'GRATR', A TONE REPRODUCTION MODEL; ILLUSTRATING THE CONVENTIONAL AND GCR OFFSET LITHOGRAPHIC WEB PRINTING PROCESS.

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ABSTRACT

An improved Jones [1], tone reproduction system the Graphic Regression Analysis Tone Reproduction or 'GRATR' model is detailed. Examples of the use of this model in describing the 4 color conventional and GCR positive acting offset lithographic printing process are reviewed. Using the 'GRATR' model the photomechanical reproduction cycle is followed from the original transparency through electronic scanning to ink on paper reproduction. The use of regression analysis to obtain the tone reproduction curves is introduced and mathematical expressions derived that can be used to model the process detailed. Such work will help users understand scanners, films, print, plate and press interaction properties as they relate to print properties and other factors.

INTRODUCTION

Jones Type Tone Reproduction Technique

In 1944 C.K.E. Mees [2] of Eastman Kodak defined tone reproduction as "concerned with the determination of the precision with which the photographic process is capable of producing a satisfactory representation of the brightness aspects of the original on a two dimensional surface".

Figure 1 depicts his cycle of the steps in the reproduction process. The radial line from each small circle connects with an enclosure in which is a statement of the essential characteristic of that particular element. The tone reproduction characteristics of each of these circles can be measured by physical and psychophysical techniques for individual analysis and study. Hurter and Driffield [3], considered the objective considerations of the problem. Renwick [4] gave a graphical solution to the problem by which it is possible to construct the tone reproduction curve showing the relationship between densities and scene brightness. This technique did not show the relationships of all the steps in the reproduction train, only a relationship between two variables.

A graphic solution now classic solution of indicating the relationships of the individual steps in the reproduction chain to one another was proposed by Jones [5] in 1931.

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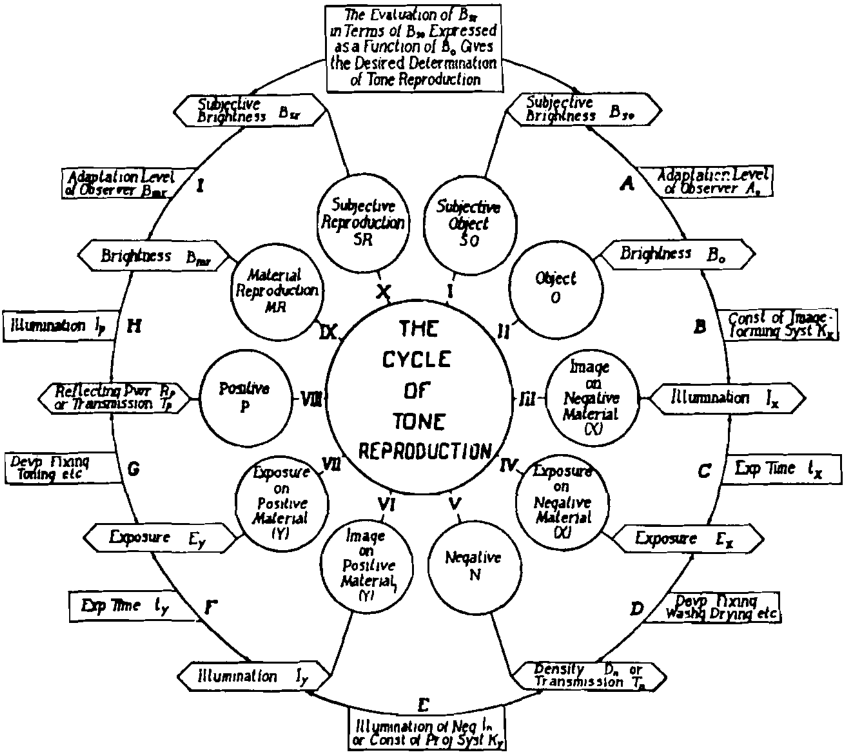


Figure 1

In this diagram depicting the tone reproduction curves of an amateur photographic system. Figure 2, details a "Jones" four tile or quadrant diagram. It is composed of several interlocking separate tiles whose ordinates and abscissa are related to one another in such a way that they are common to the adjacent graph. Some of the graphs are therefore upside down or otherwise oriented.

