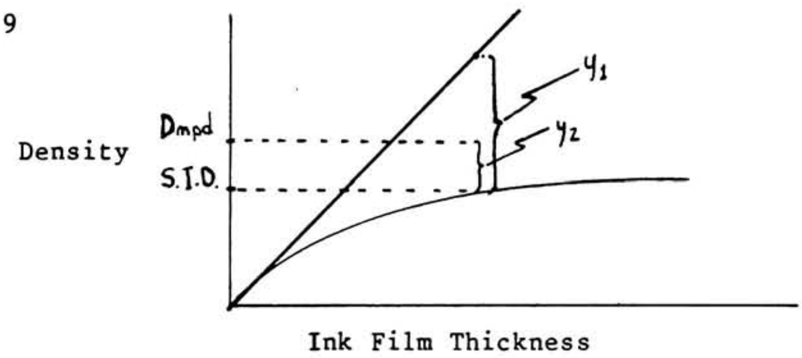
Equation 8

$$D\ total = D1 + D2 - \frac{(D1)(D2)}{D\ mpd}$$

Where D mpd = Maximum Printable Density

MPD is the point which marks the highest density attainable for increasing ink film thickness. After this point is reached, further increases in ink film thickness will not increase density. As can be seen in Figure 9, if ink trap were to be predicted for newsprint, the densities would give low % trap readings for the Preucil equation.

Figure 9



Failure of Newsprint to Follow Additivity Rule

At a normal SID level of 0.90 for newsprint, the Preucil equation would predict % trap using a $\Delta D = y_1$ while the Hamilton equation uses a $\Delta D = y_2$. The Custom Color Analysis System uses a MPD = 1.5 for newsprint. The Hamilton equation is as follows. See Equation 9.

Equation 9

$$\%\ Trap = \frac{\ln\left[1 + \frac{(Dop - D1)}{D\ mpd - Dop}\right]}{\ln\left[1 + \frac{(D2 - Ds)}{D\ mpd - D2}\right]} \times 100$$

The circled areas represent the Preucil equation. An example of the correction made by the MPD term can be found in Appendix A.

Ink trap measurement can be used as a qualitative control measure where a change in apparent trap can indicate a change in actual trap.

FOOTNOTES - CHAPTER III

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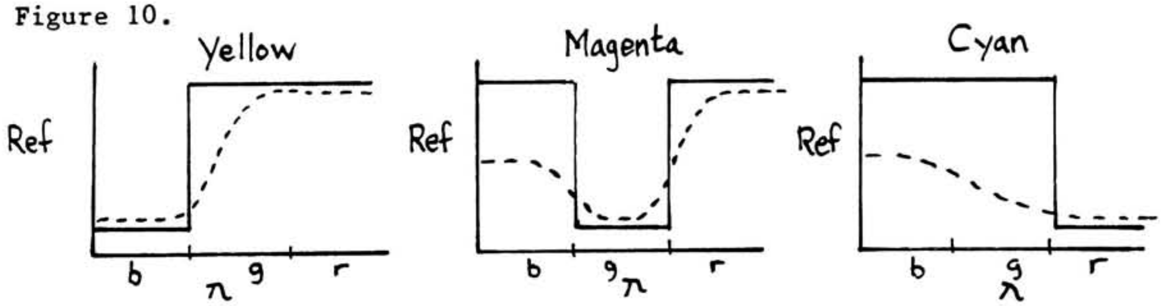
IV - Color Measurement

The Subtractive Color Triangle is a color space suggested by Pruecil (1960) and later revised by the Graphic College of Denmark to include hue error and grayness. Hue error defines the purity of the yellow, magenta and cyan inks by comparing real inks to the ideal. Ideal process inks have a uniform high absorbtion in one-third of the visual spectrum and zero absorption (100% transmission) in the remaining two-thirds. Real process inks absorb "unwanted" colors outside the one-third division of the wanted color. Figure 10 (Hardy 1937) is a graphical representation of ideal ink and real ink responses to white light illumination (D-5000).

Figure 10.



Ideal Ink and Real Ink Reflection Curves

Percent reflection versus wavelength curves reveal that yellow ink on paper should absorb all blue light and reflect all red and green; magenta ink should absorb all green and reflect blue and red; cyan ink should absorb all red and reflect blue and green. It should be remembered that one hundred percent reflection corresponds to zero

percent absorption. The real ink curves show that in actuality the percentages are somewhat less in the unwanted colors.

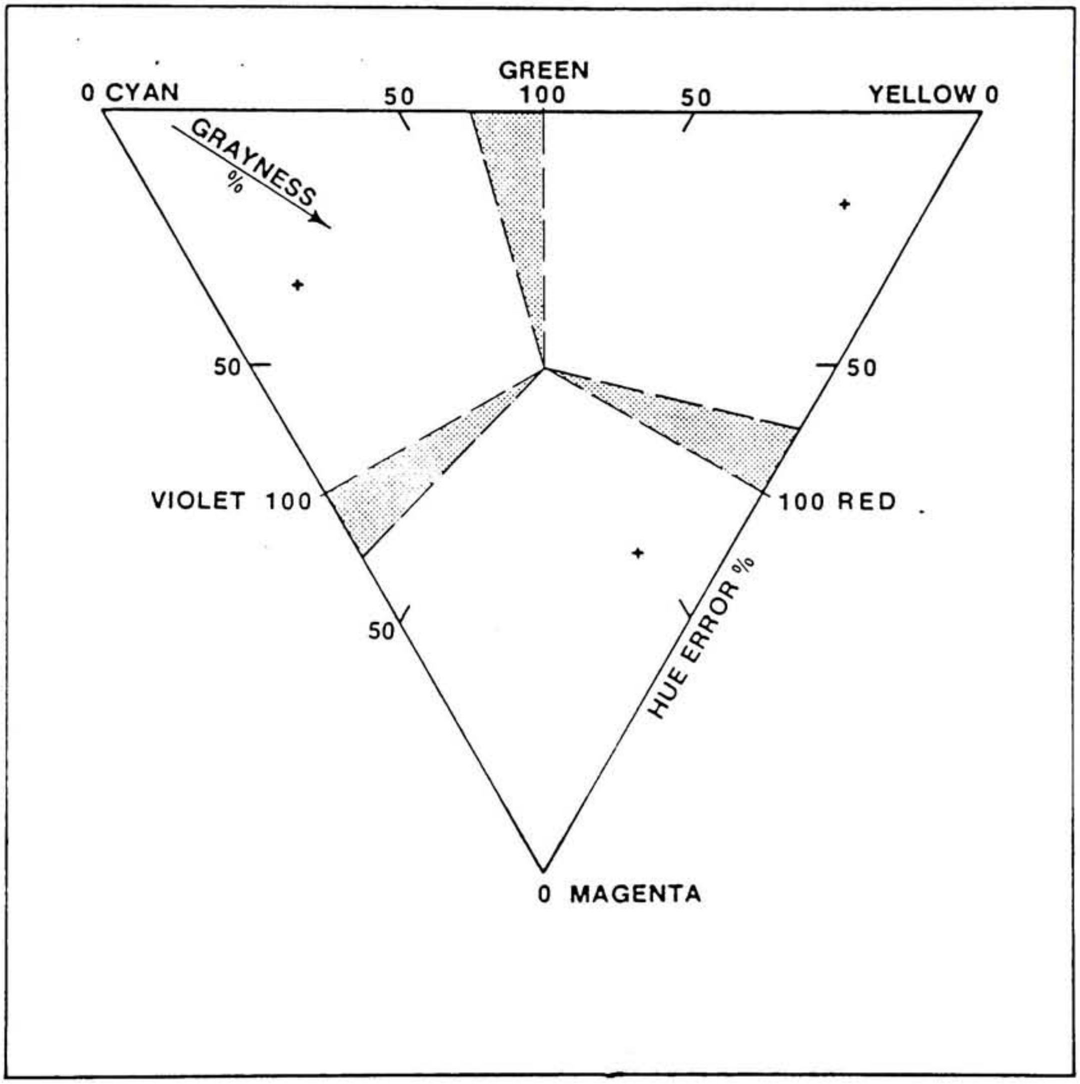
Yellow ink is near ideal, absorbing slight amounts of green (unwanted color). Magenta and cyan inks have higher absorptions for blue and green respectively. Hue error gives an indication of the amount of unwanted color in an ink. Equation 10 (Preucil 1957) uses reflection density to determine hue error. The density measurements of the yellow, magenta and cyan patches are made through three filters, red, green and blue. The spectrophotometric readings are again analogous to narrow-band densitometry. The three densities for each process ink color will have low(L), middle(M) and High(H) value. These values are used to form a ratio of densities.

Equation 10.

$$\% \text{ Hue Error} = 100 \frac{M - L}{H - L}$$

When plotting hue error on the subtractive color triangle (see Figure 11 next page) the direction of the plot depends on the color of the lowest absorption band. By reviewing Figure 10 it can be seen that for yellow the direction would be toward red; magenta toward red; and cyan toward blue. Hue error for all inks will always follow these directions (Yule 1967). A more thorough explanation of the dependency of plot direction would involve the color corresponding to the highest unwanted density or middle value (M). The direction of the plot would be towards the complimentary of this color. For yellow the M value is obtained with the green filter therefore the direction would be toward magenta. Ideal inks would have a hue error of 0%. The lower the

Figure 11



Subtractive Color Triangle

percentage, the closer the ink plots to a triangle apex. As percentages increase, the plot moves towards the midpoints of the lines in the manner stated above.

A word of caution must be stated with respect to the hue error. Hue error deals with a relationship between a real ink and an "... imaginary idealized ink of doubtful value" (Yule 1967). Ideal ink color gamuts would not be as complete as those obtained with real inks which contain overlaps in their absorption bands. Therefore, the word error is a slight misnomer in that a hue error percentage is actually desirable.

Grayness is obtained by using a ratio of the lowest unwanted density to the highest density as in Equation 11 (Preucil 1957).

Equation 11.

$$\% \text{ Grayness} = 100 \ (L/H)$$

Ideal inks which have an L value equal to zero would have 0% grayness, and would plot at a triangle apex. A 100% grayness figure would plot at the center of the triangle indicating equal density for the high (H) and the low (L). 0% grayness indicates maximum color saturation and 100% grayness indicates a neutral.

Because of the lack of consistency amoung conventional densitometers the subtractive color triangle has not been adopted as an international standard system. To obtain consistent measurements, readings must be compared relative to a single specific instrument. One advantage the system has is that the parameters are obtained by a ratio of densities thus making the system sensitive to variations in ink-film thickness (Yule 1967).

Spectrophotometric Curves are completely objective measurements being totally independent of the characteristics of color vision. These curves show the amount of reflection and absorption at small intervals of the visual spectrum. The accepted convention for plotting these curves is to show reflection density on the y-axis and wavelength on the x-axis. The reflection densities are measured at 20nm wavelength intervals from 400 to 700 nm. The process inks, overprints and substrate are all measured. These measurements can be used to provide a quality control check for both paper and inks.

The CIELab Color Volume is a color descriptor which has gained acceptance in the graphic arts due to the ease in understanding the coordinate system and the fact that it deals with color differences and can provide an objective evaluation. It is not encumbered by the horseshoe shaped curve of the chromaticity chart nor does it involve subjective evaluation like the Munsell System which bases color differences on equal changes as a viewer would see them rather than mathematically.

Clulow (1972) defines the three necessities for calculation of any C.I.E. specification for color as:

a) The spectral energy distribution of the chosen illuminant.

b) The amounts of the color-matching functions, x, y, z for the standard observer.

c) The spectral reflection characteristics of the measured speciman, best obtained by the use of a full spectrophotometric curve.

Pearson (1986) called this a S.A.D. system referring to the Source,

the Attenuator (or sample) and the Detector. For the Customized Color Analysis System: S = D5000

A = Spectrophotometric curves of the target

D = The standard observer functions

Calculation of the CIE values for a printed sample are based on the spectrophotometric curves using narrow band filters of 20nm width. These CIE values are then converted to CIELab coordinates of L*a*b* using Equations 12, 13 and 14.

Equation 12

$$L^* = 116(Y/y_o)^{1/3} - 16$$

Equation 13

$$a^* = 500\ [(X/x_o)^{1/3} - (Y/y_o)^{1/3}]$$

Equation 14

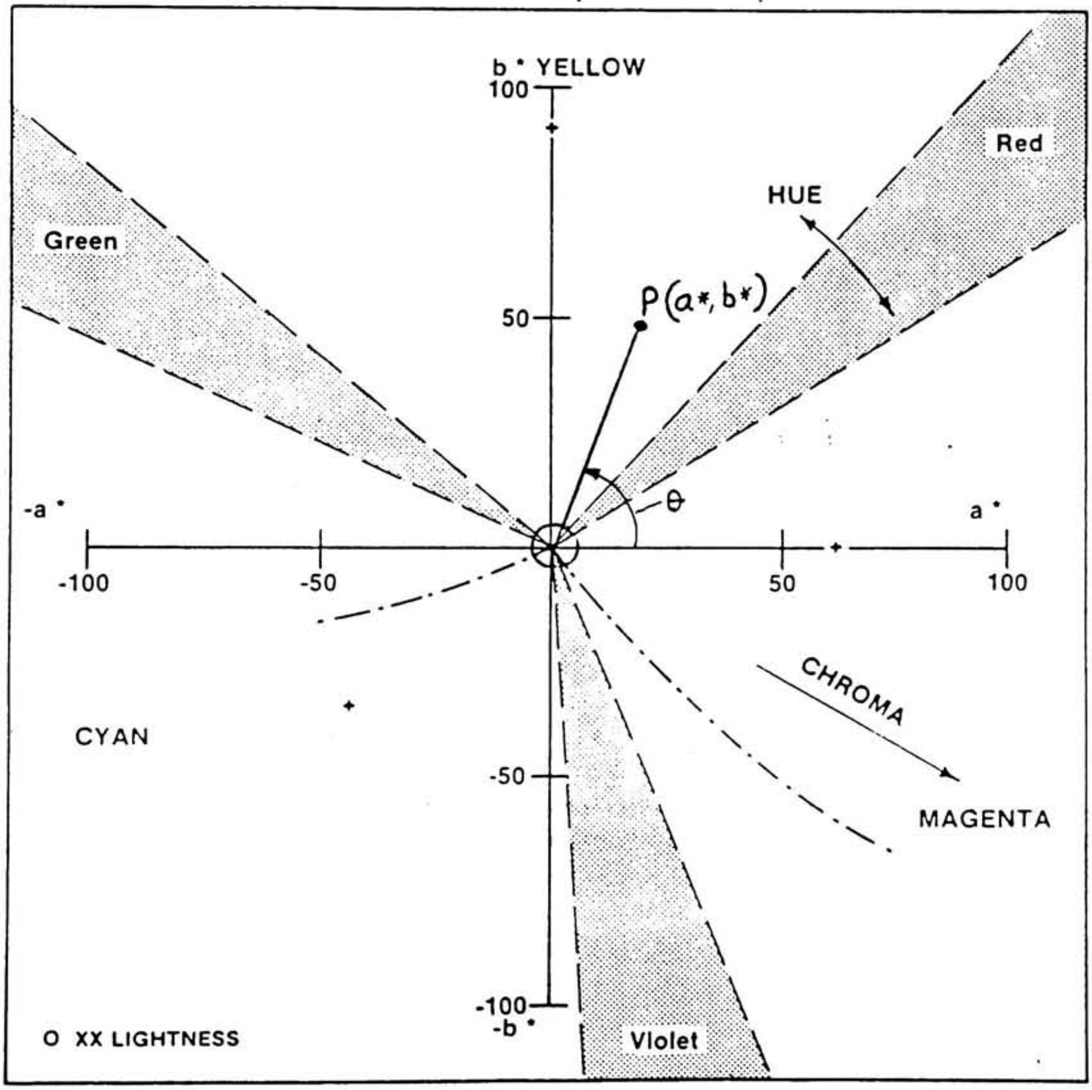
$$b^* = 200\ [(Y/y_o)^{1/3} - (Z/z_o)^{1/3}]$$

Where X, Y and Z are the tristimulous values of the color in question computed from the CIE color matching functions $\bar{x}$, $\bar{y}$, $\bar{z}$ and x_o, y_o, z_o are the tristimulous values for the reference white of $BaSO_4$ under 5000K illumination.

The CIELab system (Figure 12) is a three dimensional space with a* on the x-axis, b* on the y-axis and L* on the z-axis.

The plot of a point "P" using coordinates (a*,b*) will determine the hue of the color. This can also be designated as the hue angle θ

Figure 12



CIELab Color Volume

The Chroma of the color is described by the straight line distance from point P to the origin. This distance is found by solving the Pythagorean theorum as in Equation 15.

Equation 15

$$\text{Chroma} = \sqrt{(a^*)^2 + (b^*)^2}$$

Chroma is a synonym for saturation. The origin is designated as neutral gray, therefore as the chroma or length of the line OP increases, the grayness or neutrality of the color decreases. The perimeter connecting the plotted points does not define the entire color gamut of the inks. If more points were plotted the gamut would become larger and more circular.

L* designates the lightness of the color. The L* values projecting from the origin would range from white (100) to black (0) with all neutral grays inbetween. L* values at a given point "P" indicate the value of the color where value=lightness.

Both the Subtractive Color Triangle and the CIELab Color Volume have hue tolerances for the overprint colors of red, green and blue shown as shaded areas.

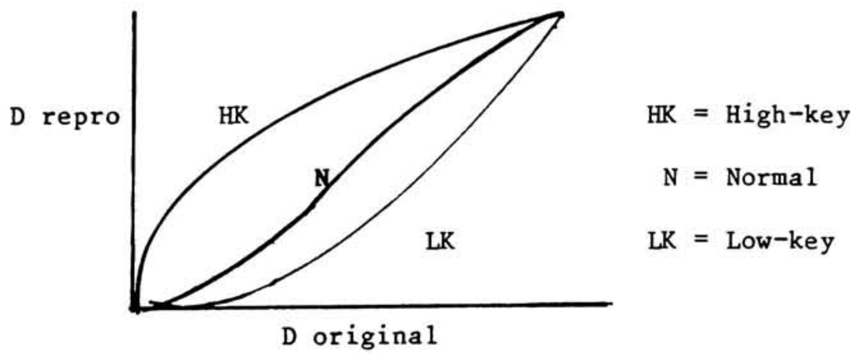
FOOTNOTES FOR CHAPTER IV

Clulow, F.W. 1972	"Color: Its Principles and Their Applications", Morgan and Morgan, Inc., New York
Hardy, Arthur and Wurzburg, F.L. 1937	"The Theory of Three-Color Reproductions" Journal of the Optical Society of America, Volume 27, #7.
Pearson, M. 1986	Private Communication
Preucil, Frank 1960	"Color Diagrams", TAGA Proceedings, Number 12, pp. 151-155.
Preucil, Frank 1957	"Highlights of the L.T.F. Survey of Process Inks", TAGA Proceedings, Number 9, pp. 143-152, 188-190.
Yule, John 1967	"Principles of Color Reproduction", John Wiley and Sons, Inc., New York.

V. PRE-PRESS PREPARATION

Tone Reproduction curves are plotted using density of the original versus the density of the reproduciton. The curves consist of four-color, three-color, actual black and effective black. Actual black refers to the black ink on the substrate alone while the effective black is a measure of the black ink trapped over the three process color inks. The effective black is used to calculate the black printer required. A combination of the three-color densities and the effective black densities will yield the four-color densities. An increase in the black ink beyond its effective level does little to increase the maximum density of the reproduction. These curves can be plotted for high-key, normal or low-key copy as in Figure 13.

Figure 13.



Tone Reproduction According to Type of Original

Proper gray balance is an important step in adjusting separation aim points for a printing process. The cyan, magenta and yellow inks must be coordinated to print differing dot sizes to achieve gray balance. This is shown by the use of the Neugebauer equations (Yule, 1967). The

need for different dot sizes is caused by the fact that only cyan absorbs a substantial amount of red; magenta and cyan absorb green; while all three inks absorb some quantity of blue. The unwanted color absorptions as seen in Figure 10 make balancing the ink sets imperative. Even if a one-to-one tone reproduction relationship between original and reproduction could be obtained (a 45° line for Figure 13), this would not guarantee a proper rendition of neutral grays.

By using CIELab coordinates of the near neutrals the printed targets are evaluated to determine the percent dot area of the cyan, magenta and yellow. The highlight areas are biased toward the a* and b* values of the substrate. The black printer type can be chosen as skeleton, moderate or full. Skelton is defined as having a 5% Dot Area (DA) starting point at 1.3 density of original and a shadow dot of 70% at 2.8 density. Moderate has a 5% DA at 1.1 density and 90% DA at 2.8. Full black starts as close to the highlights as possible such as 5% DA at 0.9 and has a 90% DA at 2.8.

The Half-Tone Separation Aim Curves can now be generated by using information from the target patches described in Figure 6 as follows: the black scale, which is columns 1-h in row one, to compute the black printer dot areas; the L*, a*, b* values of the neutrals of rows two through five to determine gray balance requirements; and the substrate only patch to give maximum highlight available.

FOOTNOTES FOR CHAPTER V

Yule, John 1967 — "Principles of Color Reproduction", John Wiley and Sons, New York.

VI. METHODOLOGY

The hypothesis of this thesis deals with the quantification of variables associated with the entirety of a press run. To have a sufficient number of samples in which to detect changes and to save on both expense and time, a lithographic web-offset newspaper press operation was chosen. The press parameters were as follows:

1. Press - 30 inch Goss Urbanite
2. Blanket - Reeves by W.R. Smith Co.
3. Fountain Solution - V-20-20 Alkaline
4. Plates - Imperial Double Eagle Wipe-On

Flint Arrowlith Ad-Litho ink was used and the laydown order was cyan, magenta, yellow, black. The paper stock was C.I.P. Newsprint.

The separations for the high-key, normal and low-key images were produced on an electronic dot generating scanner by an operator experienced in newspaper separations. Instructions were to follow the normal newspaper specifications for these types of images. The separation information was as follows:

1. High-Key - Highlight 0.40, A-M Range 0.90, Reproduction Size 450%.
2. Normal - Highlight 0.37, A-M Range 1.25, Reproduction Size 450%.
3. Low-Key - Highlight 0.40, A-M Range 1.40, Reproduction Size 130%

All shadows - back of mirror.

All of these separation sets were produced with a 100 line/inch elliptical dot screen, skeleton black and 280% total printing dot.

A NAPS proof was made out of the final stripped up flat which contained the images, the Custom Color Analysis targets and an RIT Color Test Strip. This proof was supplied to the pressman for visual matching during the press run. To obtain acceptable quality the pressman also used density readings from the solid patches of cyan, magenta and yellow on the test strip. These density readings were matched to the normal densities used in that plant.

The targets were placed in such a way as to measure across the entire web and from the front to the back of the sheet. Four targets and four sets of high-key, normal and low-key images were used. See Figure 14.

Figure 14.

HK	LK	T	N
LK	HK	N	T
C		C	
N	T	LK	HK
T	N	HK	LK

HK = High-key

N = Normal

LK = Low-key

T = Target

C = Control Strip

Press Sheet Layout

The total number of impressions was 58,000 and the sampling

procedure was as follows:

1. Start-up - Five samples every 15 seconds.
2. After quality was reached - Five samples every 1000 impressions.

Start-up procedures for a lithographic press involve the most drastic and varied changes for the run to achieve proper color. Therefore, to document those many adjustments more samples were needed. 36 sample sets were generated for start-up. Quality was reached at the 6000 impression mark and 53 sample sets were generated to reach a total of 58,000 impressions. These sample sets were visually inspected to decrease the size of each set to one sheet. A sheet was disqualified if it had any unusual markings or smudges. If there was no discernible difference one sheet was chosen to represent the set.

To detect the start-up adjustments two targets from each sheet were evaluated for samples one through 36. By alternating the targets chosen between columns one-and-three and two-and-four, an indication of how press adjustments affected color across the entire web was obtained. For the first sample set the targets from columns one and three were evaluated. For the second sample set the targets from columns two and four were evaluated. This pattern was followed throughout the start-up. After quality was reached one target was evaluated every 1000 impressions and all four targets were evaluated every 5000 impressions. This provided adequate information by emphasizing critical changes during start-up and allowing fewer samples during the "fine tuning" of the press after reaching quality. Therefore, 80 sample sets were generated.

The sample parameters were calculated using basic statistical formulae (Leaver and Thomas, 1974). The Mean is the average value of the variate as in Equation 13 .

Equation 13

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

$\bar{x}$ = Mean
n = number of values of the variate in the sample
x_i = variate value

The Mean of the sample will measure the sample central tendency. To measure dispersion of the sample the Range, Standard Deviation and Variance were calculated. The Range is simply the difference between the largest and the smallest values of the variate. The Standard Deviation and the Variance were obtained by Equation 14 .

Equation 14

$$S^2 = \frac{\sum (x - \bar{x})^2}{n}$$

S = Standard Deviation
S^2 = Variance
x = Variate value
$\bar{x}$ = Mean
n = Number of values of the variate in the sample

The results are presented showing the variation of test data in relation to impression number.

FOOTNOTES - CHAPTER VI

Leaver, R.H. and Thomas, T.R. 1974 — "Analysis and Presentation of Experimental Results, John Wiley and Sons, New York.

VII. DATA ANALYSIS

The analysis of the sample targets was broken down into a three phase system. Phase one was the determination of the tone reproduction and computation of the halftone separation aim points. Phase two included the press performance characteristics of solid ink density, trapping, dot gain and slur. Phase three contained the color measurement system and spectrophotometric curves. Phases two and three are measures of the existing press conditions during the test run. There is little control that can be effected by the test operator due to the fact that these variables are merely measured. The choices of dot gain type, "n" value and ink laydown order are available, but in most cases will be standardized for an ink/press/paper combination.

Phase one is affected by operation choices since the halftone separation aim points are calculated. The most important area to consider for this study was the designation of the black printer. Custom Color Analysis as well as most scanners available on the marker today use computer softwear to calculate the best black printer according to the three-color and four-color tone reproduction curves and the size of the cyan printing dot. However, this softwear is not necessarily identical and differing black printers can result.

PHASE ONE

In order to compare the Custom Color to the initial halftone curves as stated in the hypothesis, the influence of the black

printer needed to be minimized. By manipulating the total printing dot allowable and designating the starting point for the black printer, the black curve for Custom Color was matched to the black curve for the initial separations. This eliminated the black printer as a variable and provided a better opportunity for direct comparison of the cyan, magenta snd yellow curves.

It should be noted that due to low three-color densities, the maximum allowable printing dot was increased from 280% to 300% for the Custom Color Analysis. This increase permitted the tone reproduction curves to fully utilize the S.I.D. level of cyan, magenta and yellow while still maintaining a skeleton black printer. Some effect in comparison may be experienced in shadow portions of the curves. As can be seen in Figure 15, the black printer coincides well up to the 60% dot area level. It is within this area that the most meaningful comparison of the color curves can be achieved.

By plotting the percent dot area of the reproduction versus the density of the original in Figures 15 and 16, the difference in initial curves versus proposed curves becomes apparent. The proposed curves' slopes are much greater in the highlight region and the dot areas for the corresponding densities are much larger. This would indicate that both the contrast and the saturation of the highlight to midtone colors would be greater for a reproduction made using the proposed curves. The shadow portion of the image would be comprised of primarily the black printer with a less than normal contribution from the three-color combination. Again, this is due to the low solid ink densities.

Figure 15

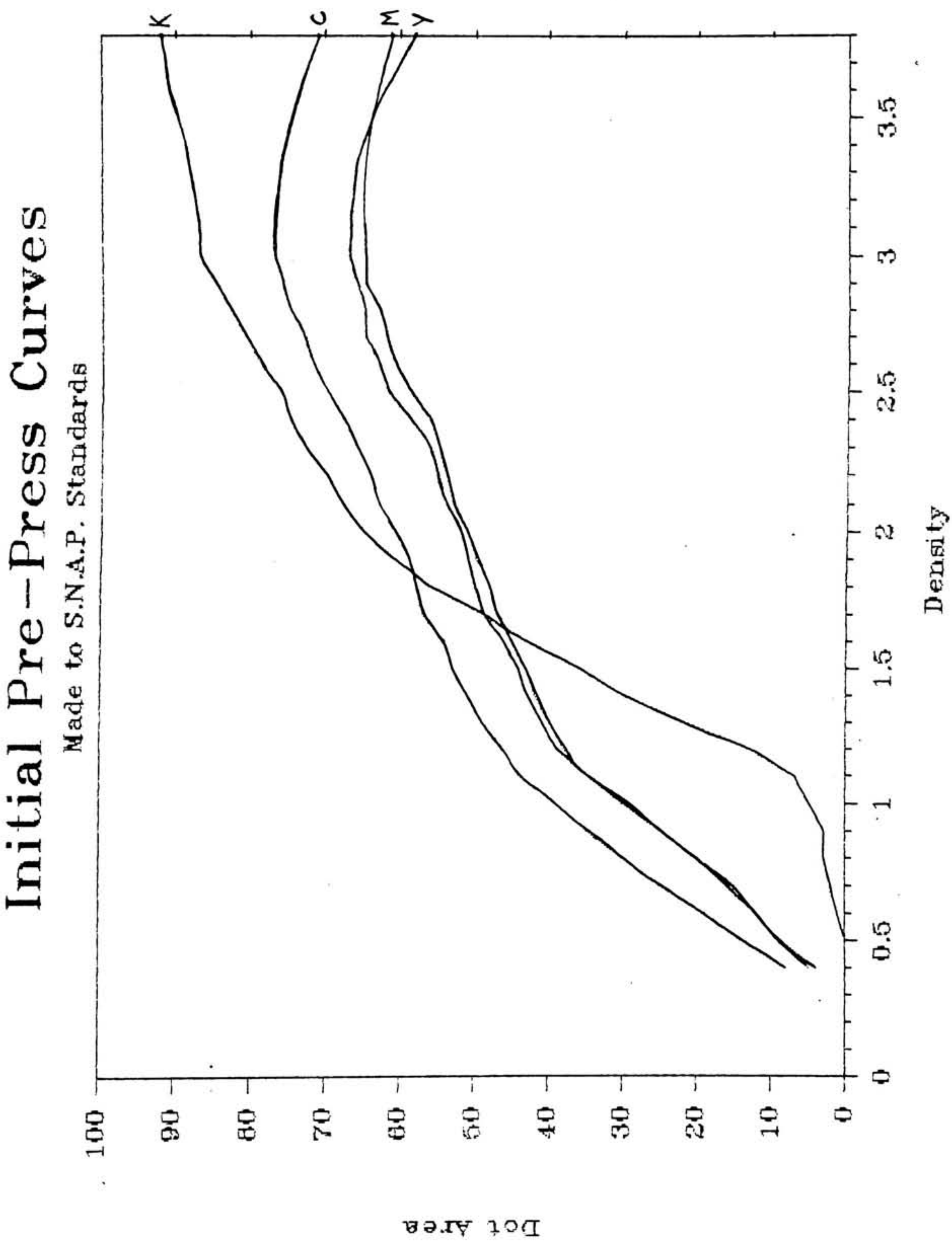
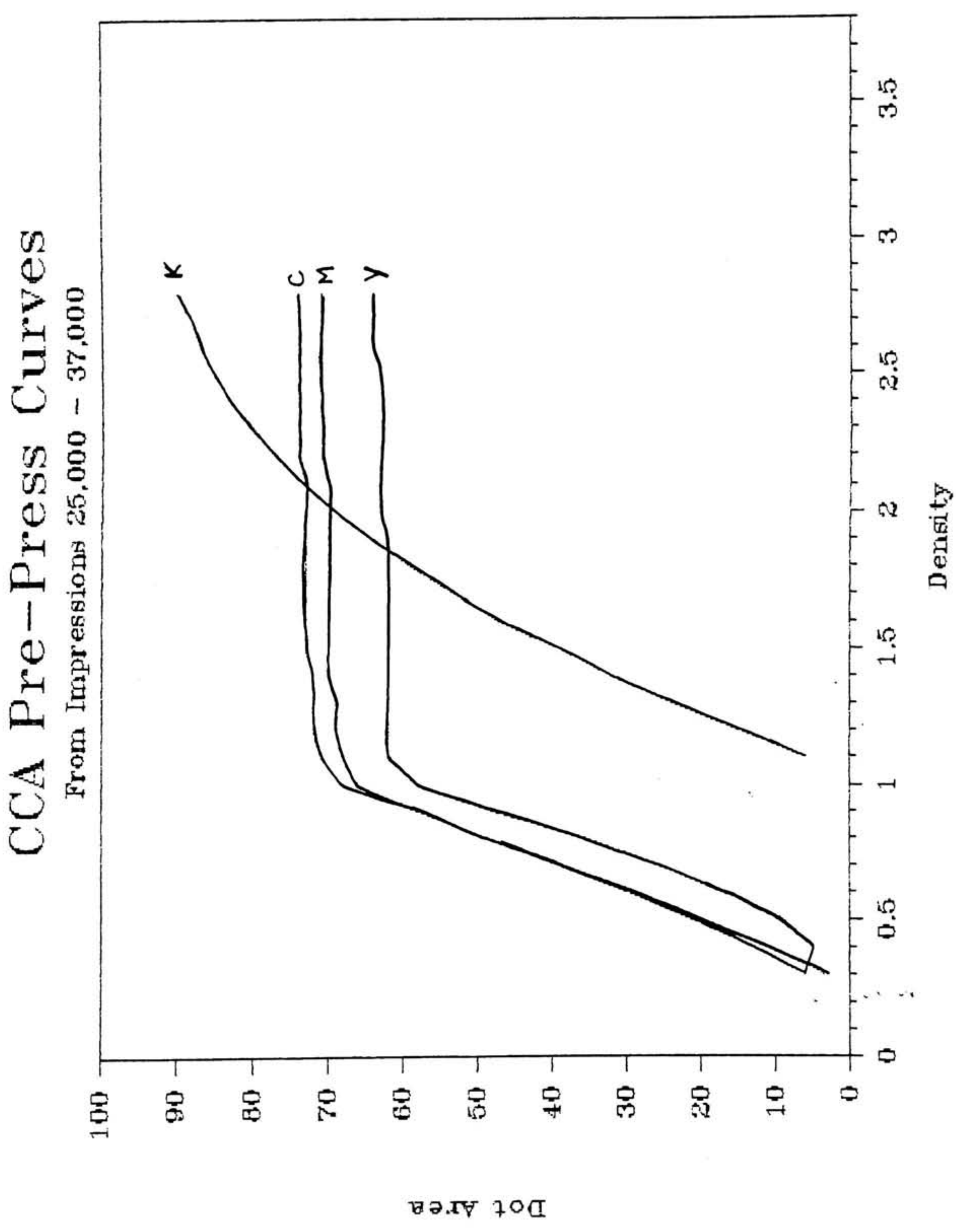

Initial Pre-Press Curves
Made to S.N.A.P. Standards
K
C
M
Y
Dot Area
100
90
80
70
60
50
40
30
20
10
0
Density
0
0.5
1
1.5
2
2.5
3
3.5

Figure 16


CCA Pre-Press Curves
From Impressions 25,000 - 37,000
K
C
M
Y
Density
Dot Area
0
0.5
1
1.5
2
2.5
3
3.5
0
10
20
30
40
50
60
70
80
90
100

The initial separations were made to S.N.A.P. (Specifications for Non-heatset Advertising Publications) standards. The black printer starting point is designated as black printing dot (k) = 1% where the cyan printing dot (c) = 30% and k = 5% where c = 40%. In the neutral shadow areas the computer software calculates the black printer and with the application of U.C.R, uses a standard of 280% total printing dot. The question that is raised here is the use of the back-of-the-mirror as a representation of the shadow portions of the image. In this case, by allowing the mirror to block the light from the photo-multiplier the shadow was designated as approximately a 3.8 density. With a total printing dot amount of 280% as maximum, the cyan, magenta and yellow curves were forced downward after a density of 3.0 and the black printer curve was flattened out reaching its maximum only after the 3.0 density.

A density of 3.8 is not realistic when compared to a normal transparency. For most transparencies the shadow density can vary from 2.4 to 3.0 (Southworth 1979). A density within this range should be chosen from a neutral gray scale to simulate a shadow area. This would allow the four colors to attain their maximum dot area within the range of the transparency.

Using the back of the mirror to simulate a transparency shadow is a technique used by most scanner operators as a time saving step eliminating the need to inspect the image for a shadow area or use the gray scale. However, the compromise that occurs due to incorrect placement is not worth the time saved.

By comparing the initial and proposed curves it would be predicted

that a second press run would produce a higher contrast in the highlight to midtone range. Because of this higher contrast, the dot areas would be larger for all three colors thus producing colors which would be more saturated than those produced by the initial press run.

A problem which must be avoided in dealing with newsprint is the fill-in or plugging up of the middletone to shadow areas. S.N.A.P standards avoid this situation by lengthening the A to M range as was done in the initial separations to compensate for dot gain. Dot gain has been estimated to be 25% at 50% dot area for newsprint using an 85-line screen ruling(Southworth). This press run averaged approximately 22% dot gain using a 100-line screen ruling. The lower dot gain could be explained by the fact that low solid ink densities were maintained throughout. If dot gain could be kept at this lower level the proposed curves could be used without the usual sacrifice made in the highlight detail. By employing UCR the neutral shadows would resist plugging.

The most important product of Customized Color Analysis test run is the resultant halftone aim points customized to press conditions. As stated in the introduction, until this time it was not known what variation occured in the suggested halftone aim points throughout a normal press run. In other words it is not known how much "fuzz" exists around the aim points or how far off you can be while still maintaining acceptability. The variation is dependent on which image is chosen as the representative sample for the analysis. Once acceptable quality was reached during the press run, samples were taken continually throughout the press run and the targets analyzed.

Each target generated a set of halftone aim curves. These curves were then statistically analyzed to obtain a representation of the "fuzz".

Figures 17 through 20 show the median, and the range between minimum and maximum for the respective halftone curves derived from the analysis of the impressions 9,000 through 59,000. There is quite a large spread, in most cases reaching +/-13 percent dot area, around the mean after the -M aimpoint. An inspection of the time series plots for the A, -M, M, -B and B patches reveals that the press events which occurred during the run were a large factor in creating this spread. See Figures 21 through 24. These points are used as standard control points in which to reference densities of an original. For a normal transparency, the AMB points relate to density in the following manner:

A = 0.3 -M = 0.6 M = 1.3 -B = 2.0 B = 2.4

A times series plot was made for each aimpoint of cyan, magenta, yellow and black. These plots consist of the Custom Color Analysis proposed dot area on the y-axis and impression number on the x-axis. To further clarify the x-axis the occurances of the press events have been marked.

Since a full subjective analysis consisting of evaluation by a panel of judges is not an objective of this thesis, another method of evaluation was necessary. During the press sheet inspection conducted to decrease the data to a manageable level(refered to in Chapter VI Methodology), the sheets were also inspected for acceptability. This inspection was conducted by three RIT School of

Figure 17

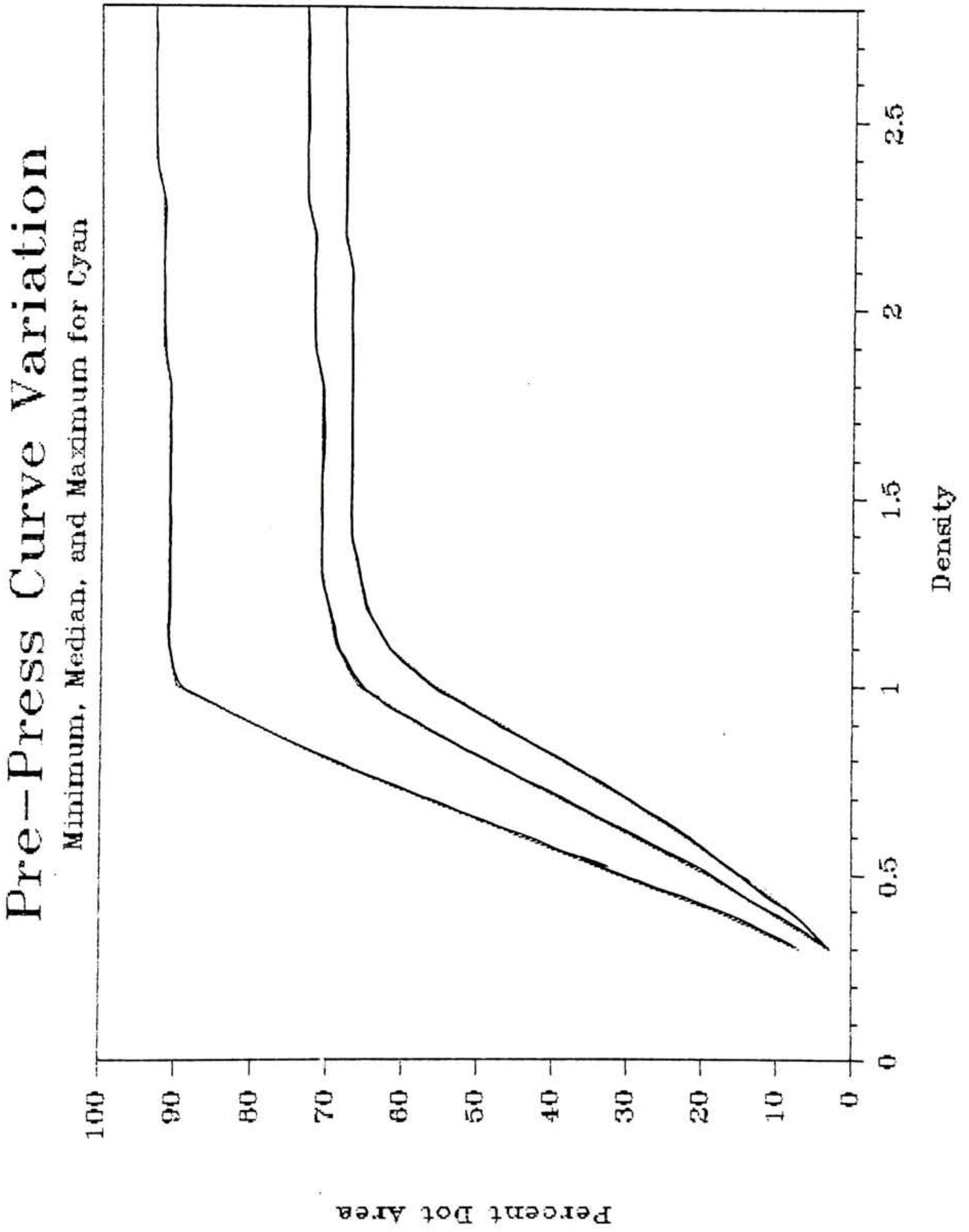

Pre-Press Curve Variation
Minimum, Median, and Maximum for Cyan
Percent Dot Area
Density
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5

Figure 18

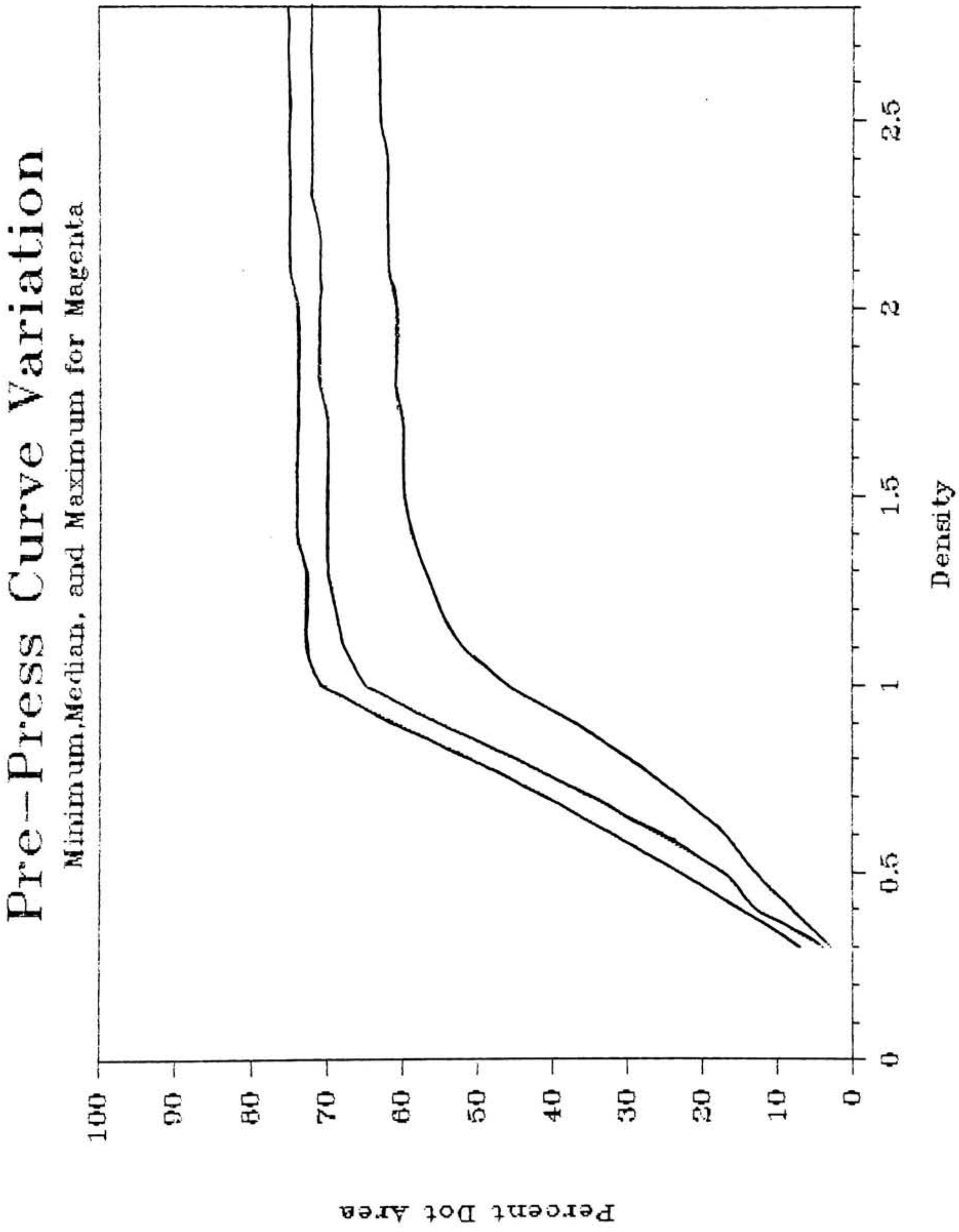

Pre-Press Curve Variation
Minimum,Median, and Maximum for Magenta
Density
Percent Dot Area
0
0.5
1
1.5
2
2.5
0
10
20
30
40
50
60
70
80
90
100

Figure 19

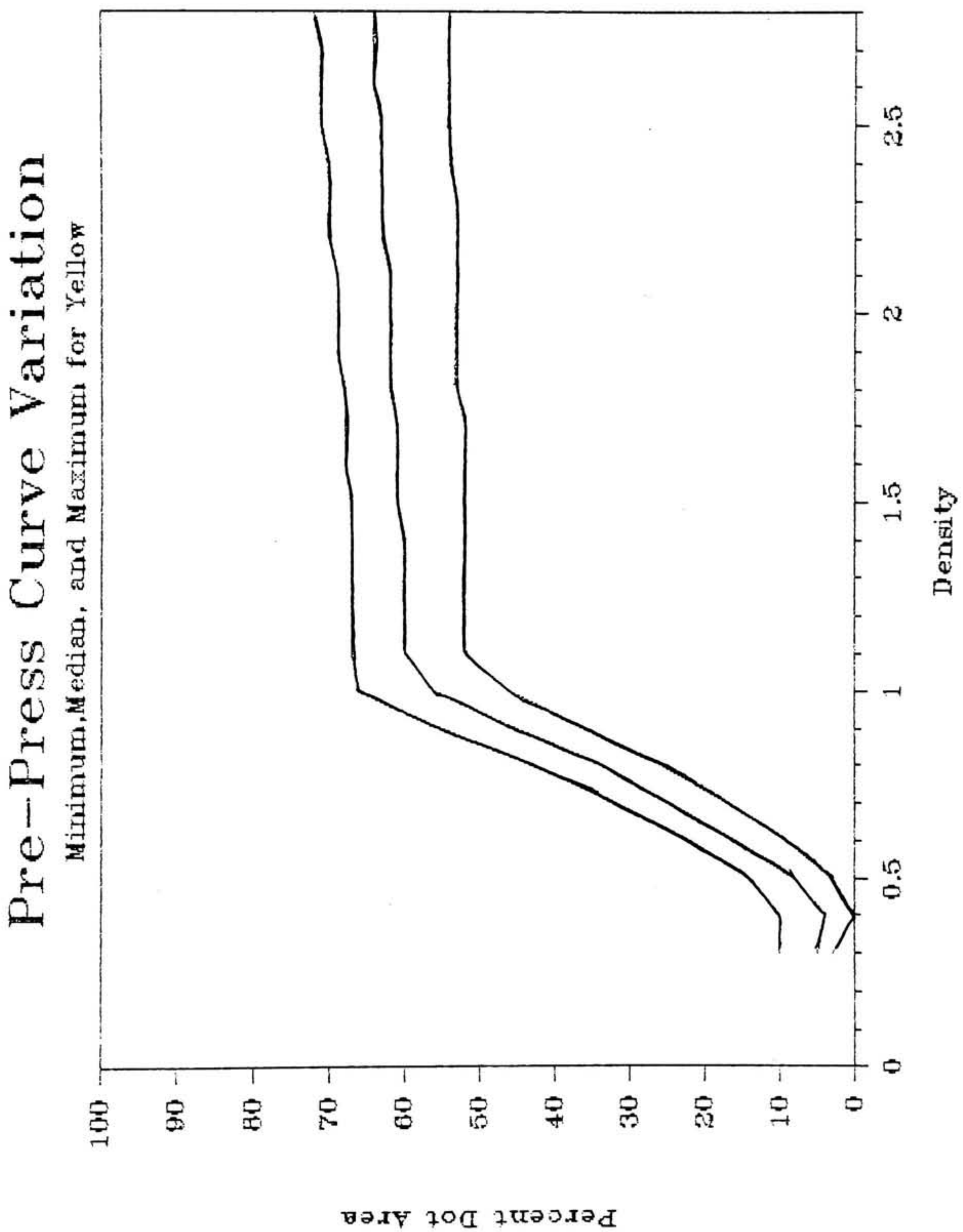
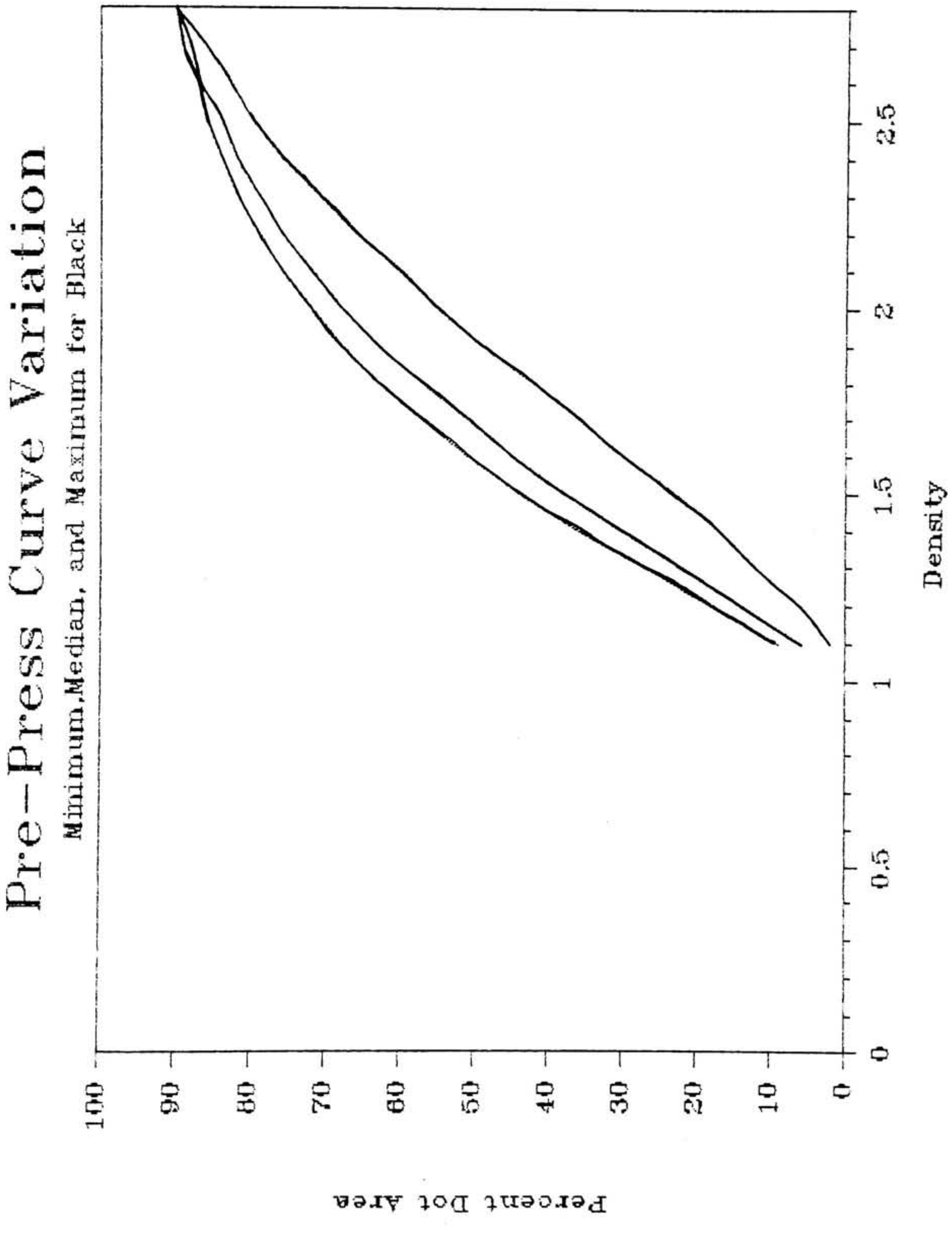