The characteristic curve or Density versus Log Exposure curve of the camera negative material is plotted as a curve A in the lower right hand quadrant tile. At the top of this quadrant is a logarithmic scale of brightness. The adjustment of the Log B and the Log Ex scales to each other is obtained if a density on the negative such as an, falls on the same vertical line as the logarithm of the brightness of the object area, rendered in the negative by a density of an.

In the lower left hand corner tile is a plot of the curve of the positive material. In this case the logarithmic exposure scale is vertical. The position of curve B, relative to the negative curve, A, must correspond to the existing printing conditions. Thus if negative density cn, is to be rendered by a relatively low density such as cp, these two points must lie on the same horizontal line. In the upper left hand quadrant the straight line C, passes through the origin at an angle of 45 degrees.

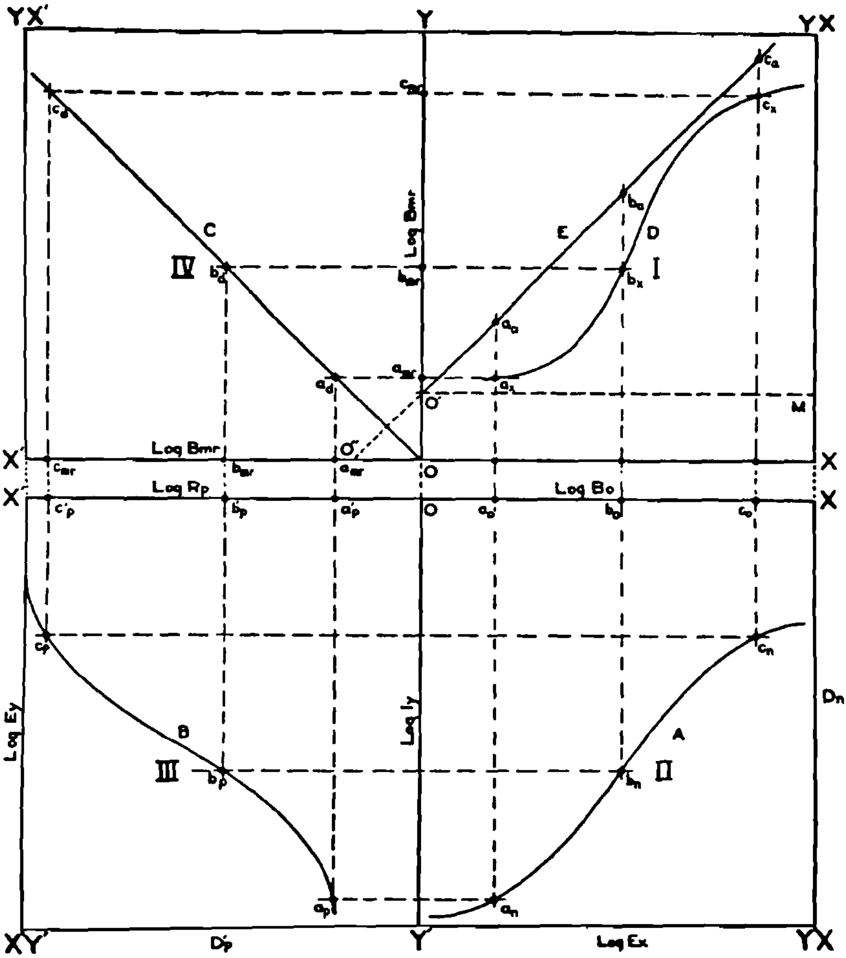


Figure 2

It is now possible to construct the tone reproduction curve D, in the upper right hand quadrant tile. For three selected object brightness ao, bo, and co, vertical lines are dropped onto the negative characteristic curve locating the points an, bn, and cn. Horizontal lines through these points establish the corresponding points cp, bp, and ap, on the positive characteristic. Vertical lines through these points cut the subjective function C, at the points ad, bd, and cd. Horizontal lines drawn through these points intersect vertical lines drawn through points ao, bo, and co establishing the points ax, bx, and cx and with sufficient points the curve D, the final desired tone reproduction curve can be drawn.