Pre-Press Curve Variation
Minimum, Median, and Maximum for Yellow
Percent Dot Area
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Density

Figure 20



Pre-Press Curve Variation
Minimum,Median, and Maximum for Black
Percent Dot Area
100
90
80
70
60
50
40
30
20
10
0
Density
0
0.5
1
1.5
2
2.5

Figure 21

Time Series Plots of A,-M,M,-B,B Points (Cyan)

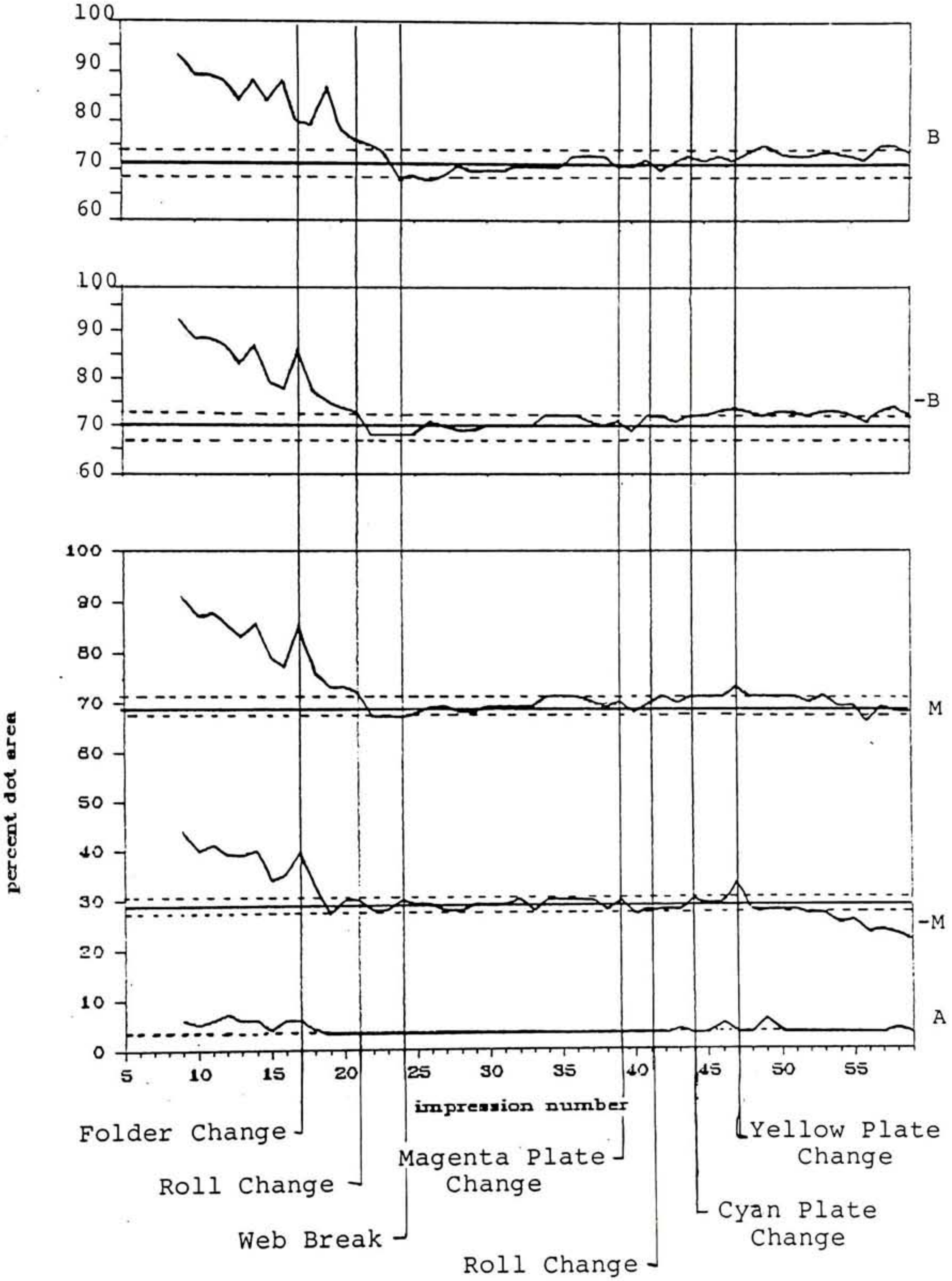


Figure 22

Time Series Plots of A,-M,M,-B,B Points (Magenta)

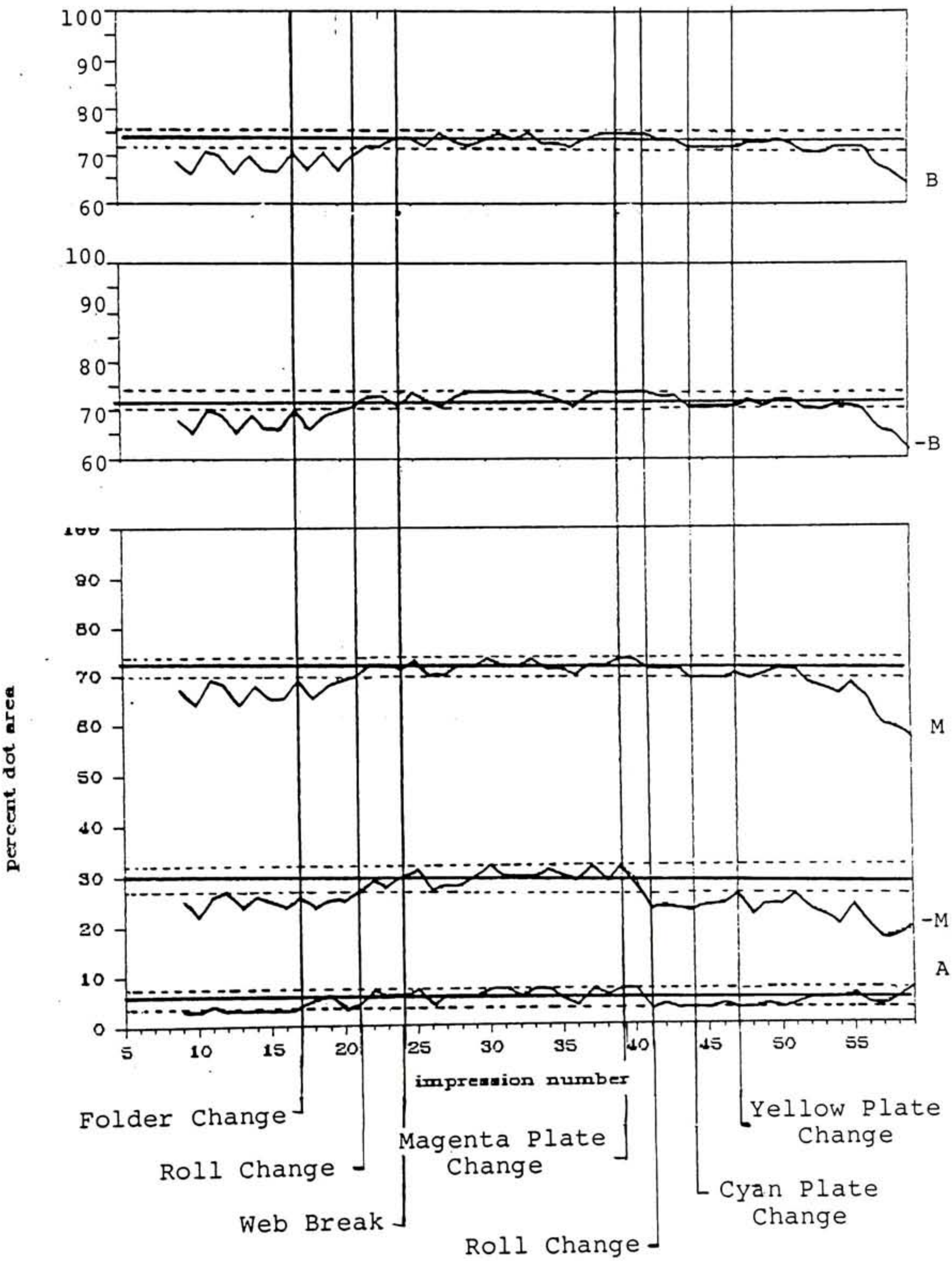


Figure 23

Time Series Plots of A,-M,M,-B,B Points (Yellow)

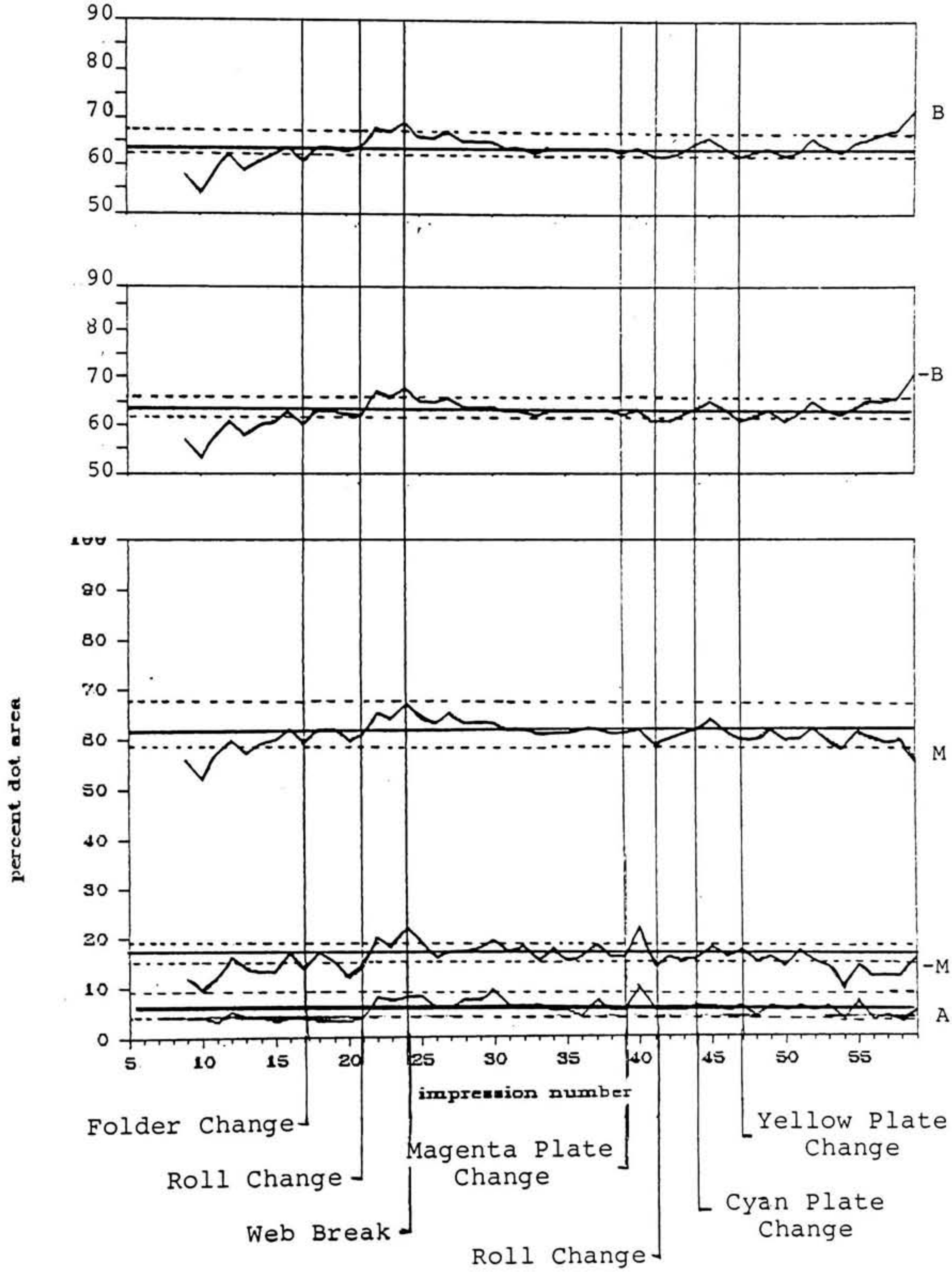
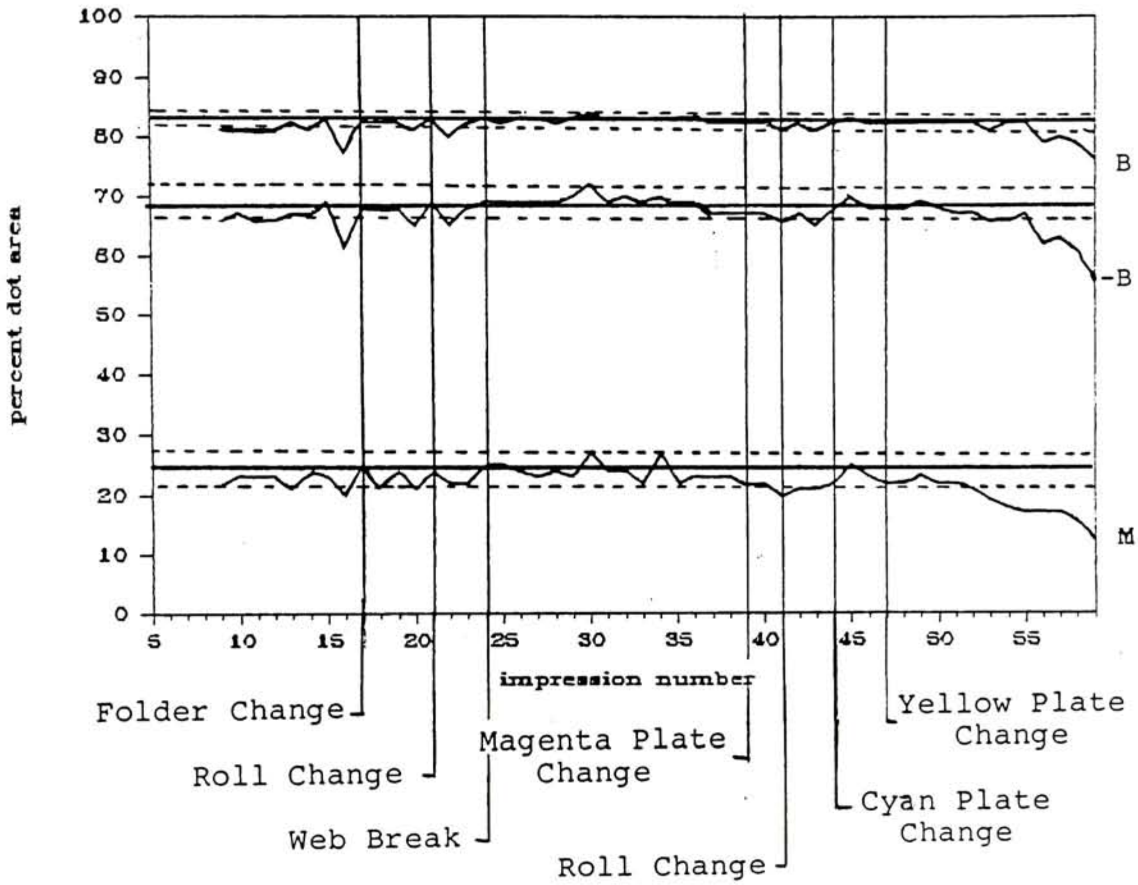


Figure 24

Time Series Plots of A,-M,M,-B,B Points (Black)



Printing graduate students. To aid the visual inspection, a record of the press events was consulted to avoid the variability inflicted by these occurences. Impressions number 25,000 to 37,000 were chosen as the most stable representative samples of the press run.

What needed to be done at this point was to eliminate the "noise" that was created by certain press events and find the halftone separation curves that best described the acceptable quality of this press run.

The quantity ΔE as derived from the CIELab Color Volume was employed. ΔE is used to describe differences that exist between two points in the CIELab Color Volume. See Equation 15.

Equation 15

$$\Delta E = \sqrt{(L* - \bar{L}*)^2 + (a* - \bar{a}*)^2 + (b* - \bar{b}*)^2}$$

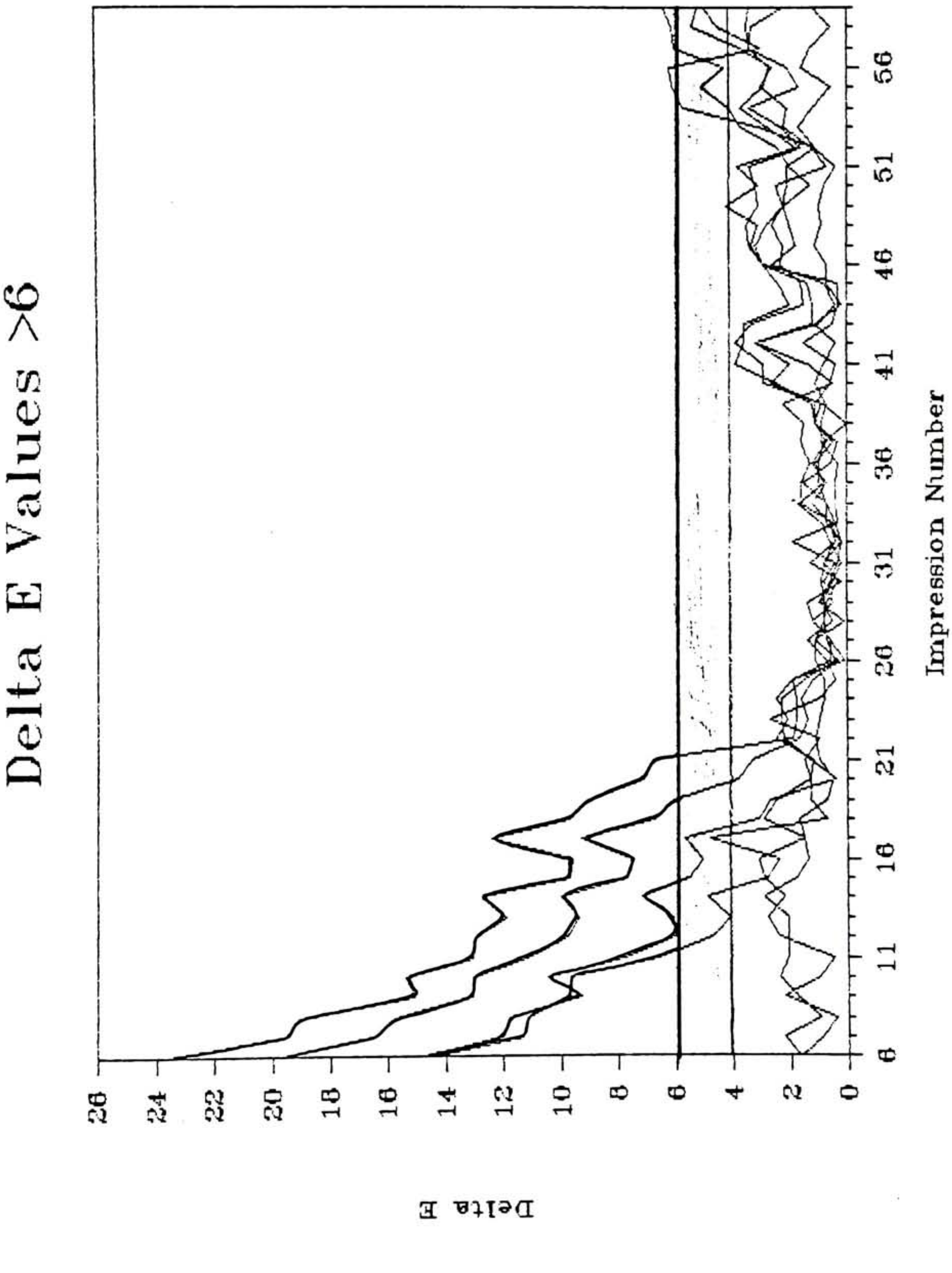
ΔE has also been used as an indicator of Just Noticable Difference (JND). Research work conducted by Stamm (1980) suggests that the average allowed tolerance or limit to which a viewer would allow a color to change, yet still evoke the desired response, was 6 ΔE units. This study also showed that ΔE values were equally represented by hue, chroma, and lightness meaning that no single dimension contributed more than any other. Other studies conducted by Schlapfer(1981, 1984) indicate that a range of 4 to 6 ΔE units is a noticeable difference, while above 6 units produces a change beyond tolerance levels.

It must be stressed that ΔE is not an indicator of whether a color is good or bad or even what that color may be. It is merely an indication of the difference of a sample from a criterion. To

establish a criterion, the CIELab coordinates of impressions numbers 25,000 to 37,000 were averaged. The average L* a* b* numbers were then used in Equation 15 to obtain a ΔE quantity relative to each sample from 9,000 to 59,000. These ΔE values are listed in Table 1. If a ΔE value for any ink or overprint was > 6, the results from that target analysis were rejected. Figure 25 is a representation of the selection process used by employing ΔE. The horizontal band represents the allowed range in which change is not outside tolerance. Below this band the difference is minimal, above the band the difference is unacceptable. The heavy black line represents the ΔE level of 6 units.

Refering back to Figures 21 through 24, the dashed horizontal lines represent the allowances using ΔE and the solid horizontal line represents the median. Without considering any type of criterion, the aim points for proposed curves varied greatly after the 5,000 impression point which marked the point of acceptable quality. The curves show that repeatability was not reached until after 20,000 impressions. This emphasized that the representative press run sample must be chosen with care. The sample must be produced when the process is stable and repeatable. The effects of press events on the calculations of the proposed curves can easily be seen. The down time that was brought about by a folder change and web break were major deterants in achieving a stable reproducable run with a short start-up time. Each stoppage created additional recovery time. The plate changes and roll changes were much shorter time periods thus their affect was more subtle. The folder change at impression 17,000 took

Figure 25


Delta E Values >6
Impression Number
Delta E
6 11 16 21 26 31 36 41 46 51 56
0 2 4 6 8 10 12 14 16 18 20 22 24 26

25 minutes while the plate or roll changes took only 3 to 4 minutes.

Figures 26 through 29 are a comparison of the percent dot area versus density for the entire press run and the curves selected using ΔE. When the process was in control the resultant "fuzz" of the curves was much smaller. The cyan curve is the best example. Without a selection process, the percent dot area range at .90 density of original point was +/-16%. By using the information from the ΔE calculations to select appropriate samples, the range was reduced to +/-3%. The magenta, yellow and black halftone curve ranges were also reduced.

Table 2 gives a listing of the range between minimum and maximum dot area of the proposed curves for cyan, magenta, yellow and black over the complete density range. It should be remembered that these curves are derived directly from the CIELab measurements to insure proper gray balance. This prevents the individual highs and lows of the curves from acting independently. For instance, although the range of the magenta halftone curve is +/-7% at its largest, the cyan and yellow curves would still correspond to it to achieve the proper gray balance. The three curves interact, therefore one curve variation leads to compensation by the other curves.

Phase Two

Phase two of the data analysis includes the press characteristics of solid ink density, trapping,dot gain and slur. The time series plots of density versus impression number give a good indication as to why the ΔE values of the first 20,000 sheets were unacceptable.

Figure 26

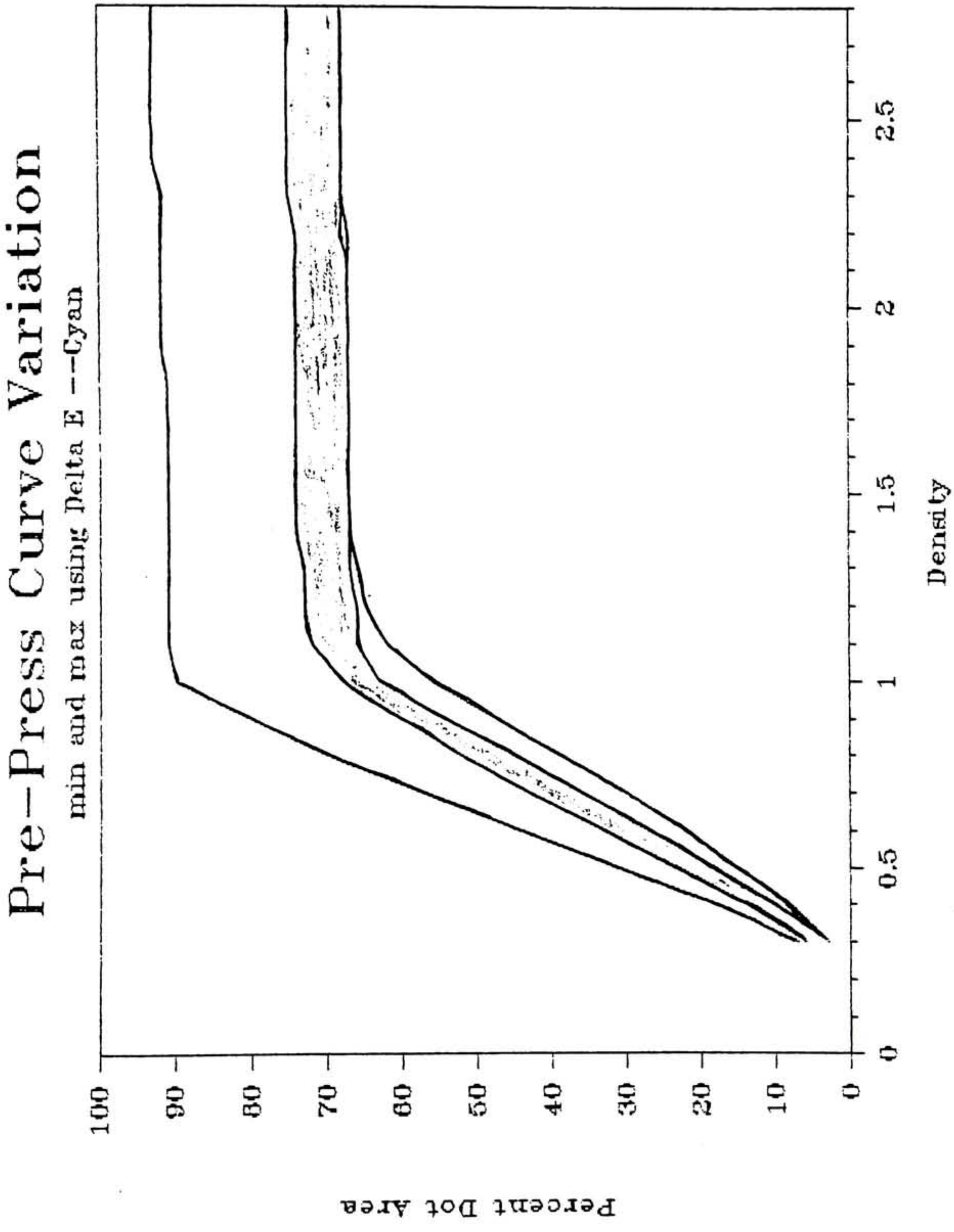
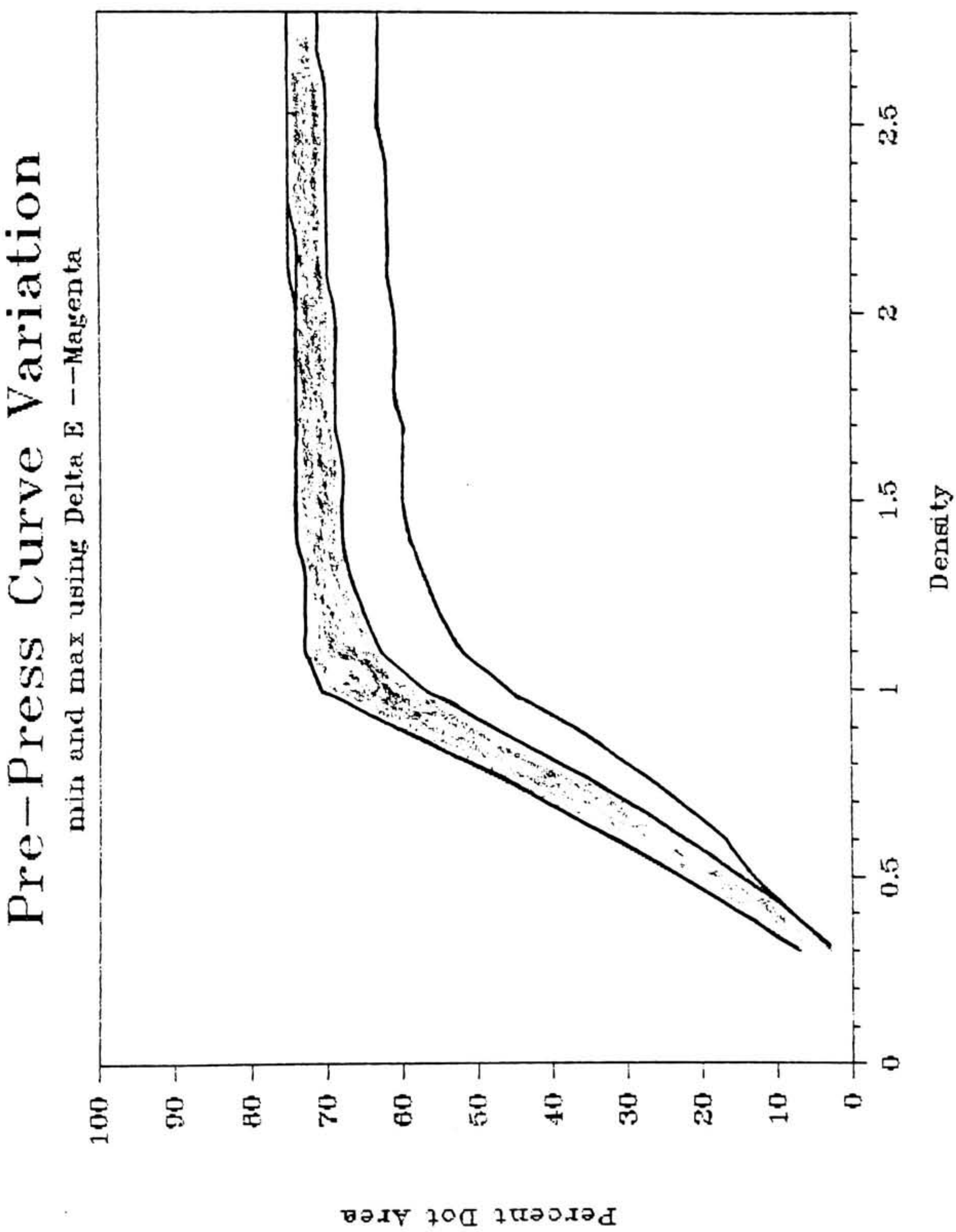

Pre-Press Curve Variation
min and max using Delta E --Cyan
Percent Dot Area
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Density

Figure 27



Pre-Press Curve Variation
min and max using Delta E --Magenta
Percent Dot Area
100
90
80
70
60
50
40
30
20
10
0
Density
0
0.5
1
1.5
2
2.5

Figure 28

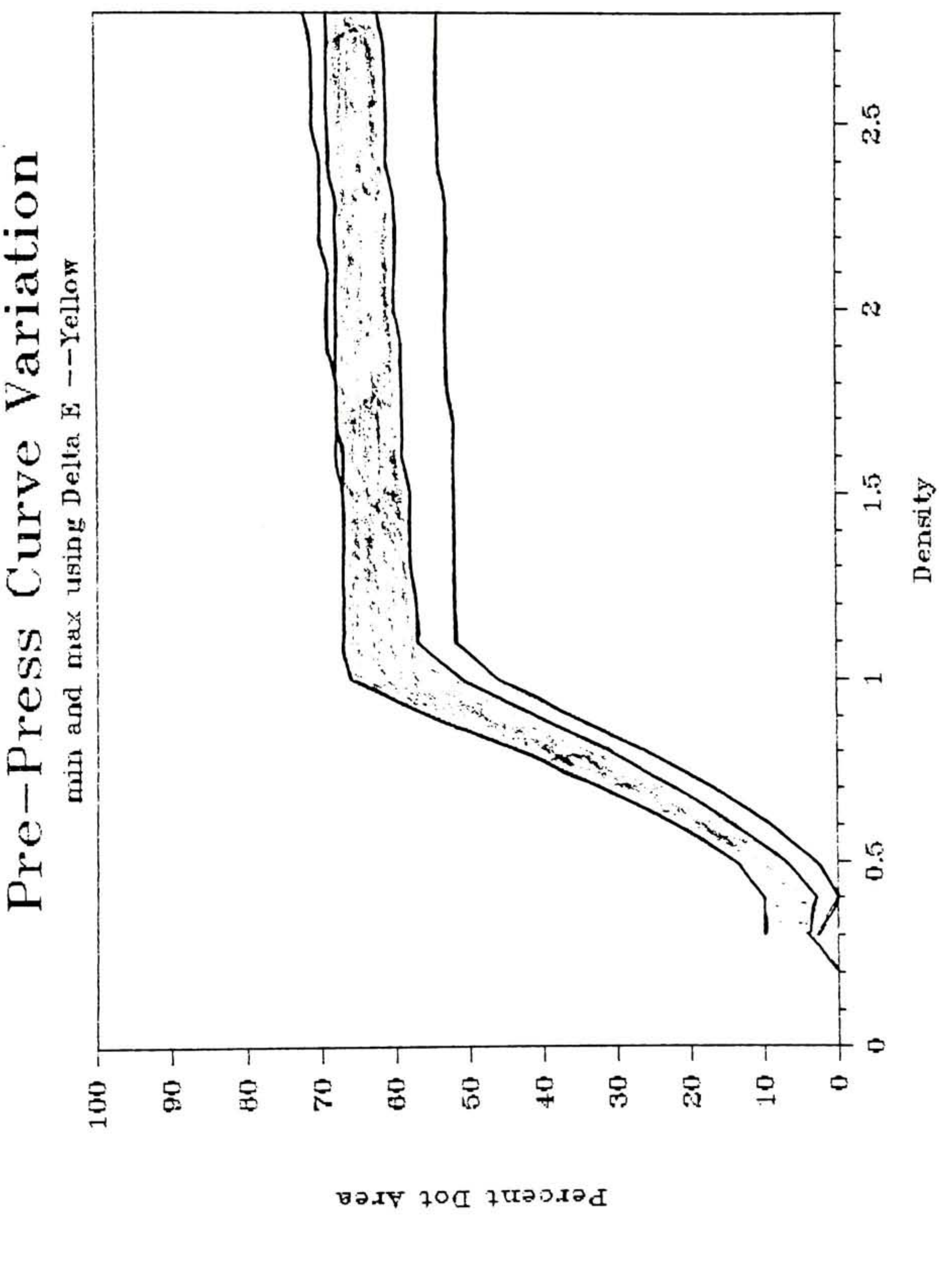
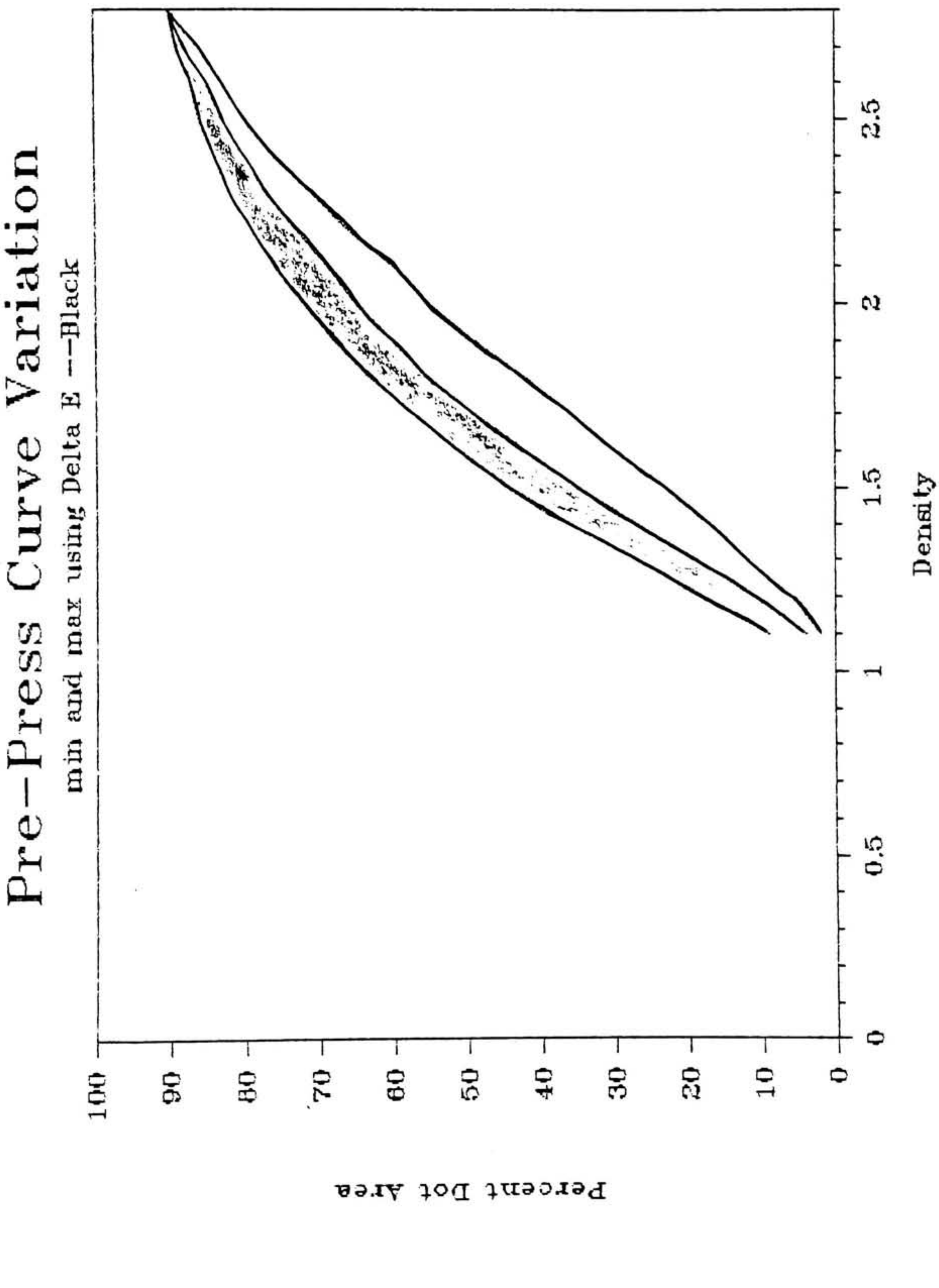

Pre-Press Curve Variation
min and max using Delta E --Yellow
Density
0
0.5
1
1.5
2
2.5
Percent Dot Area
0
10
20
30
40
50
60
70
80
90
100

Figure 29


Pre-Press Curve Variation
min and max using Delta E --Black
Percent Dot Area
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Density

See Figures 30-35. Both the cyan and 3-color curves experienced low density levels and did not stabilize until after the 21,000 impression mark. These low levels prevented the combination of the process inks from generating the necessary colors.

Due to the stipulation of a skeleton black printer and the designation of its specific starting point, the use of U.C.R. made it impossible to derive pre-press curves from some samples. These were samples which had low 3-color solid ink densities. By specifically designating the starting point of the black printer to eliminate it as a variable, the point at which the 3-color curve broke from the 4-color curve was also designated. The subsequent curve points for the black printer were also designated from the original pre-press curves (Figure 15). This effectively fixed points A, B, and C marked in Figure 36. Points A and B were fixed by the initial pre-press curves. Point C was fixed by the placement of point A. Point D represents the necessary 3-color density which when combined with the effective black curve will yield the proper 4-color density while remaining within a U.C.R total printing dot of 300%. This point will vary with the levels of 3-color solid ink density. If point D drops to a density of less than point C, a negative slope for line $\overline{CD}$ would occur giving an unacceptable result. The darkest shadows of the reproduction should correspond to the darkest portion of the original. The 3-color curve must be broken from the 4-color curve so that a continuous and positive slope is maintained.

The negative slope condition for $\overline{CD}$ occured in the analysis of the impression numbers less than 10,000. Once the 10,000 level was

Figure 30

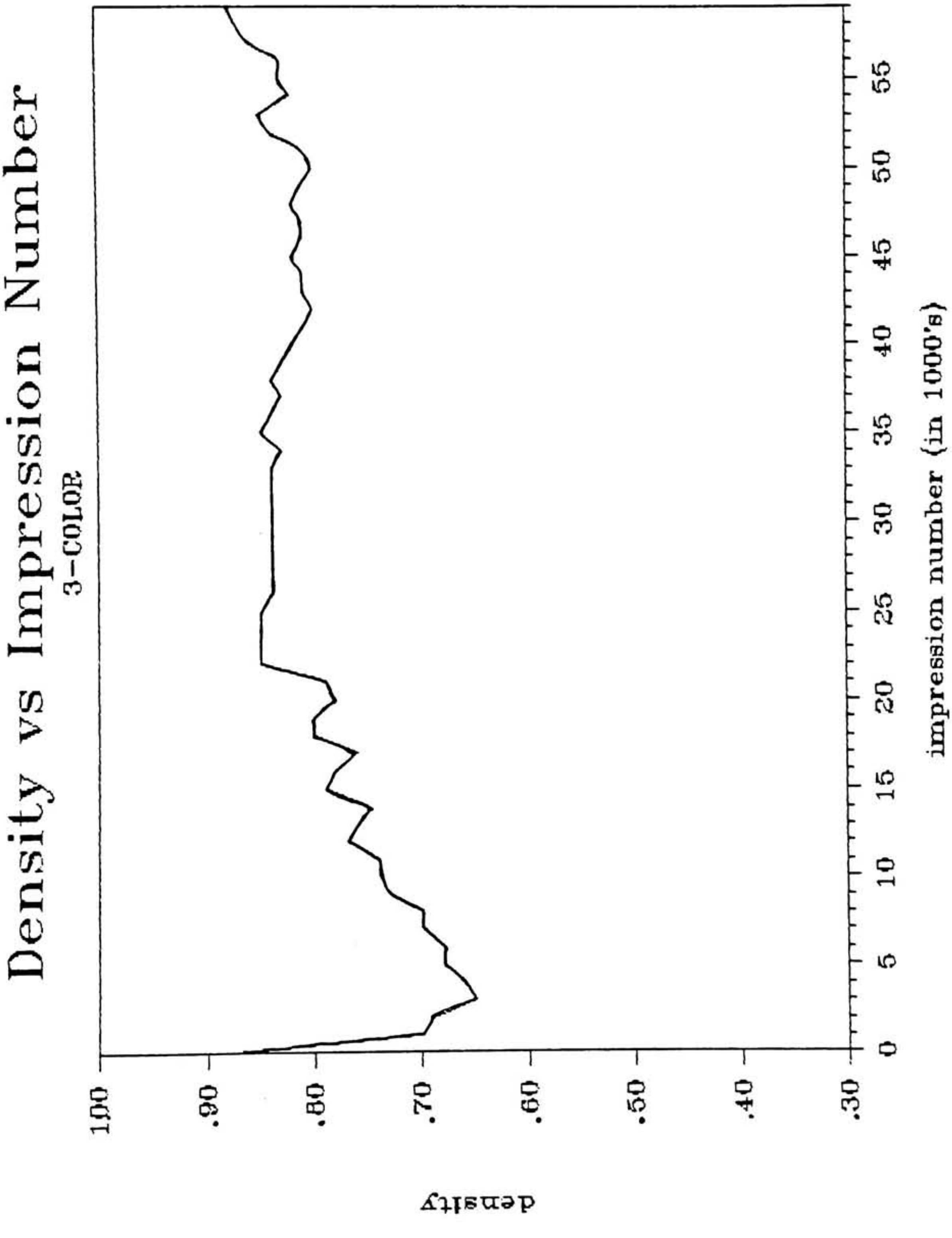

Density vs Impression Number
3-COLOR
density
impression number (in 1000's)
1.00
.90
.80
.70
.60
.50
.40
.30
0
5
10
15
20
25
30
35
40
45
50
55

Figure 31

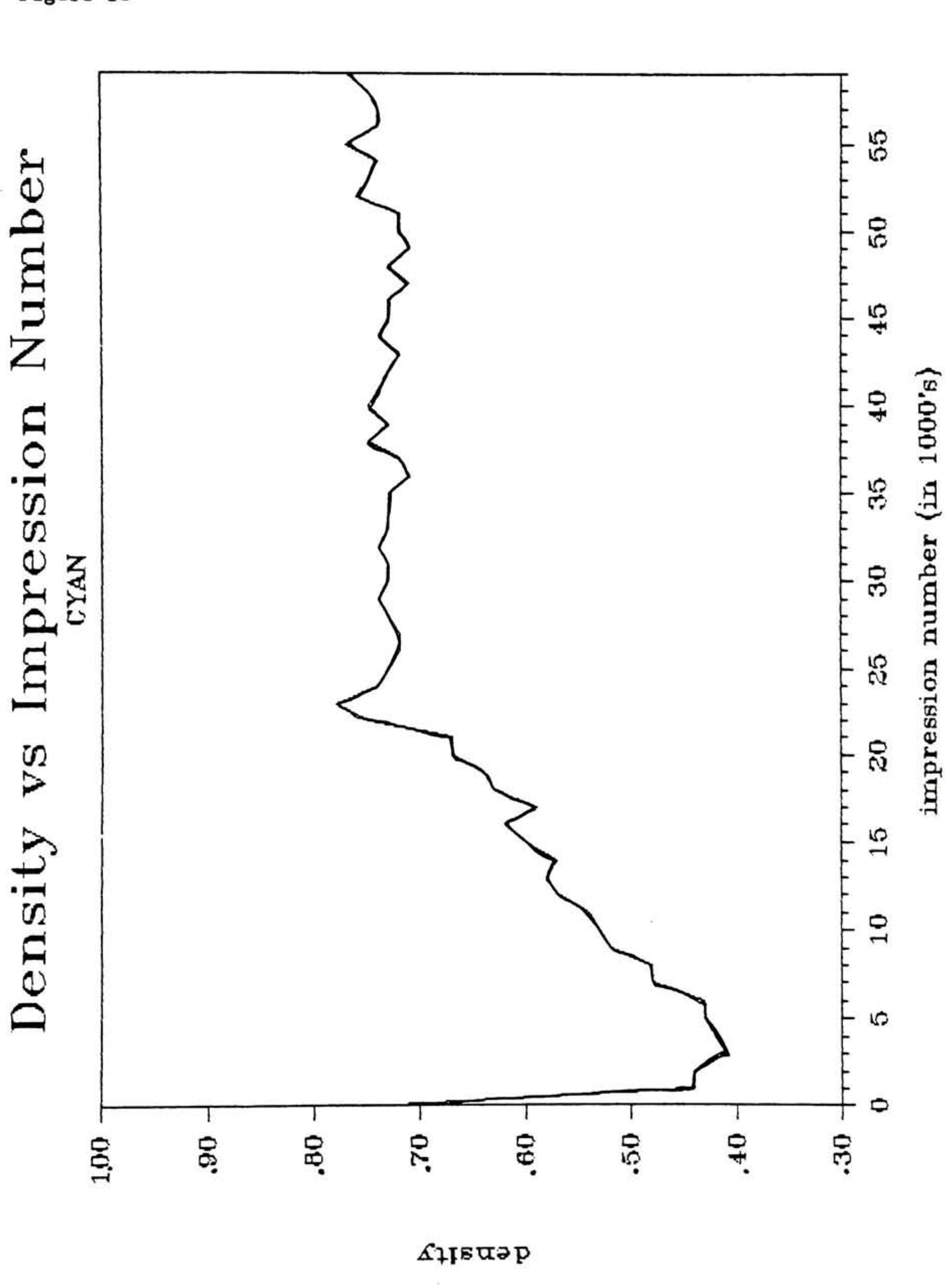
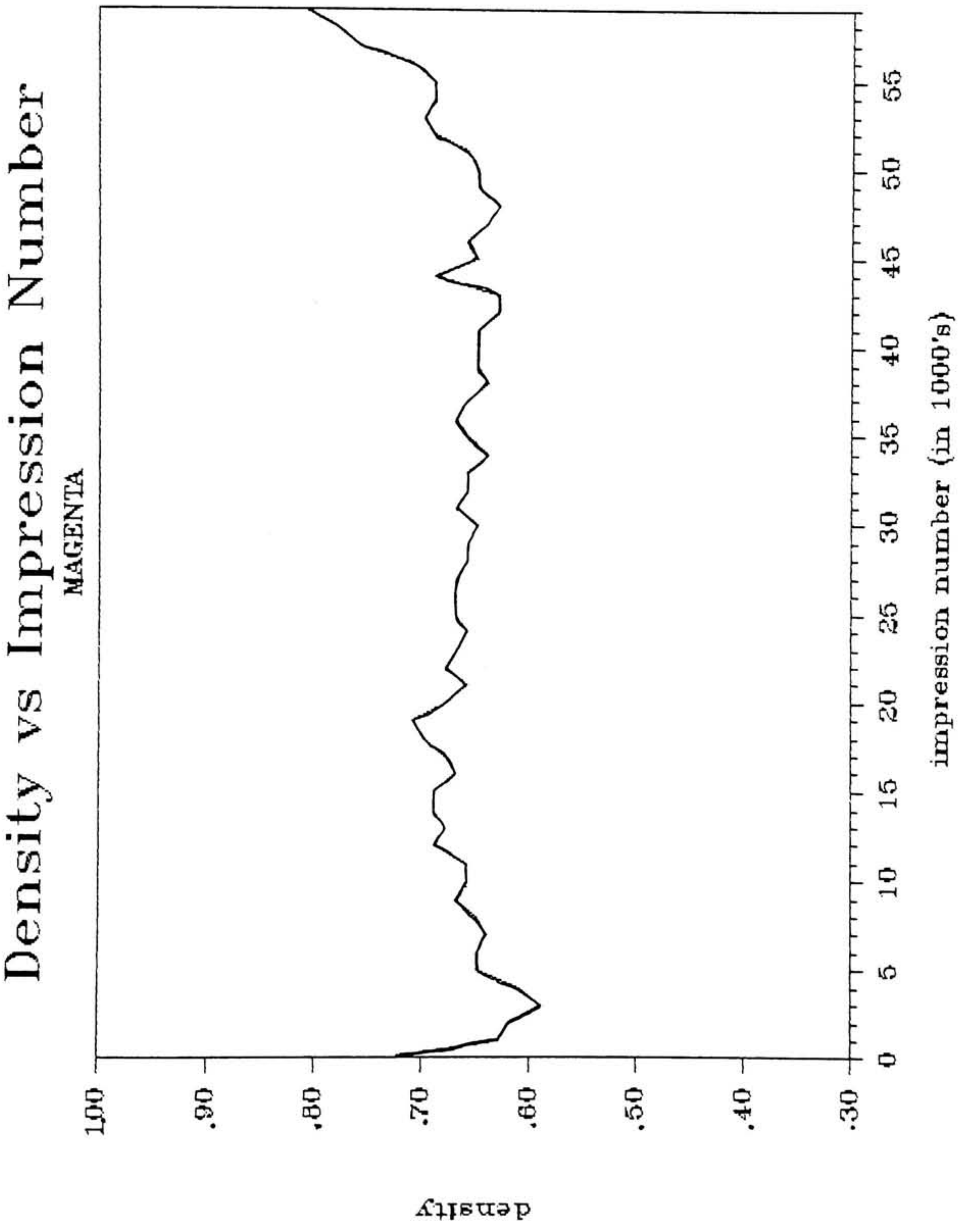

Density vs Impression Number
CYAN
density
1.00
.90
.80
.70
.60
.50
.40
.30
impression number (in 1000's)
0
5
10
15
20
25
30
35
40
45
50
55

Figure 32



Density vs Impression Number
MAGENTA
density
impression number (in 1000's)
1.00
.90
.80
.70
.60
.50
.40
.30
0
5
10
15
20
25
30
35
40
45
50
55