Knowing the relationship between 2 of these succeeding steps in the process it is possible to construct a graphical relationship between the steps. If the derived curve or line between two of the measured graphs is a straight line at 45 degrees the relationship between each of these curves is linear at a 1 to 1 ratio.

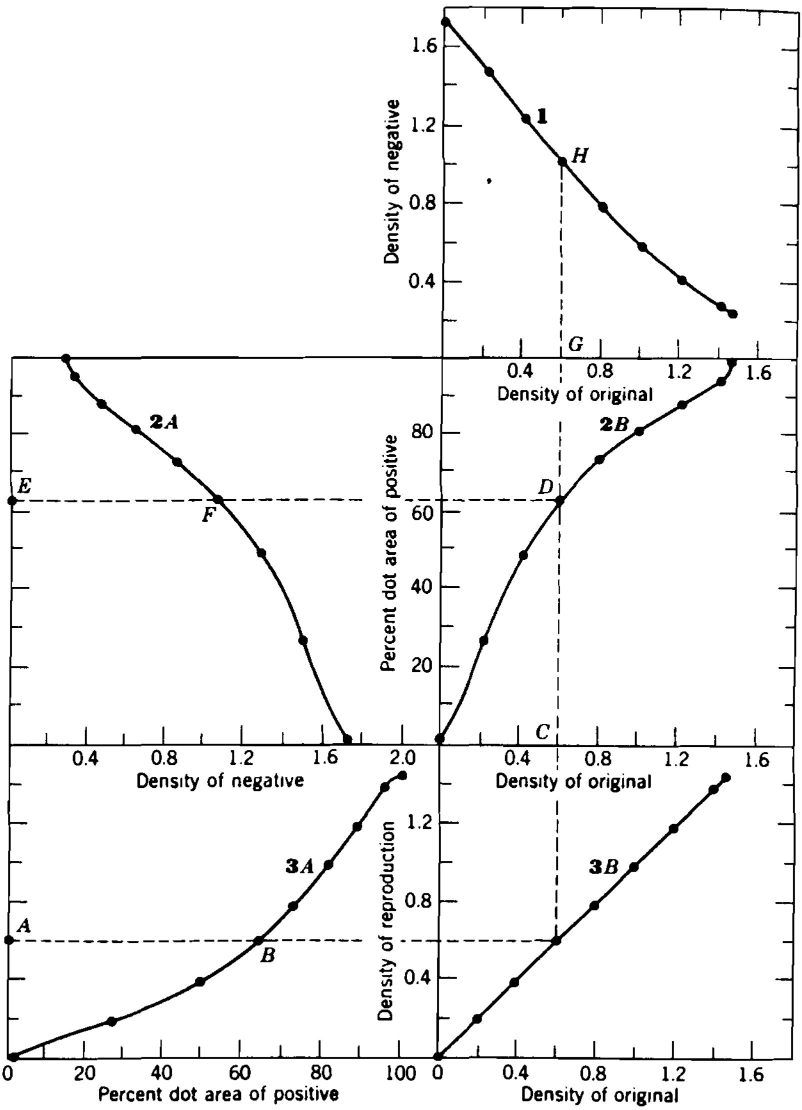


Figure 3
Tone Reproduction Diagram

Jones [6] utilized this technique with ever increasing complexity depending on the steps of the reproduction process to evolve techniques that eventually helped in the understanding of the ASA speed values and inter camera and image effects of various imaging processes.

Yule and Clapper [7] using Jones, (figure 3) proposed an expanded tone reproduction diagram, consisting of the many more steps to depict the graphic arts reproduction train. Other investigators also tried to adapt the tone reproduction diagram for graphic arts use.

Those works do not characterize the process as it is practiced today. It is now estimated that 98% of halftone separations are made by means of a computer operated digital scanner, and that color reproduction is now largely webfed heat set printing.

Further more, although the concept of Undercolor Removal (UCR) was employed and incorporated into former tone reproduction analysis, the extended technique of Grey Component Replacement (GCR) is not. When this avenue of investigation was last explored GCR was only a laboratory anomaly. It took the advancements in microelectronics and computer power to enable that practice to be as widely practiced as it is today.