Figure 33

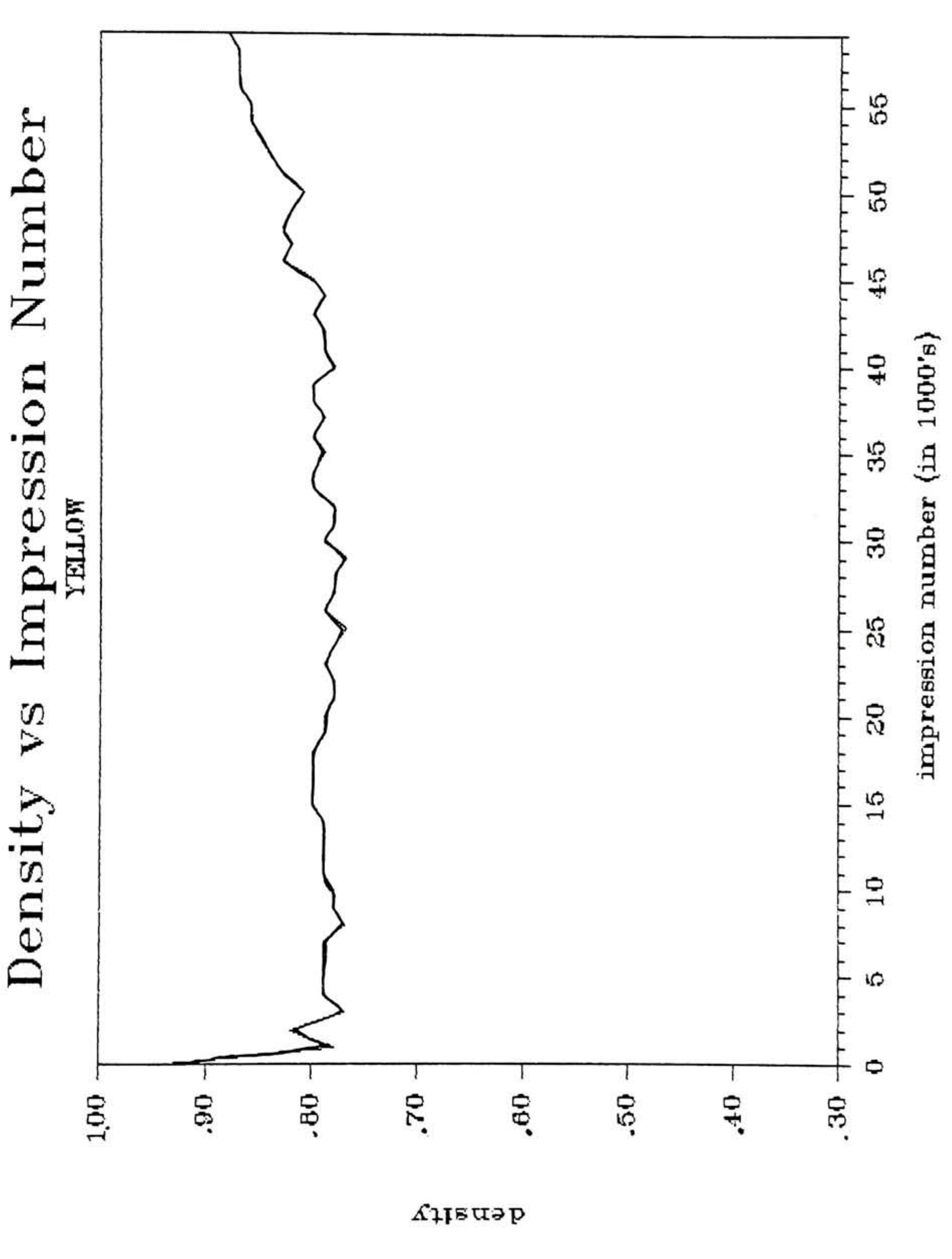

Density vs Impression Number
YELLOW
density
1.00
.90
.80
.70
.60
.50
.40
.30
0
5
10
15
20
25
30
35
40
45
50
55
impression number (in 1000's)

Figure 34

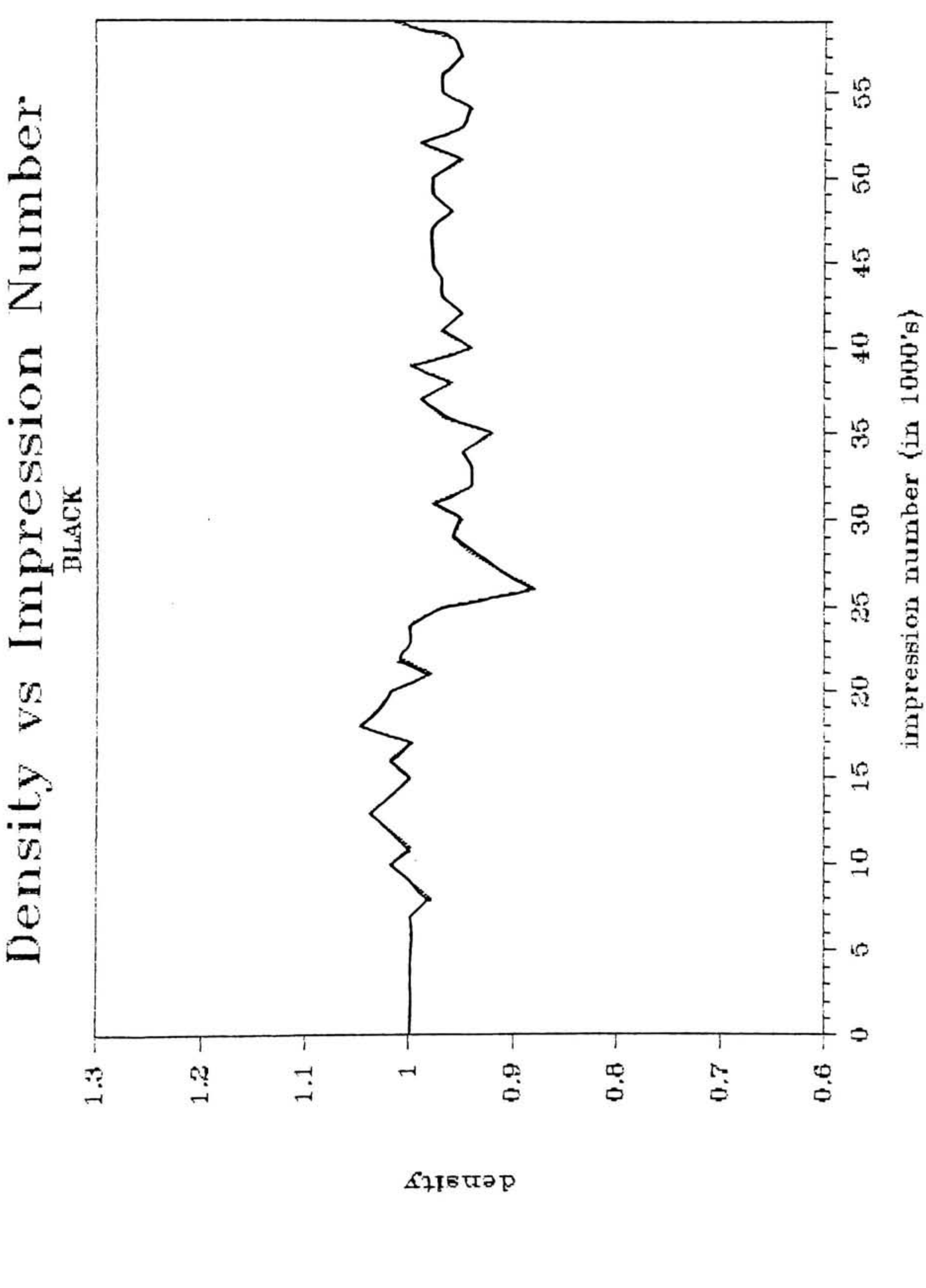

Density vs Impression Number
BLACK
density
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
5
10
15
20
25
30
35
40
45
50
55
impression number (in 1000's)

Figure 35

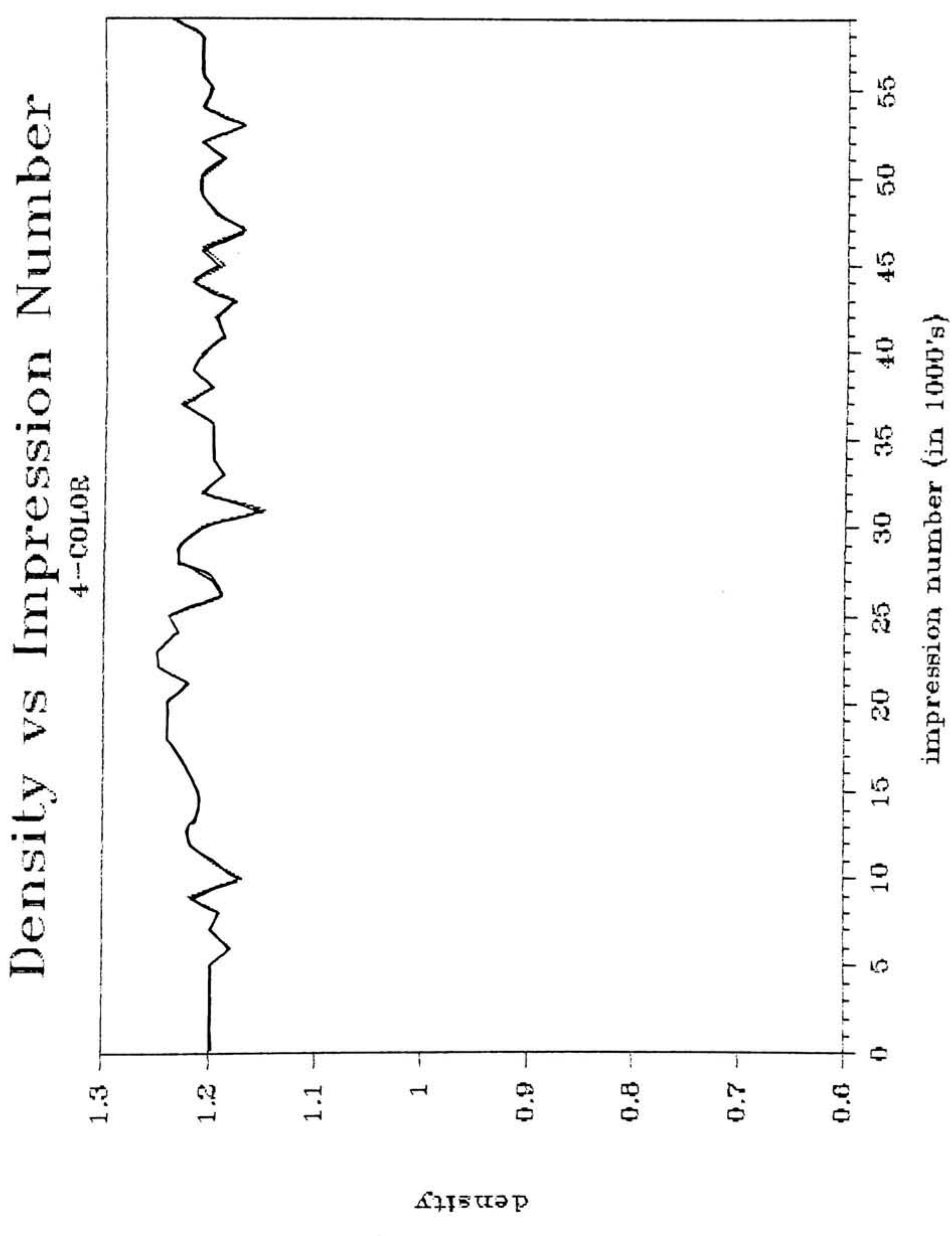
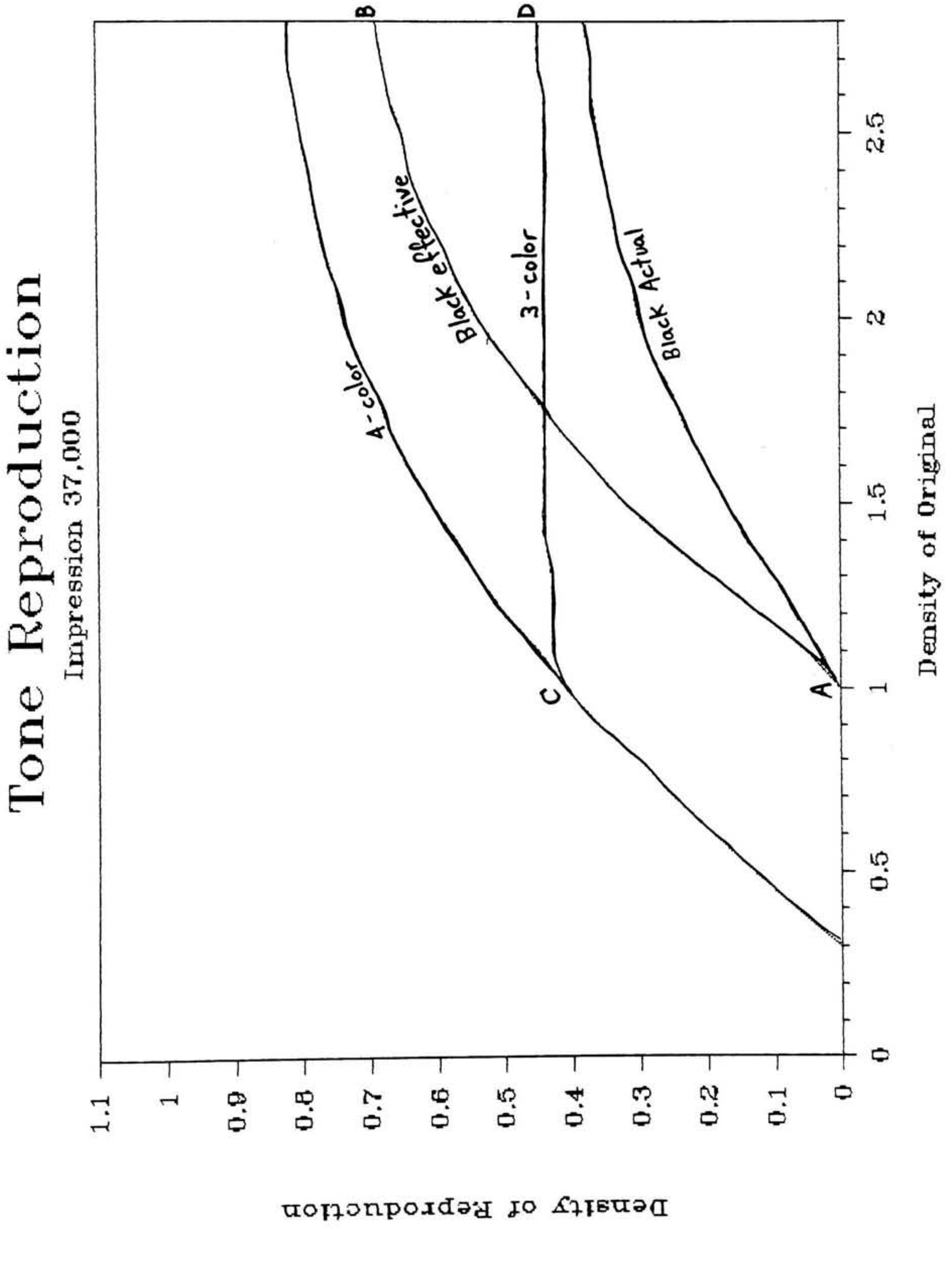

Density vs Impression Number
4-COLOR
density
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
impression number (in 1000's)
0
5
10
15
20
25
30
35
40
45
50
55

Figure 36


Tone Reproduction
Impression 37,000
A-color
Black effective
3-color
Black Actual
A
B
C
D
Density of Original
Density of Reproduction
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0.5
1.5
2
2.5

reached the subsequent analyses were acceptable. Figures 31 and 32 show the dramatic rise and stabilization that took place for the cyan and 3-color. It is interesting to note that the 3-color curve was most stable for impression numbers 25K through 37K which were selected as the samples indicative of the entire press run.

Dot gain time series plots showed that once the press was stabilized, a level of 22% +/-2% for cyan, magenta and yellow was maintained for 50% dot area. The black median was 20% dot gain +/-2% for 50% dot area. Some interesting observations can be made from Figures 37-40. The dot gain was low for cyan until 20,000 impressions. By referring back to the density plots, it can be seen that the low density for cyan caused the dot gain to be abnormally low. Only after the density level was stabilized did the dot gain also reach a normal percentage.

The magenta curve of Figure 38 shows a classic example of dot sharpening. This press configuration used a direct plate to substrate method only for the magenta unit. At 40,000 impressions, the magenta plate was replaced. The time series plot shows that from impressions 25,000 to 39,000 the dot gain percentage decreased from 20% to 12%. After the plate was changed, the dot gain percentage increased to 26%. This change is also reflected in the time series curves of the AMB points. Figure 18 shows the aim points for magenta. The -M curve shows a dot area decrease from 33% to 23% when the magenta plate change ocurred.

Percent trapping of the inks remained fairly stable throughout the press run. Several peaks in the curves occur which can be attributed

Figure 37

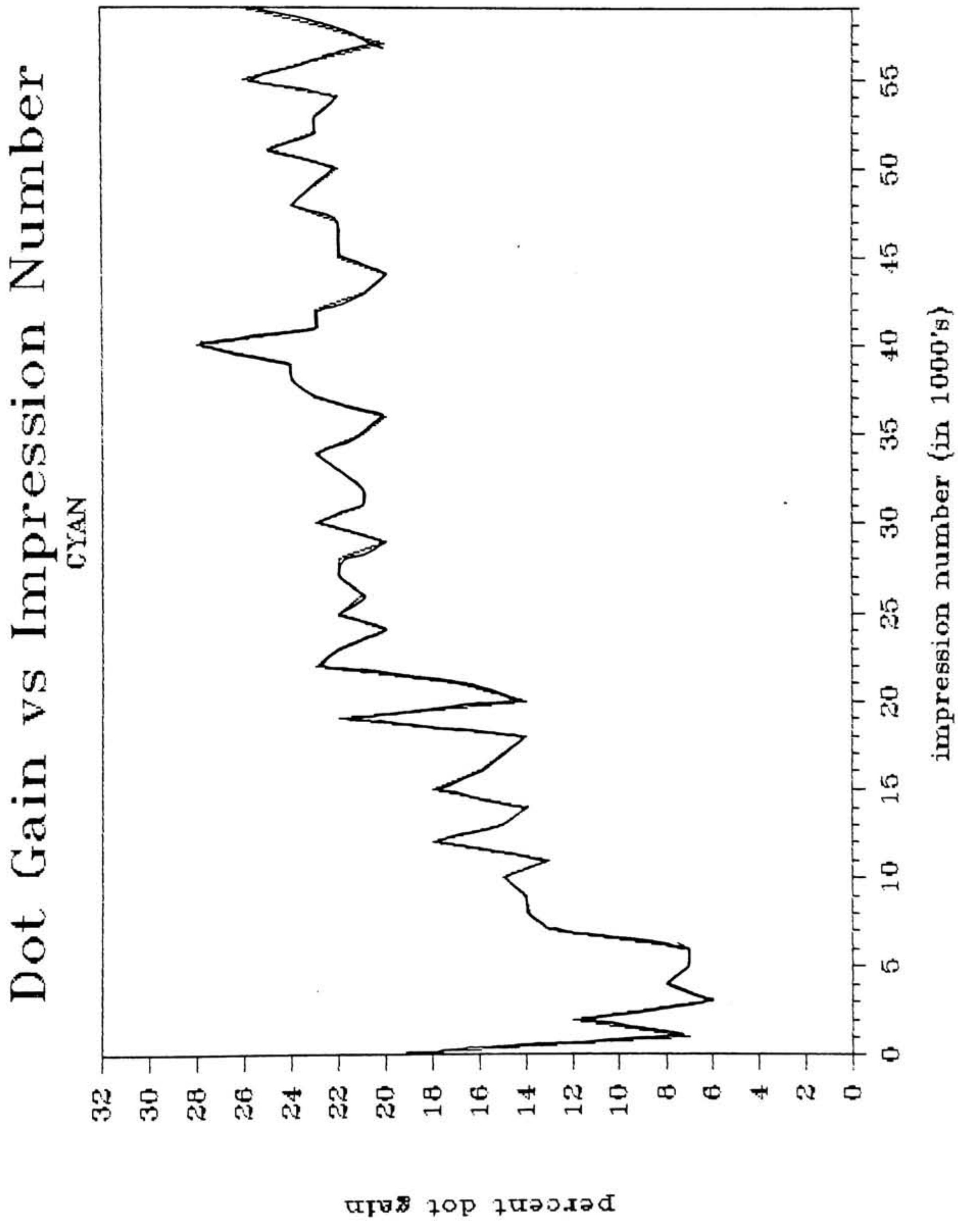

Dot Gain vs Impression Number
CYAN
impression number (in 1000's)
percent dot gain

Figure 38

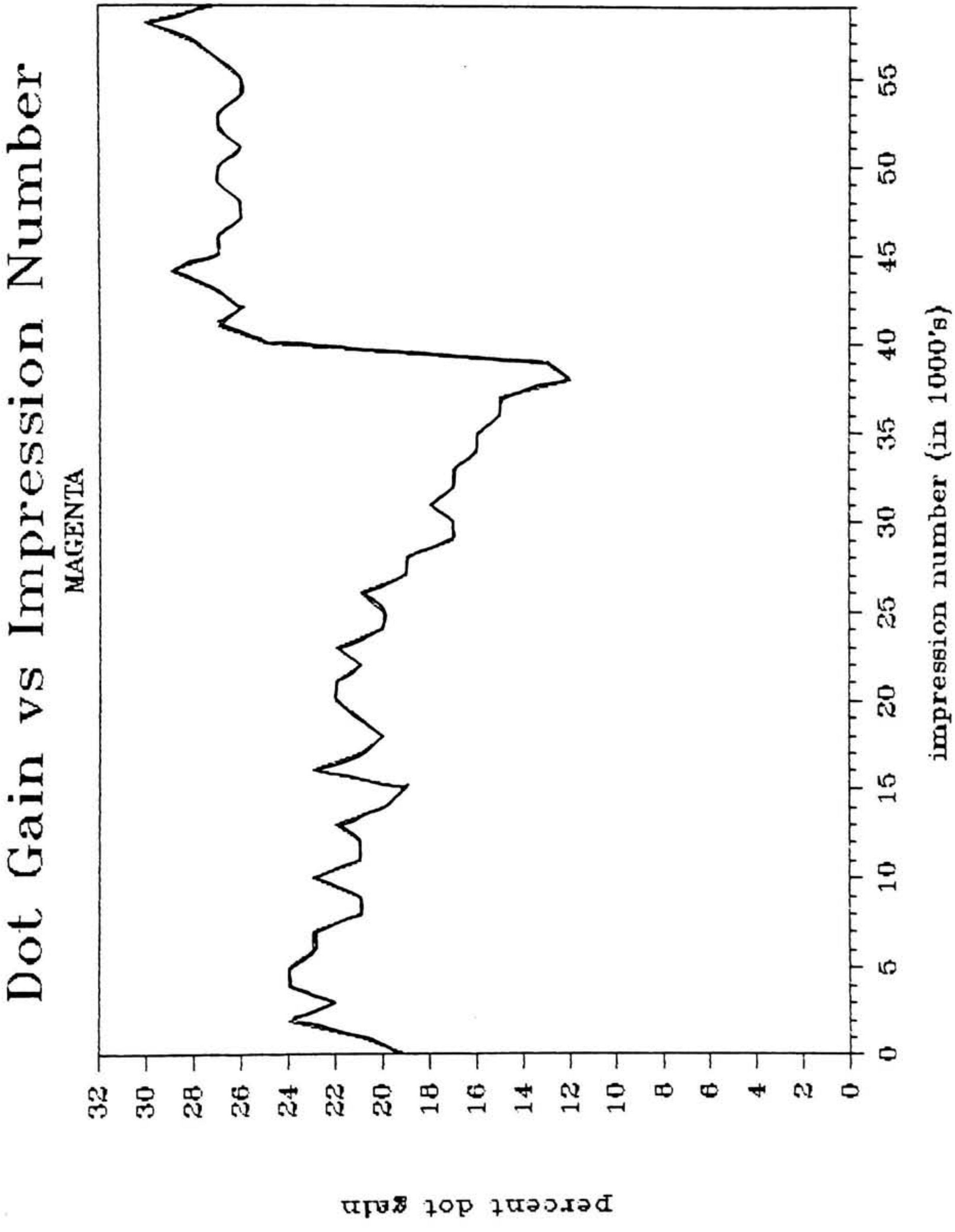

Dot Gain vs Impression Number
MAGENTA
impression number (in 1000's)
percent dot gain
0 5 10 15 20 25 30 35 40 45 50 55
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

Figure 39

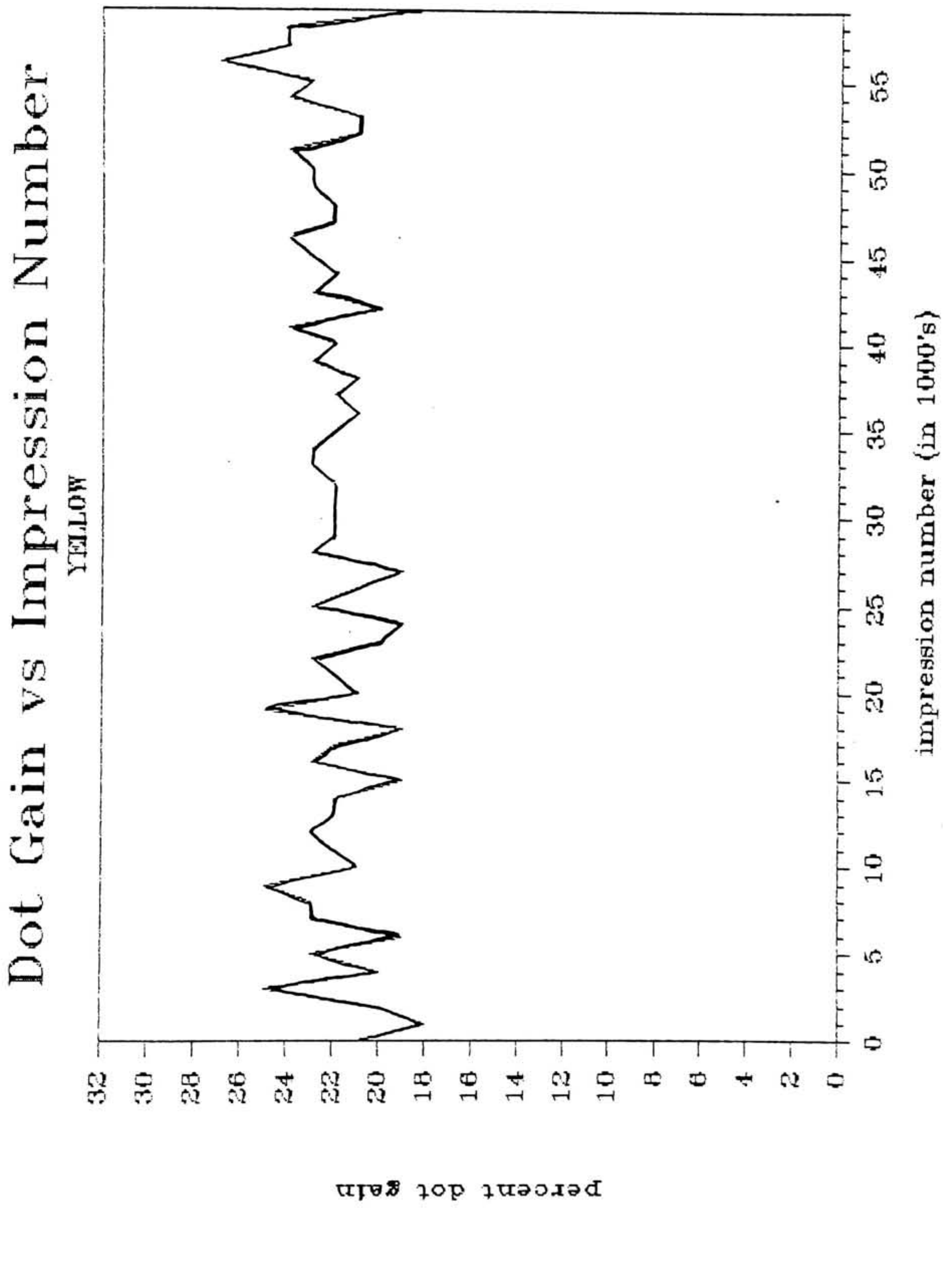
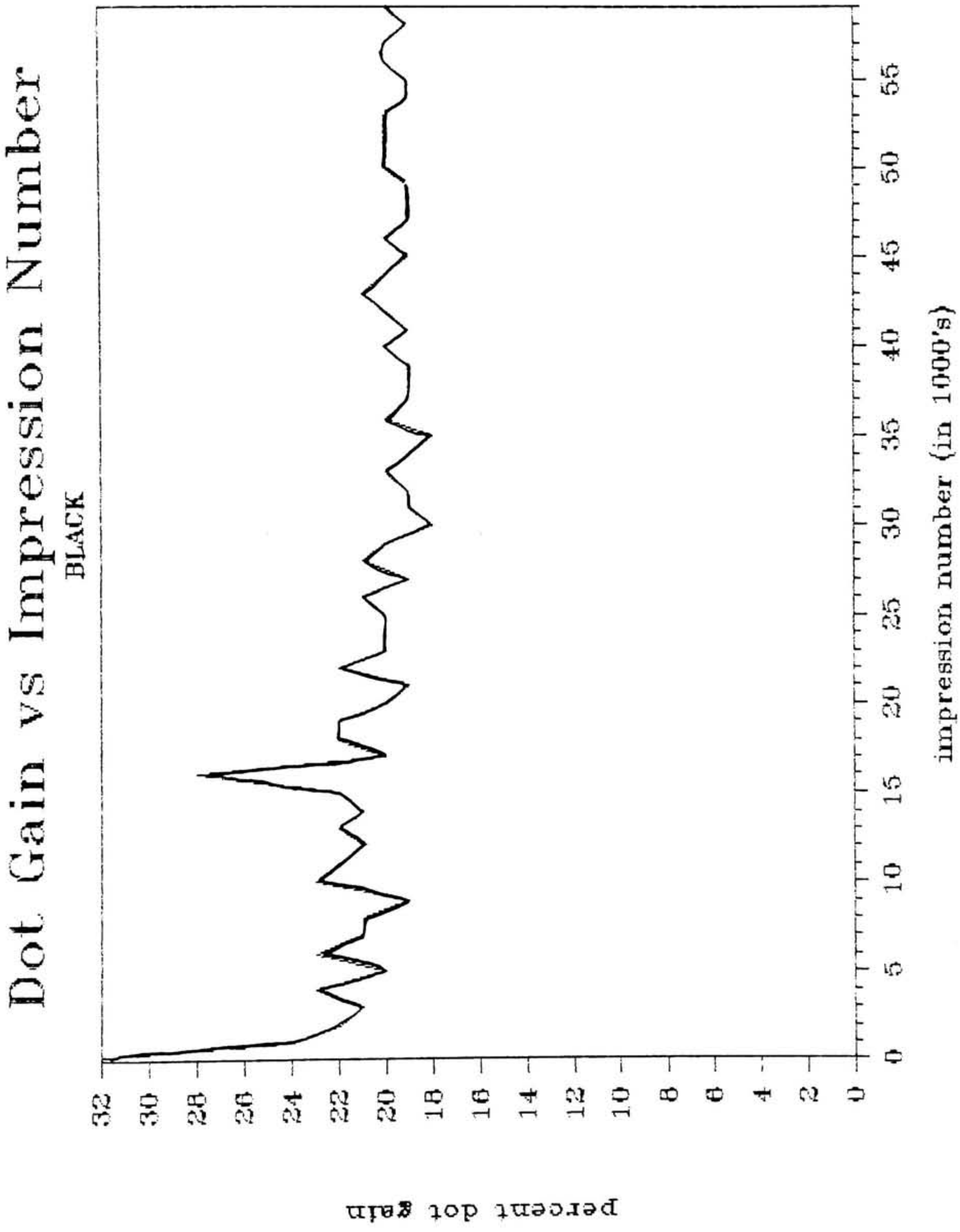

Dot Gain vs Impression Number
YELLOW
impression number (in 1000's)
percent dot gain
0
5
10
15
20
25
30
35
40
45
50
55
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

Figure 40


Dot Gain vs Impression Number
BLACK
impression number (in 1000's)
percent dot gain
0
5
10
15
20
25
30
35
40
45
50
55
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

to the press events. See Figures 41-44. The slur percentages also remained fairly stable for the run. Figures 45-48 show the percent slur plotted against the impression number. Magenta and yellow did not experience a problem. There were several peaks in the curves yet overall the slur was maintained at approximately 3%. The cyan and black curves did exhibit higher slur percentages indicating a possible mechanical problem in the press. The black slur percentage median was 8% while the cyan slur percentage median was 11%. Since a slur percentage greater than 5% will effect a hue shift it would be proper to make mechanical adjustments to these particular units to decrease the percentages. If these percentages reflect normal operating conditions, the slur percentages should be taken into account when choosing a target with the average slur or choosing two targets, one with maximum slur and one with minimum slur. The evaluation of these targets can then be compared against each other.

The following set of curves, Figures 49-52, makes it apparent that the cyan and black inking units have a definite direction of slur. The Y axis of these figures represents the angle at which the dot is distorted. Zero degrees represents the direction of the paper travel through the press. The cyclical pattern which can occur with dot slur is exhibited in the magenta and yellow. The slur degree angles vary +/- 30 in direction. The black and cyan however, do not have as great a variation in the direction of slur. The black and cyan slur degree angles only vary approximately 5°- 7°showing a trend toward a single direction.

Figure 41

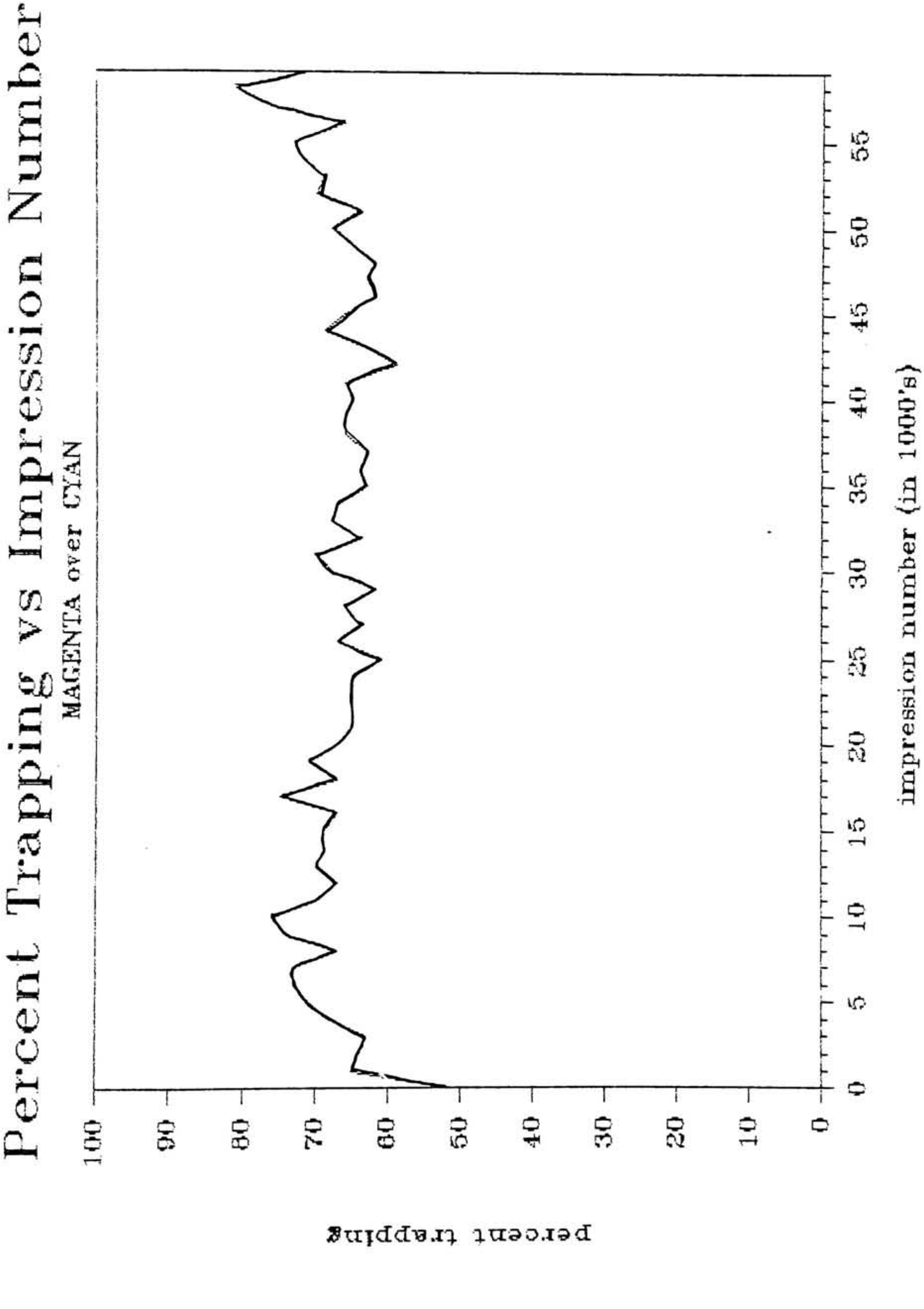

Percent Trapping vs Impression Number
MAGENTA over CYAN
impression number (in 1000's)
percent trapping
0
5
10
15
20
25
30
35
40
45
50
55
0
10
20
30
40
50
60
70
80
90
100

Figure 42

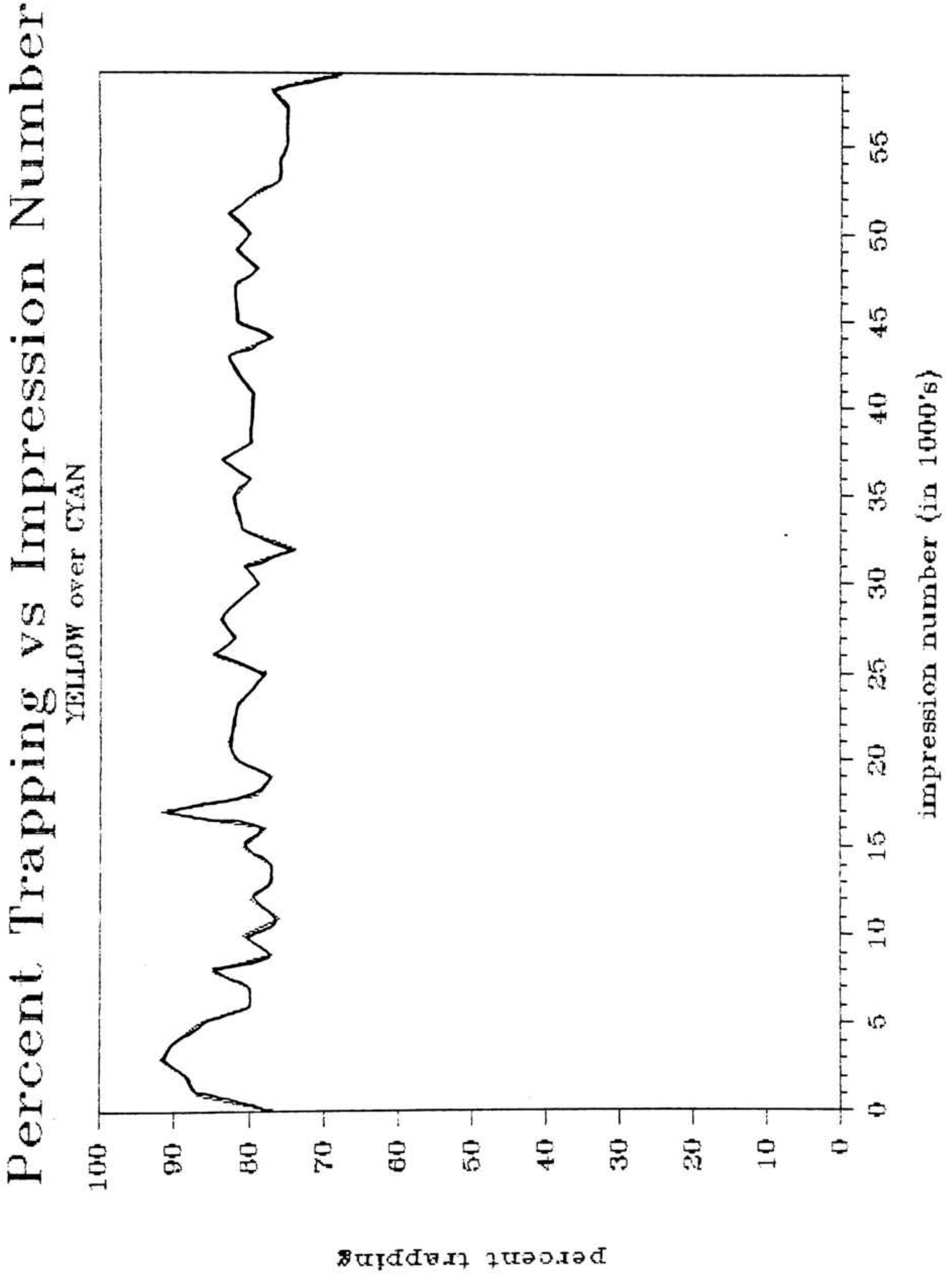

Percent Trapping vs Impression Number
YELLOW over CYAN
percent trapping
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
55
impression number (in 1000's)

Figure 43

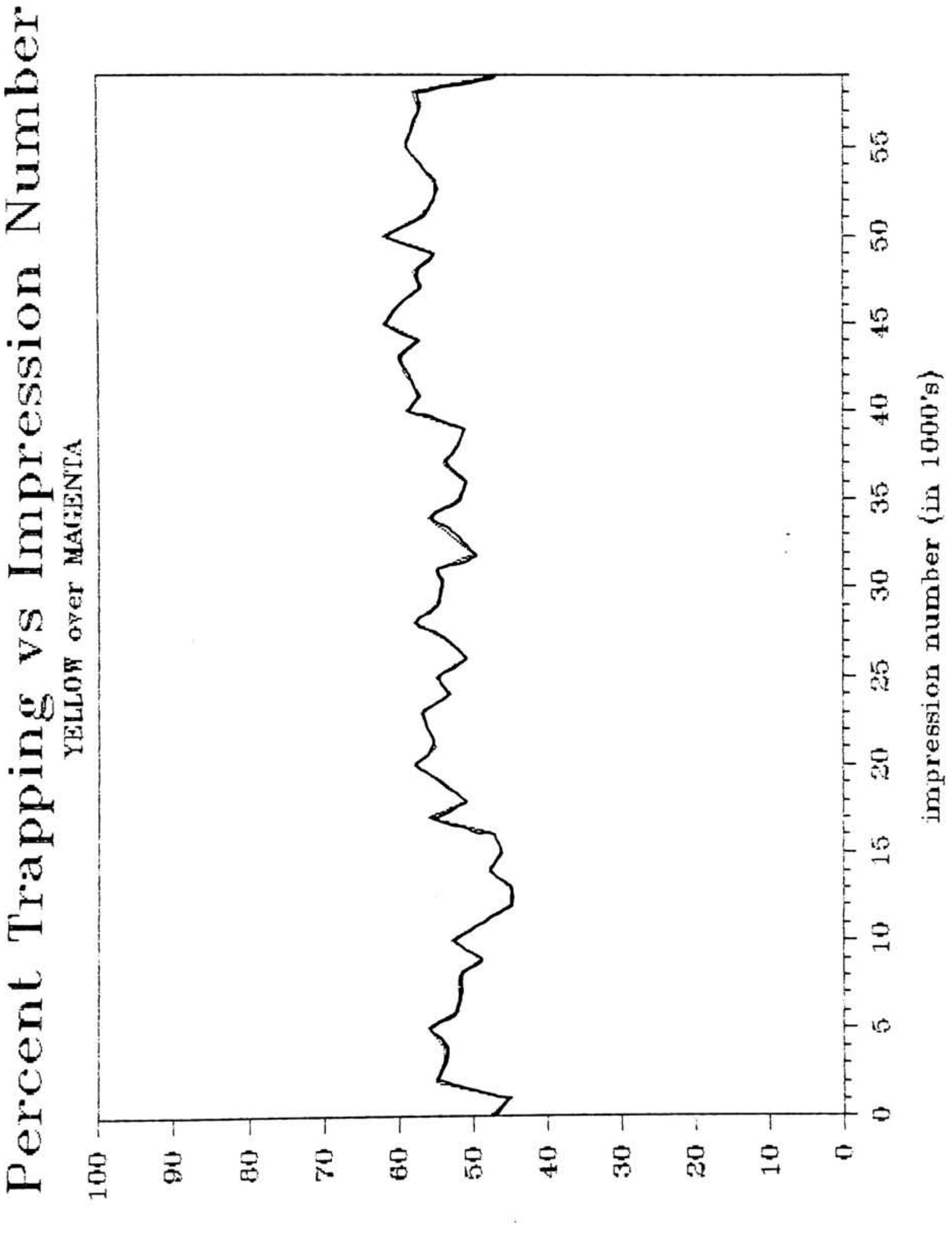

Percent Trapping vs Impression Number
YELLOW over MAGENTA
impression number (in 1000's)
percent trapping
0 10 20 30 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55

Figure 44

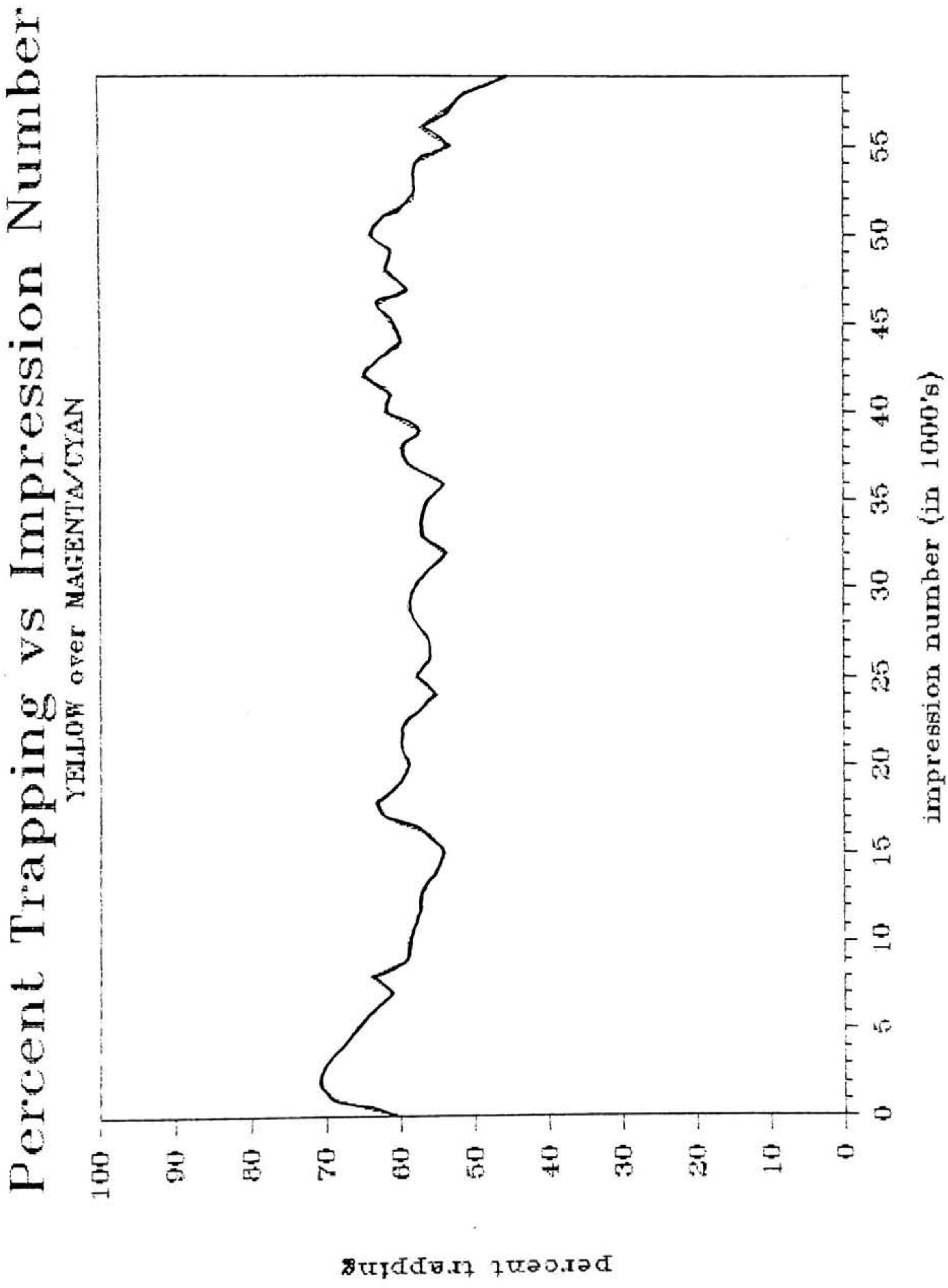

Percent Trapping vs Impression Number
YELLOW over MAGENTA/CYAN
percent trapping
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
55
impression number (in 1000's)

Figure 45

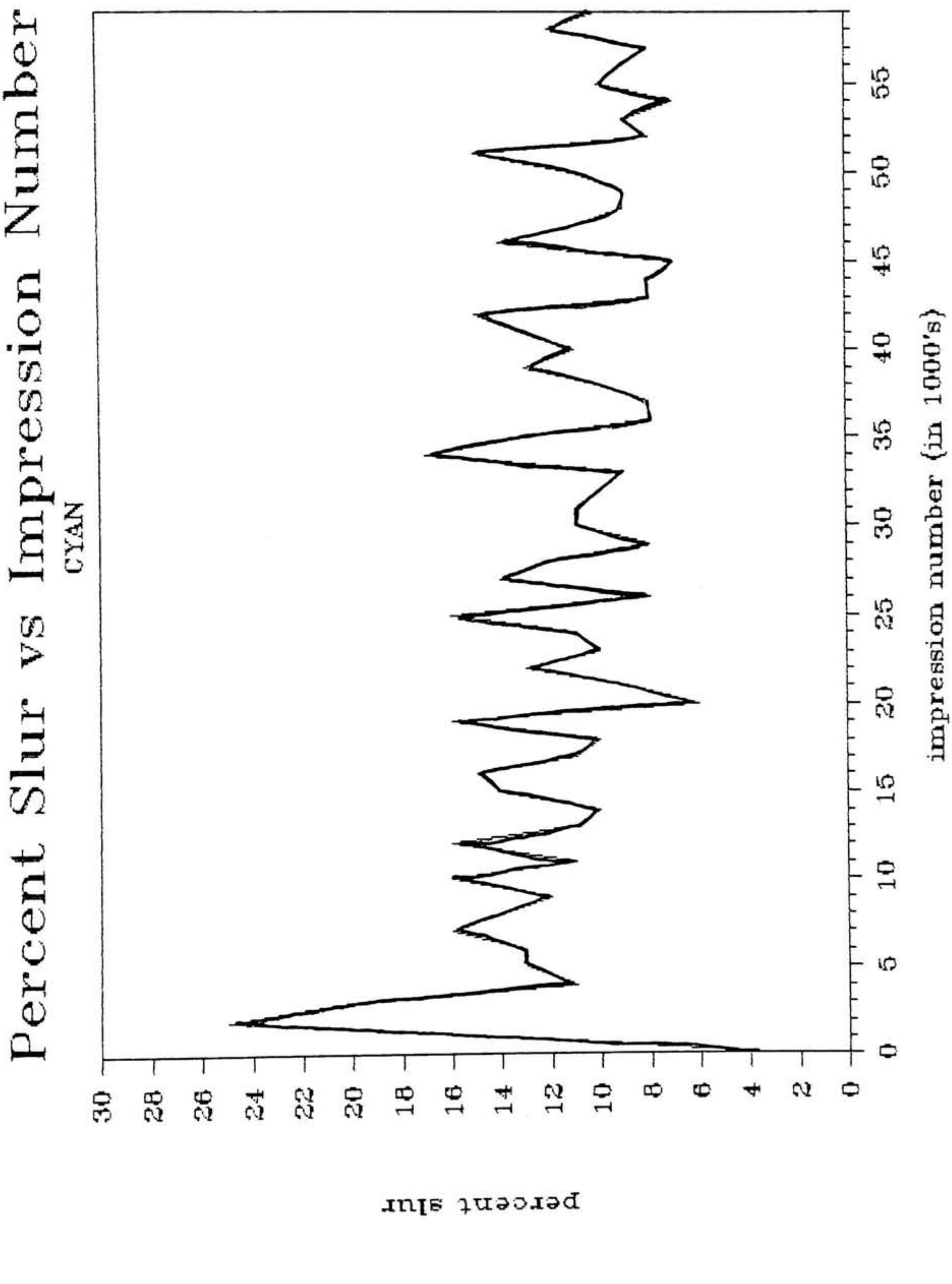

Percent Slur vs Impression Number
CYAN
percent slur
impression number (in 1000's)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
5
10
15
20
25
30
35
40
45
50
55

Figure 46

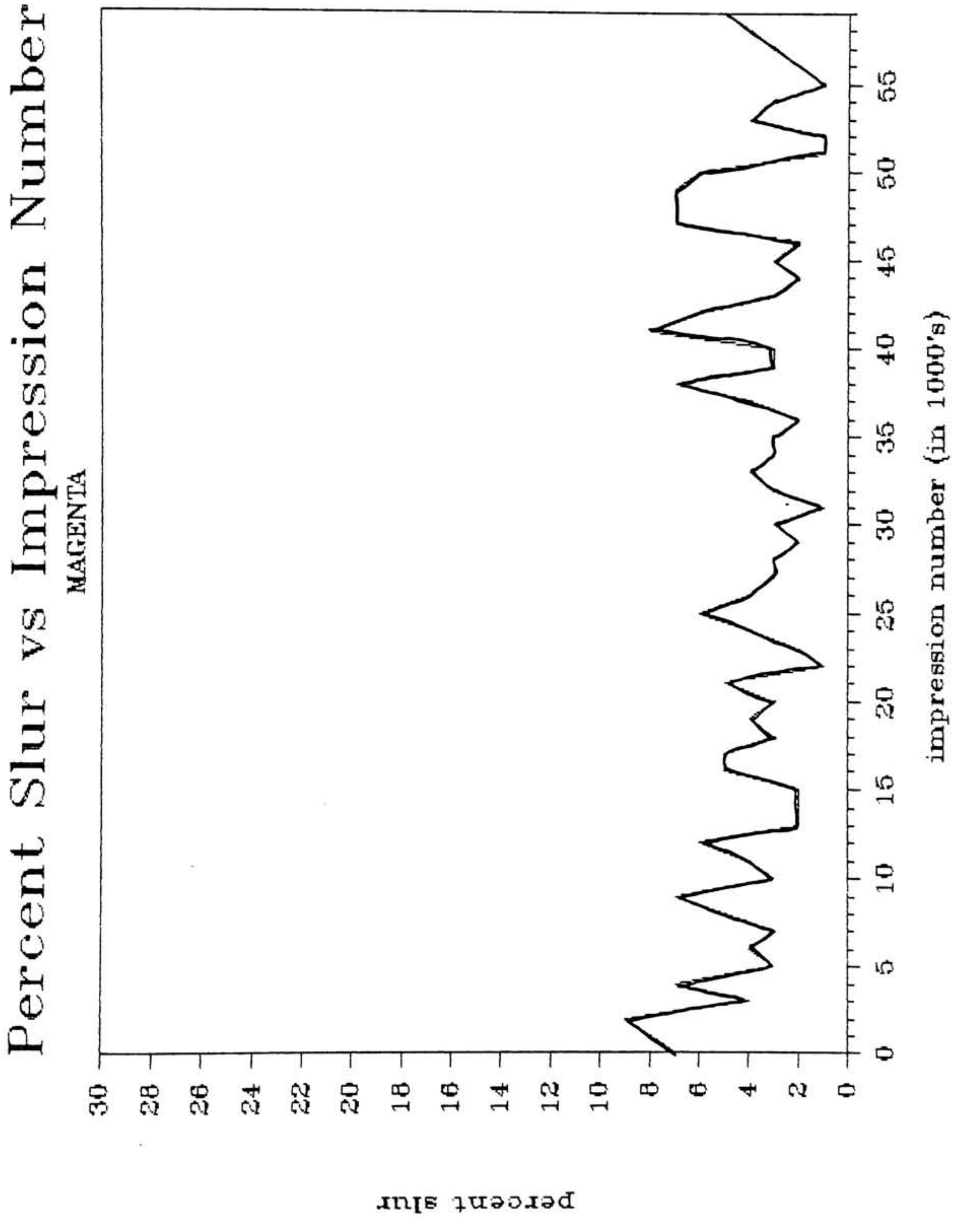

Percent Slur vs Impression Number
MAGENTA
percent slur
impression number (in 1000's)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
5
10
15
20
25
30
35
40
45
50
55

Figure 47

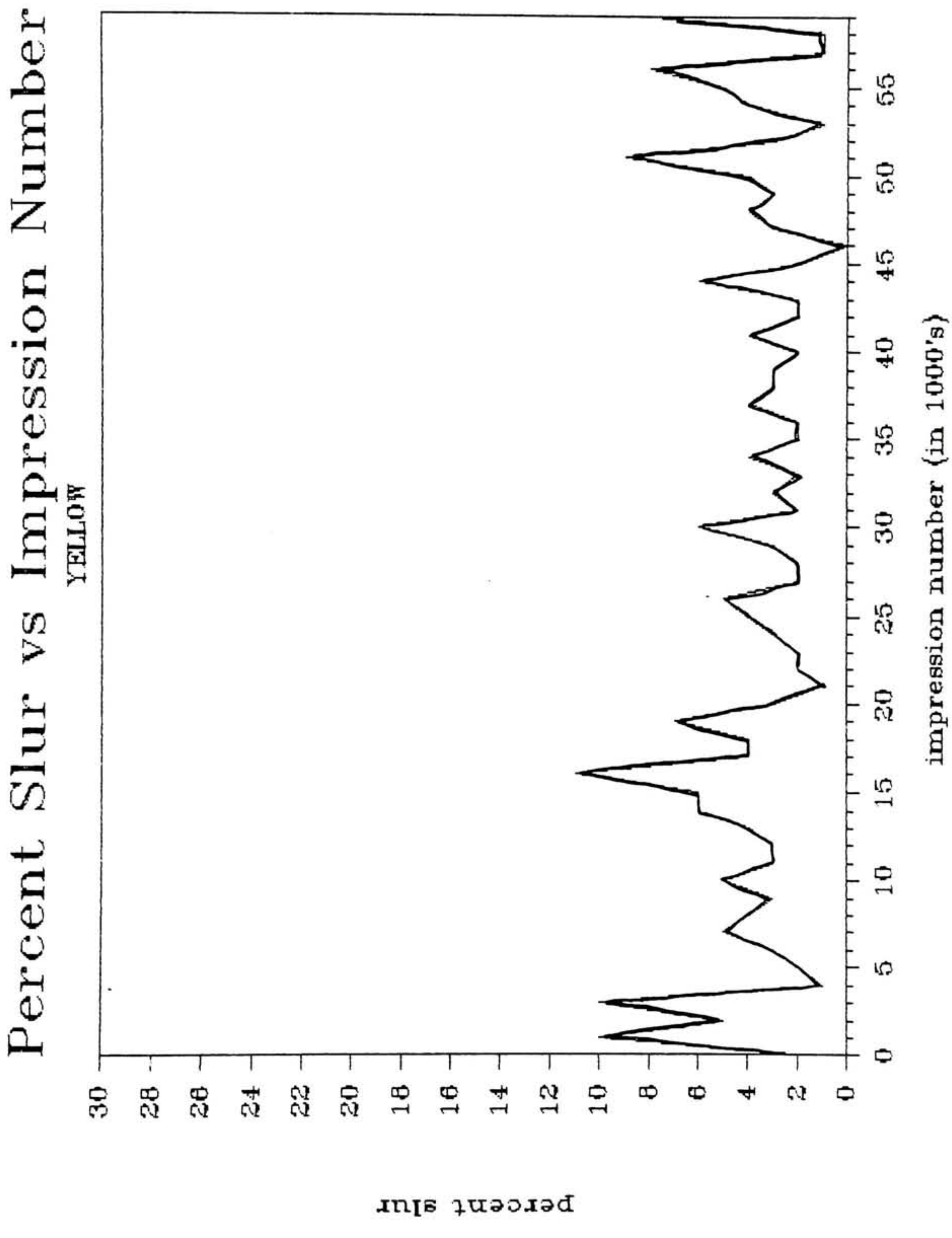

Percent Slur vs Impression Number
YELLOW
percent slur
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
impression number (in 1000's)
0
5
10
15
20
25
30
35
40
45
50
55

Figure 48

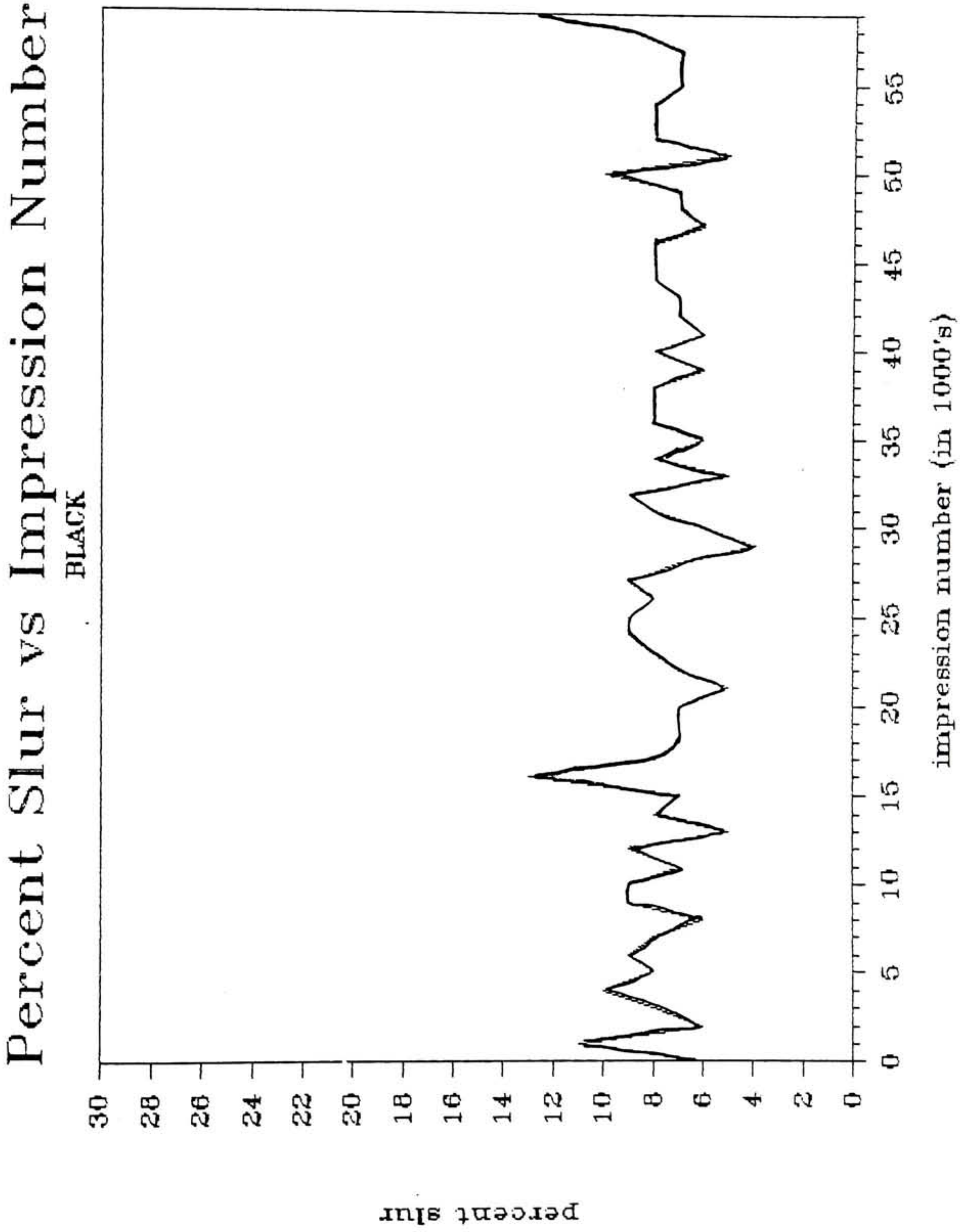

Percent Slur vs Impression Number
BLACK
percent slur
impression number (in 1000's)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
5
10
15
20
25
30
35
40
45
50
55

Figure 49

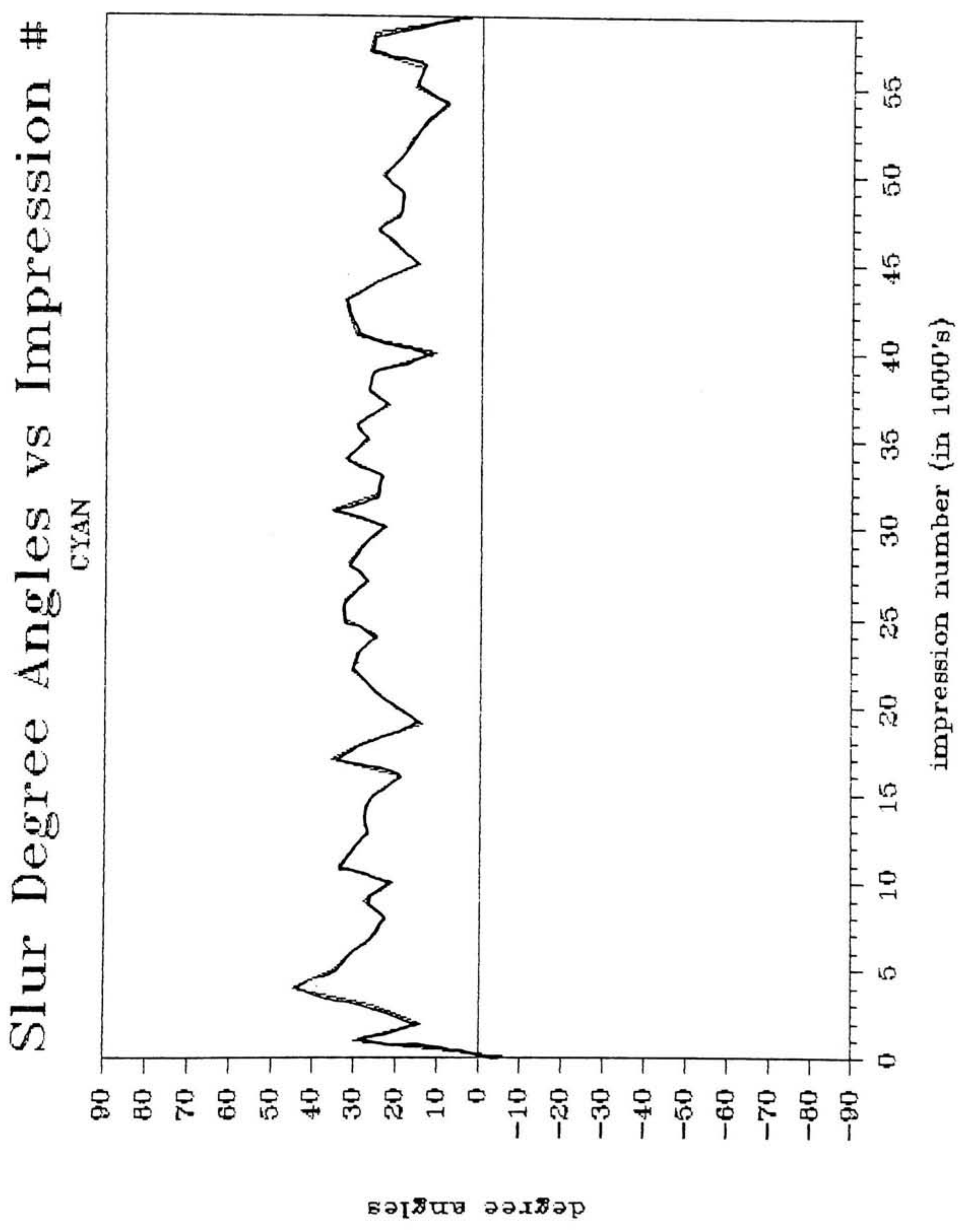

Slur Degree Angles vs Impression #
CYAN
degree angles
impression number (in 1000's)

Figure 50

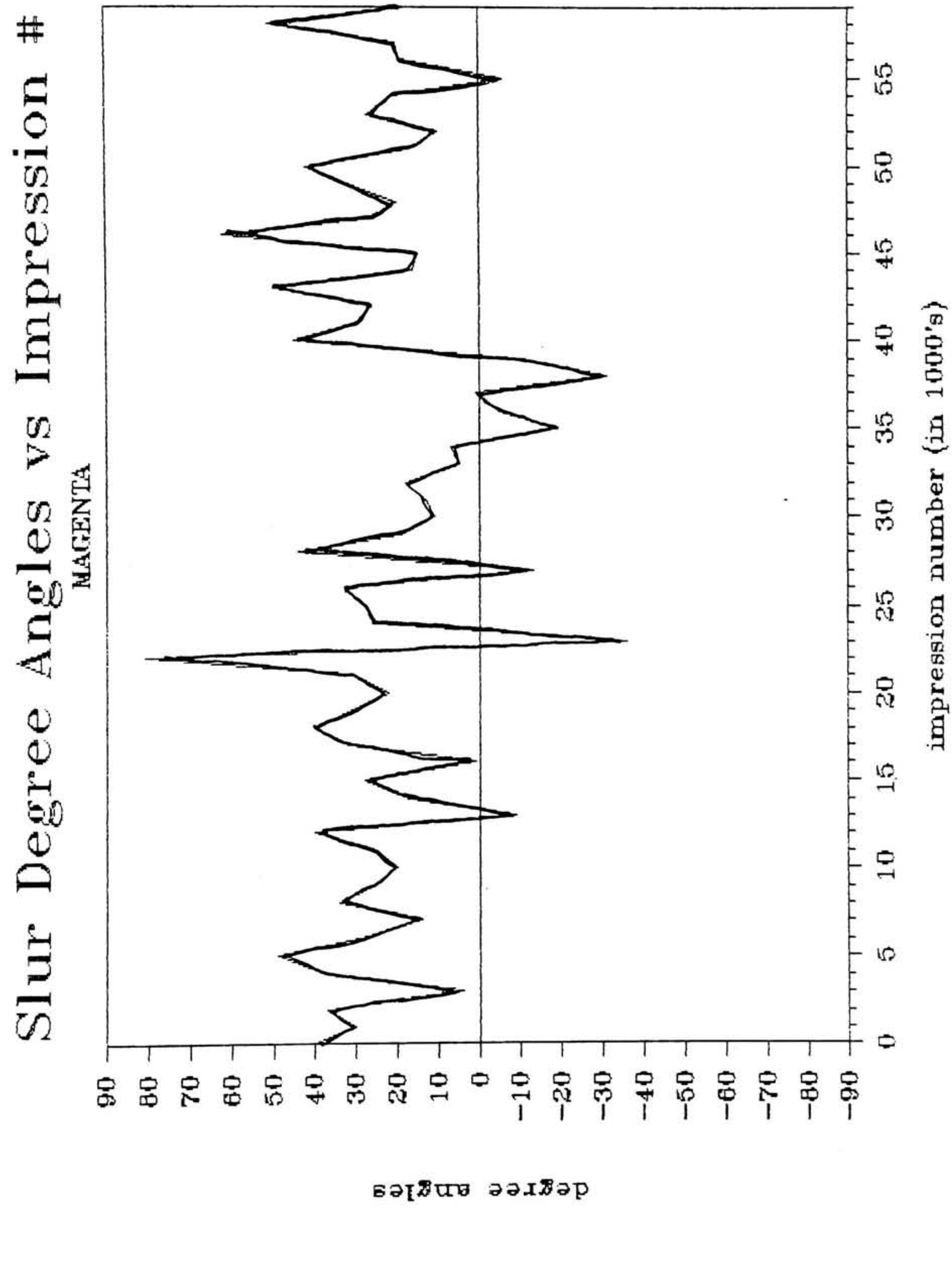

Slur Degree Angles vs Impression #
MAGENTA
impression number (in 1000's)
degree angles
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
0 5 10 15 20 25 30 35 40 45 50 55

Figure 51

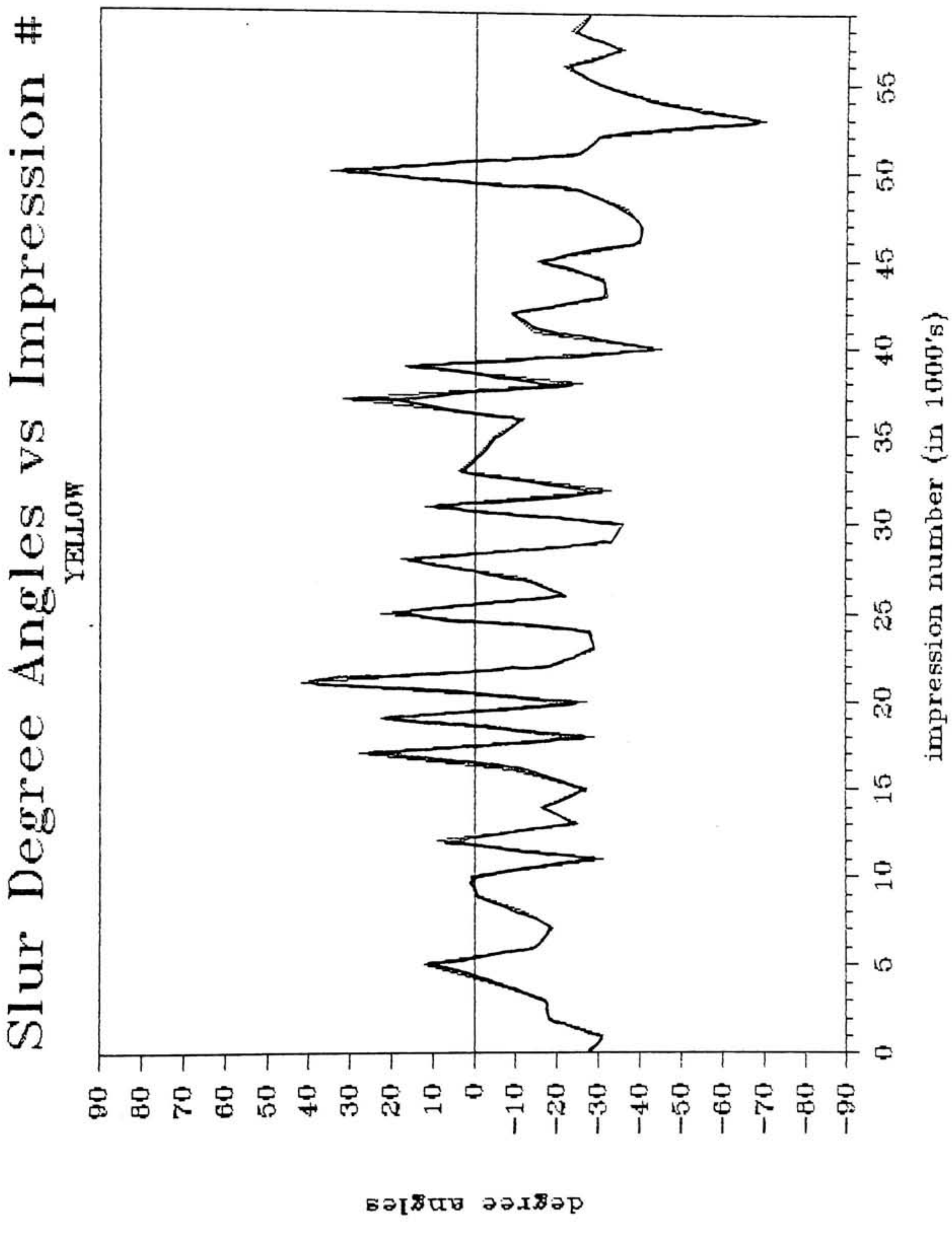
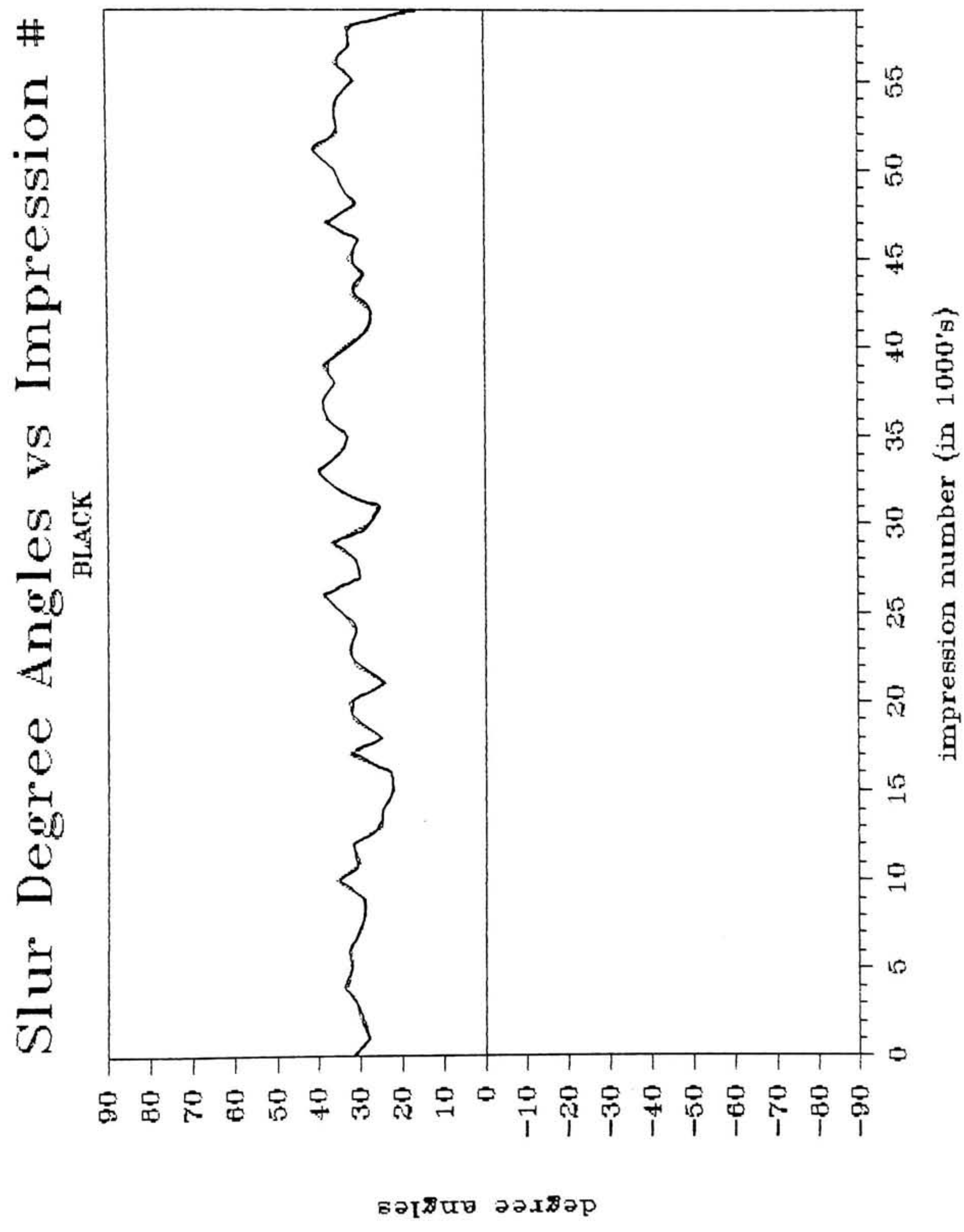

Slur Degree Angles vs Impression #
YELLOW
impression number (in 1000's)
degree angles
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
5
10
15
20
25
30
35
40
45
50
55

Figure 52


Slur Degree Angles vs Impression #
BLACK
degree angles
impression number (in 1000's)
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
5
10
15
20
25
30
35
40
45
50
55

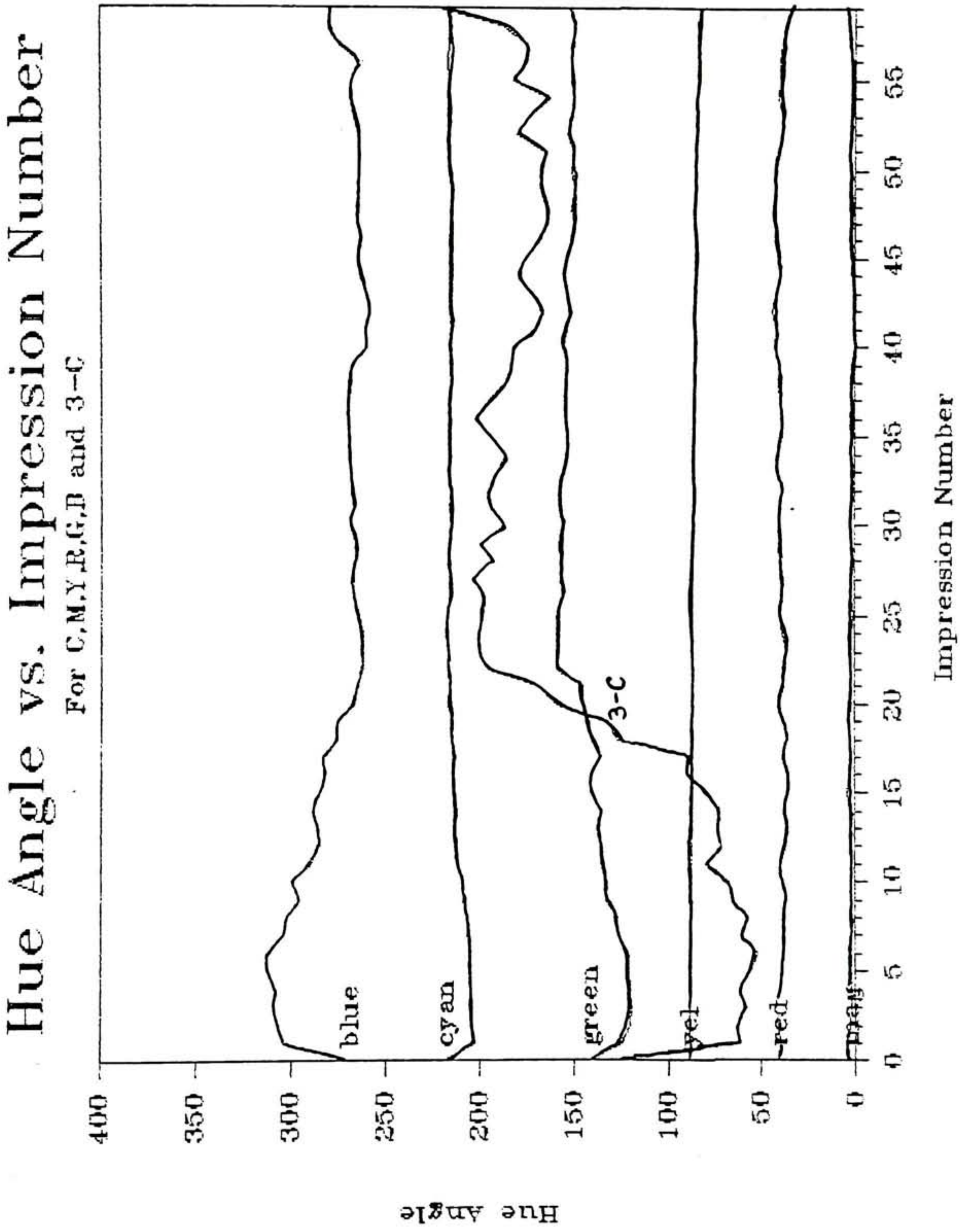
PHASE THREE

Phase three of the data analysis further confirms the cyan printer as the limiting factor in achieving acceptable quality. Figure 53 is a time series plot of hue angle. As would be expected the three primaries, cyan, magenta and yellow, remain fairly level with no major deviations. The combinations of the primaries to achieve the secondaries of red, green and blue should, if all else remains equal, produce curves which also have only slight deviations. This is true in the case of red. However, for green and blue the hue angle curve shows some deviation from a stable horizontal line. By referring back to Figure 10, it can be seen that green results from a combination of yellow and cyan ink and blue results from a combination of magenta and cyan. Cyan is the common factor in these two secondaries and an inspection of Figure 32 shows that the point at which the cyan solid ink density stabilized corresponds directly to the stabilizing point for the green and blue hue angle. Prior to the cyan ink stabilization the hue angle of the blue was at its largest at 313° tending towards a magenta color. The hue angle of the green was at its smallest at 119° tending towards a yellow color. Thus if the combination of two primaries is not in correct proportion, the secondary produced will favor the stronger primary.

Proper gray balance was also an unstable curve. A dramatic shift occurred at the 20,000 impression mark again corresponding with the stabilization of the cyan solid ink density.

An interesting comparison can be made between chroma and hue

Figure 53


Hue Angle vs. Impression Number
For C,M,Y,R,G,B and 3-C
Impression Number
Hue Angle
blue
cyan
green
yel
red
mag
3-C
0
5
10
15
20
25
30
35
40
45
50
55
0
50
100
150
200
250
300
350
400

angle. In Figures 54 and 55 chroma has been plotted versus hue angle in a scatter diagram configuration. Figure 54 plots points for all impressions and Figure 55 plots points for above 21,000 impressions only. As in previous plots it is quite apparent what effect the below 21,000 impression data has on variability. The yellow, magenta and red scatter diagrams are similar for both figures. In fact, except for a few outliers, the diagrams are nearly identical. The cyan, blue and green diagrams show the deviations that occurred.

The cyan ink, unlike the other two primaries of yellow and magenta experienced a hue angle shift. As the cyan chroma increased its hue angle increased. The yellow and magenta chromas changed but the hue angles were consistent (no horizontal change in the scatter diagram). The hue angle shift for cyan was due to the low density during start-up and the fact that newsprint was the stock. The low density would cause the chroma to drop and it would also allow the yellow nature of the newsprint substrate to influence the hue angle. This tendency towards yellow would lower the hue angle degrees. Refer to Figure 12.

The blue variation shows that as the chroma increased the hue angle decreased. Blue is a combination of magenta and cyan. As the chroma decreased there was less influence by the cyan. The blue color became more magenta as its hue angle increased (Figure 12). A higher chroma meant an appropriate amount of both cyan and magenta to give blue.

The green variation is a bit more complicated. As the chromas decreased, the hue angle increased. A comparison of Figure 54 and 55 shows that the lower chroma and higher hue angle was the desirable result. The lowering of the green chroma was caused by the increase

Figure 54

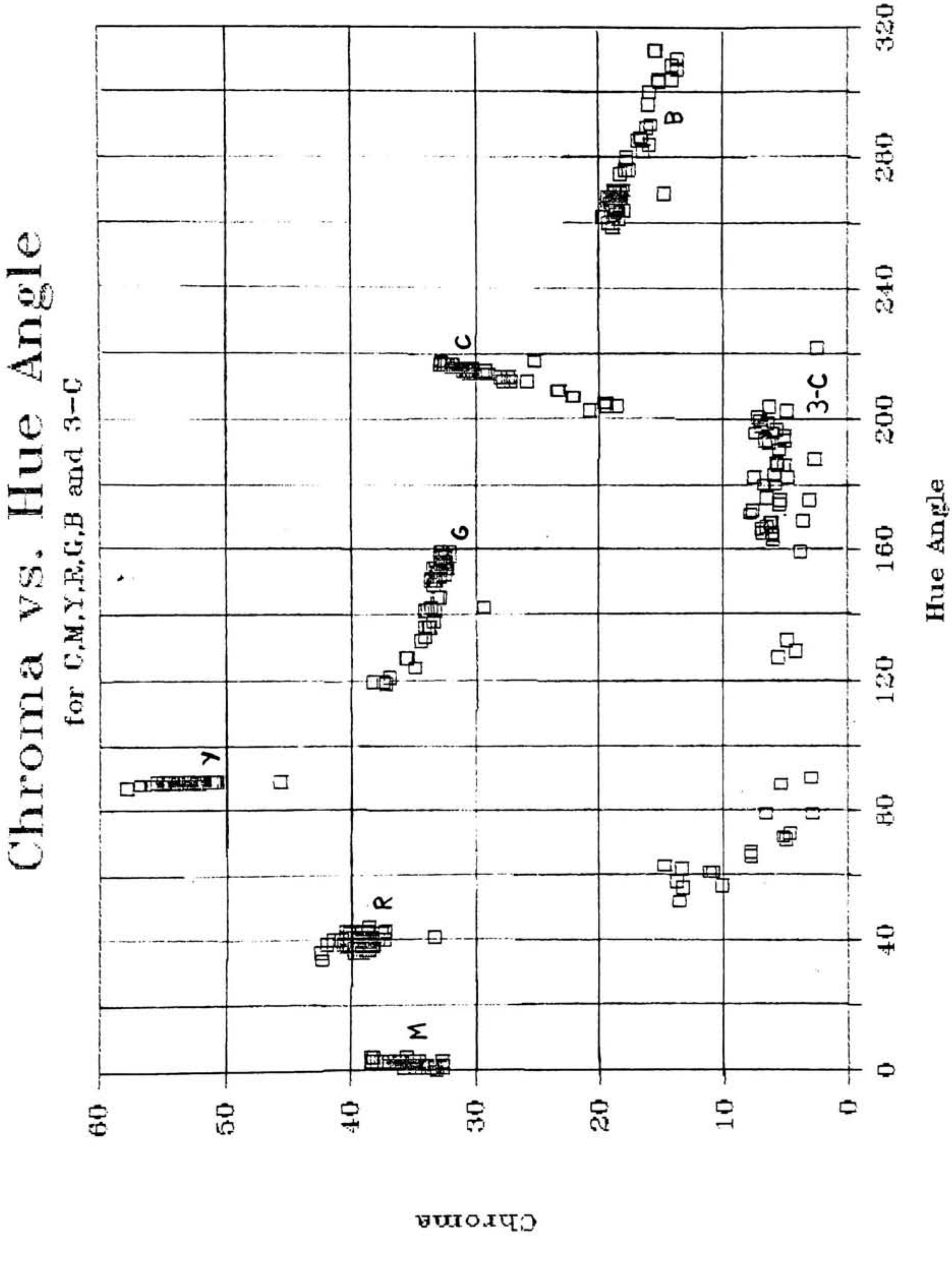
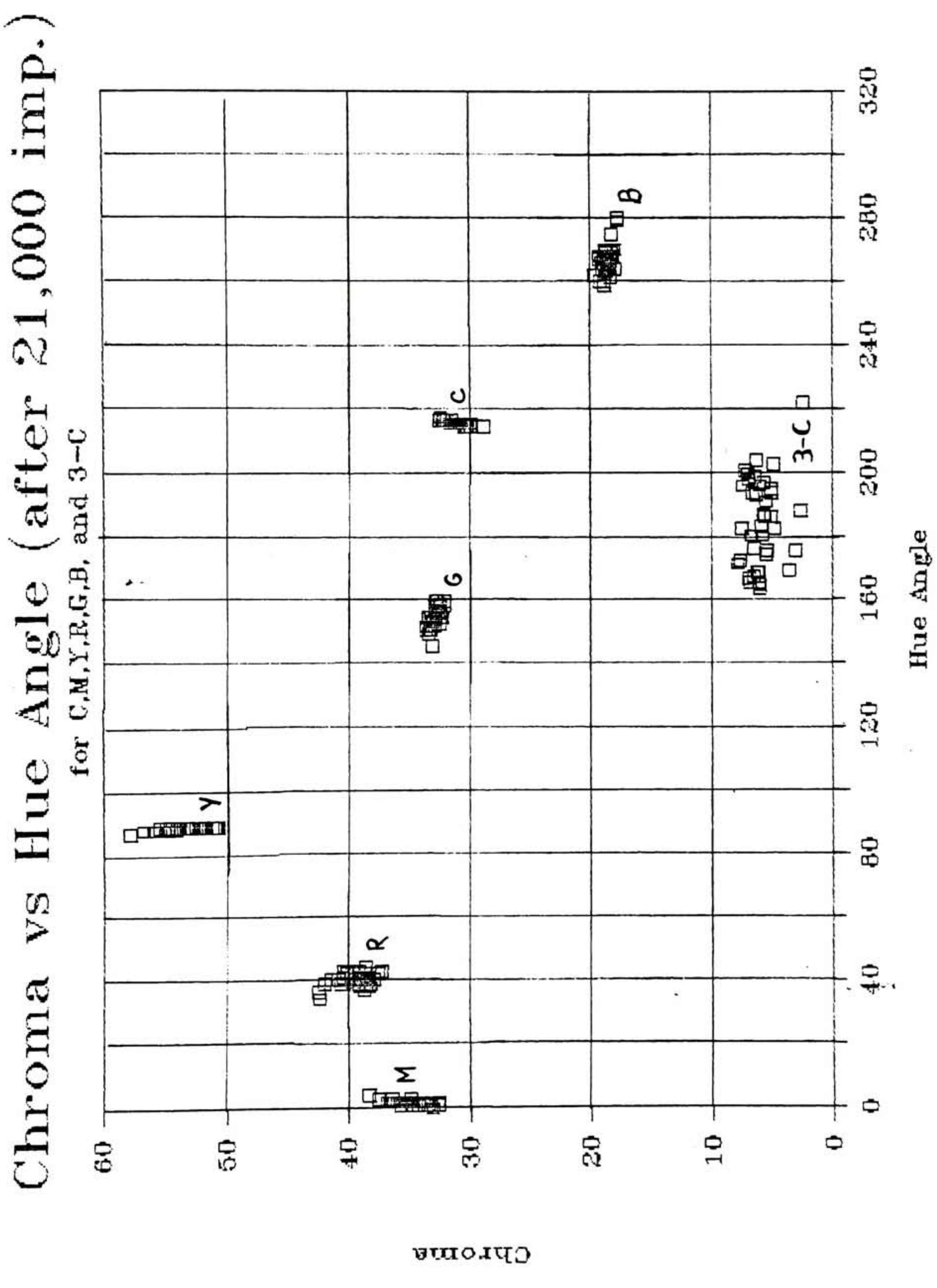

Chroma vs. Hue Angle
for C,M,Y,R,G,B and 3-C
Chroma
Hue Angle
0
10
20
30
40
50
60
0
40
80
120
160
200
240
280
320
M
R
Y
G
C
B
3-C

Figure 55


Chroma vs Hue Angle (after 21,000 imp.)
for C,M,Y,R,G,B, and 3-C
Chroma
Hue Angle
0
10
20
30
40
50
60
0
40
80
120
160
200
240
280
320
M
R
Y
G
C
B
3-C

in cyan ink. Referring back to Figure 10, for a real ink reflection curve the cyan ink has the worst "contamination" in the green band of the spectrum. Instead of allowing the green component of white light to be reflected by the substrate, the cyan ink actually absorbs some of the light. Some of the wanted color of green is absorbed along with the unwanted color. As the cyan ink density level was increased it acted as an absorber of the green light and lowered the chroma. The hue angle changed from a yellowish cast to a green.

By comparing Figures 54 and 55 it can be seen that after 21,000 impressions the scatter diagrams appear more uniform. The primaries of cyan, magenta and yellow show only a vertical change which is a variability in chroma or saturation. The secondaries of red, green and blue (eliminating one or two outliers) show a more formless cloud shape or cluster of points. The three color diagram shows how proper gray balance was quite unpredictable without the correct combinations of primaries.

FOOTNOTES FOR CHAPTER VII

Schlapfer, K. 1984 — "Bewertung von Farbabweichungen im Auflagedruck" UGRA - Mitteilungen, Nr. 3, Nov. 1984.

Schlapfer, K. 1981 — "Zusammenhang Zwischen der Volltondechte, der Punktverbreiterung und dem Farblichen Aussehem im Druckbild", UGRA - Mitteilungen, Nr. 2, Aug. 1981.

Southworth, Miles 1979 — "Color Separation Techniques", Livonia Press, Livonia, New York.

Stamm, Scott 1980 — "An Investigation of Color Tolerance", RIT School of Printing Master's Thesis.

CHAPTER VIII - Summary, Conclusions and Recommendations

This study provides a compilation of data concerning press characteristics as measured by the Kodak Customized Color Analysis Target. Previously, only a small percentage of targets for a given press run were chosen for analysis. These targets constituted a representative sample of the ordinary capabilities of that press. By analyzing targets throughout the press run, the four objectives outlined in the hypothesis were fulfilled.

The variability in the press performance characteristics was well documented. The main emphasis of this data confirms the importance of selecting a press sheet for analysis when the press is in its most stable and reproducible operation. The time series plots show how each variable was in constant change throughout the run. The target also showed the effects of press events such as a web break, roll change or plate change. These events all had an effect on the final output curves. The variables which are part of the analysis are all standard in the graphic arts industry and provide meaningful data when investigating the possibility of improper press conditions. In this case, there was a distinct problem with the cyan ink density levels. This in turn increased the difficulty of maintaining proper gray balance. The cyan unit also had a slur problem which would warrent investigation.

The variability in the halftone aim points was quite large. See Table #2. It was determined that the large range of the complete

press run was caused by abnormal press conditions and when these conditions were eliminated the range became smaller. The AMB point ranges for the ΔE samples were approximately +/- 3-4% dot areas. Therefore, this would indicate that separations customized to press conditions could be done within a small percent difference, yet apply to an entire press run experiencing "normal" variability. In other words, the Customized Color pre-press curves are not so specific that if only a single sheet were analyzed, the press would have to match the conditions that produced the sheet exactly to get an acceptable result. Customized Color allows the press to experience a normal amount of variability.

Increasing the use of the CIELab coordinate system and trying to define color in a more scientific manner is an encouraging step for the graphic arts industry. Trying to determine and explain its usefulness in printing terms is a difficult task. The dilema of translating ΔE units or CIELab coordinates into density or percent dot area is not easily solved. What this study has presented is the idea of ΔE as a determination for meeting a criteria.

The data and conclusions of this study have been compiled in such a way as to facilitate and encourage further study. The most obvious next step would be to use the Customized Color curves presented here to make separations for a second press run. This press run would include the new customized separations and the old standard separations. The reults of this press run would provide the data to answer further questions about Customized Color.

1. By using the subjective analysis of a panel of judges, which set of separations produced better results?
2. Does a ΔE quantity agree with the subjective analysis results?
3. Is the press easier to control during start-up and is start-up time lessened?
4. Is acceptability easier to maintain?

Other studies could also be undertaken to investigate and fine tune the Customized Color data. During a press run the inking levels could be manipulated to see the effects on the suggested Customized Curves. The effect of a pre-determined shift in the ink amount on the output curves could be shown.

Further applications of Customized Color could be applied to other printing techniques. Flexography and Gravure could be tested to find how the target information must be evaluated to meet the needs of color separation curves for those presses. Generic film to be used for both offset and gravure processes could be compared. The standards for halftone gravure has caused some confusion between printers and separation houses. The completeness of the Customized Color report would allow one to study the relationships of gravure and offset printing produced by the same separation films.

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APPENDIX A

Example of the use of the MPD term:

Normal Density for Cyan = 0.80

Normal density for Magenta = 0.80

MPD for Newsprint = 1.5

Preucils Assumption:

D total = Dl + D2 = 0.80 + 0.80 = 1.6

Hamilton Assumption:

$$D\ total = D1 + D2 - \frac{(D1)(D2)}{D\ mpd} = 0.80 + 0.88 - \frac{(0.80)(0.80)}{1.5} = 1.17$$

Typical overprint density for Magenta over cyan = 1.0

A percent trap calculation which assumes a D total of 1.6 would create a far greater error than assuming D total = 1.17.

APPENDIX B

TABLE 1 Delta E Values

Imp	C	M	Y	R	G	B	3-C
6	14.5	1.2	1.7	1.6	23.7	14.8	19.7
7	11.3	1.8	2.2	Ø.9	19.6	12	16.5
8	11.2	Ø.6	1	Ø.4	19.1	11.8	15.8
9	9.7	Ø.9	1.8	2.2	15.1	9.3	13.1
1Ø	9.7	Ø.8	2.4	1	15.4	1Ø.5	13.1
11	6.6	1.1	2.1	Ø.5	13.1	7.8	11.2
12	4.7	2.4	2.1	2.4	13	6	9.8
13	4.1	1.9	2.1	2.8	11.9	6.1	9.4
14	4.9	1.1	2.9	2.2	12.8	7.2	1Ø
15	2.8	2.3	1.8	2.9	9.7	5.5	7.7
16	2.4	2.4	1.4	3.1	9.6	5.1	7.5
17	4.8	1	1.5	1.5	12.4	5.7	9.3
18	Ø.7	1.2	1.7	2.9	9.7	3.1	6.7
19	1.3	1.2	Ø.7	2.5	9.1	2.7	6.1
2Ø	1.3	1.2	Ø.5	1.3	7.1	Ø.4	3.8
21	1.2	1.7	1	1.5	6.8	1.3	3.3
22	2.5	1	1.1	1	1.9	2.2	1.7
23	2.1	Ø.8	1	2.7	1.8	2.3	1.4
24	2.5	Ø.9	Ø.8	1	1.8	2.3	1.6
25	1.9	Ø.5	Ø.8	Ø.4	1.9	1.5	1.2
26	Ø.1	2	1.1	Ø.7	Ø.6	Ø.4	Ø.3
27	Ø.6	Ø.9	1.1	1.4	Ø.6	Ø.7	1.1
28	1.2	Ø.7	Ø.1	Ø.5	1.2	Ø.8	Ø.8
29	Ø.5	Ø.1	1	Ø.9	1.4	Ø.7	Ø.8
3Ø	Ø.8	Ø.5	Ø.6	Ø.5	Ø.2	Ø.3	Ø.9
31	Ø.4	Ø.5	Ø.3	Ø.2	1.3	Ø.8	Ø.8
32	1.9	Ø.1	Ø.2	Ø.6	Ø.4	Ø.2	Ø.4
33	Ø.3	Ø.5	Ø.7	Ø.9	Ø.5	Ø.4	Ø.6
34	Ø.4	Ø.5	Ø.7	1.7	1.6	Ø.7	1.2
35	Ø.4	Ø.6	1.5	Ø.8	1.6	1	Ø.7
36	Ø.3	1.6	Ø.6	1.1	1.3	1	1.2
37	Ø.9	Ø.9	Ø.3	Ø.5	1.6	Ø.8	Ø.7
38	Ø.9	Ø.1	1.1	1.1	1.5	Ø	1.1
39	Ø.7	Ø.4	1.1	Ø.9	2.2	Ø.8	1.2
4Ø	1.1	3.6	Ø.6	2.6	Ø.5	2.9	2.5
41	Ø.8	4.2	Ø.4	2	1.4	2.9	3.9
42	Ø.4	3.4	1.5	3.2	3.2	3.9	3.6
43	1.1	3.6	Ø.5	1	1.2	3.3	3.6

Delta E Values (cont.)

44	Ø.2	3.1	Ø.3	Ø.4	1.2	1.5	2
45	Ø.7	1.8	Ø.3	Ø.8	1.4	1.6	2.4
46	Ø.7	1.6	2.9	2.6	2.9	2.3	2.9
47	1.1	1.8	3.2	1.8	3.3	2.2	3.4
48	Ø.9	2.3	2.8	2	3.1	2.6	3.5
49	1	3.5	2.2	2.2	4.2	2.2	3.1
5Ø	Ø.8	3.1	1.3	2.5	3.1	2.1	3.2
51	Ø.4	2	2	Ø.7	3.8	2.1	3.4
52	1.1	1.8	2.4	1.2	1.8	1.1	1.6
53	1.7	1	3.7	2.2	2.8	3.1	2.3
54	1.2	1.3	4.1	2.1	3.7	5.7	3.4
55	Ø.6	1.3	5.1	3	2.9	6.1	1.7
56	1.6	1.4	4.3	2.6	2.7	6.2	2.1
57	1.3	Ø.6	6	3.7	3.4	3	3.4
58	Ø.6	Ø.7	6.1	5.4	3.3	4.5	3.5
59	1.2	3.2	6.4	5.2	2.2	5	3.4

Table 2.

The Range Between Minimum and Maximum Dot Areas(%) for the Complete Press Run(col.#1) and for Samples Selected by Delta E (col.#2)

	Col#1				Col#2			
Density	C	M	Y	K	C	M	Y	K
.3	4	4	7	-	3	4	6	-
.4	10	7	10	-	4	7	7	-
.5	16	10	11	-	5	8	7	-
.6	22	15	13	-	6	10	8	-
.7	27	18	15	-	7	11	10	-
.8	31	21	17	-	7	12	12	-
.9	33	24	19	-	6	13	14	-
1.0	34	25	20	-	5	14	15	-
1.1	29	19	15	7	6	10	10	5
1.2	26	17	15	12	7	8	10	7
1.3	25	16	15	12	6	6	9	8
1.4	24	15	16	19	7	6	8	9
1.5	24	14	16	21	7	6	8	9
1.6	24	14	16	21	7	6	8	9
1.7	24	14	16	21	7	6	8	8
1.8	24	13	16	21	7	6	8	8
1.9	25	13	17	19	7	6	8	8
2.0	25	13	17	17	7	5	8	7
2.1	25	12	17	16	7	5	7	7
2.2	25	12	17	13	6	4	7	6
2.3	25	12	18	11	7	5	7	5
2.4	25	12	18	8	7	5	7	4
2.5	25	11	18	6	7	5	7	3
2.6	25	11	18	4	7	5	7	2
2.7	25	11	18	3	7	4	7	1
2.8	25	11	18	0	7	4	7	0