In the graphic arts where an existing image such as a transparency or separation film is to be reproduced the characteristics of the original are likely to be measured in density, a logarithmic measure. Since the lithographic process utilizes halftone images percent dot area, a linear metric, is usually used to characterize that process. Therefore a Jones type tone reproduction analysis should include both log and linear measures. Former investigators mixed both metrics in a single tone reproduction diagram without a smooth conversion from one metric to the other. The lack of a smooth transition between reproduction steps made judgements difficult.

It is the intent of this work to introduce a simplified more concise computer based tone reproduction modelling technique which uses regression analysis. This mathematical technique expresses the various interactions involving original, scanner, and scanner film as well as dot gain differences between separation films and plates.

The use of such mathematical modelling permits a greater understanding of the reactions and allows analysis of the relevant equations to quantify differences. A 'GRATR' model will allow "what if?" computations to help further the investigation of the tone reproduction cycle. This paper will also present 'GRATR' models for the conventional and GCR positive acting offset lithographic process. The GCR data will be presented at several levels.

EXPLANATION OF THE 'GRATR' MODEL

The Tone Reproduction diagram for this process is illustrated in an array of 8 Tiles in rows of 2 Tiles each. Figure 4. Starting from the upper left corner the Tiles are numbered left to right row after row.

Tile 1 in the upper right portion of the diagram is used to represent the image to be scanned or the original transparency. Since the original image to be scanned is usually an

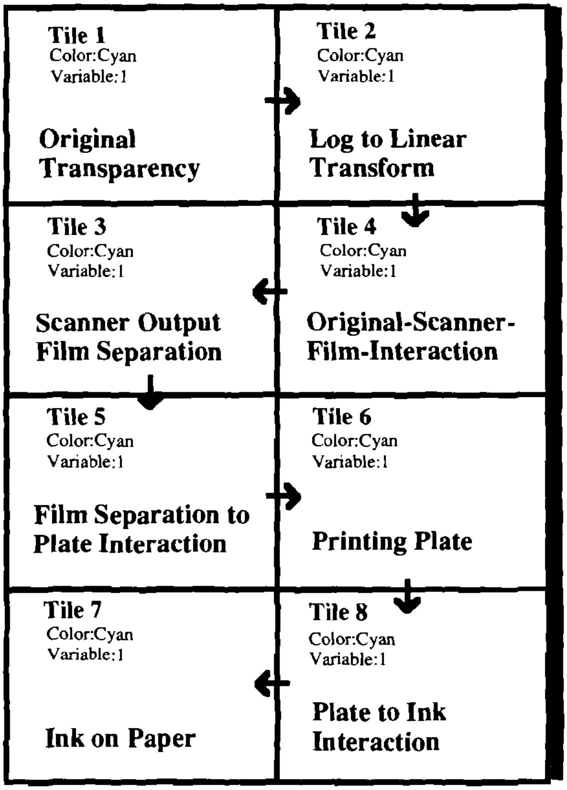


Figure 4
'GRATR' Model Schematic

Ektachrome transparency the values plotted are the color densities obtained by the use of Status A densitometry of a grey scale step image.

In order to facilitate a meaningful smooth transition of data through the 'GRATR' Model, Tile 2 is a Log to Linear transform which is an exponential function. This allows succeeding steps to be depicted with the same coordinates, step wedge position versus percent dot area.

Tile 3 depicts the information resulting from the scan of Tile 1. This is the halftone separation film produced by electronic means.

Tile 6 details the plate image obtained by contact printing the separation film image of Tile 3 onto a printing plate using electronic planimetry as taught in Fisch/Cavin [8].

Tile 7 represents the percent dot area values for the color ink on paper image resulting from web offset printing the plate values in Tile 6.

The analysis Tiles 4, 5, and 8 can be either graphical transitions derived in the same manner as classical Jones or the graphic output of mathematical regression analysis. A classical Jones diagram is a point by point analysis using adjacent tile values. When regression analysis is employed a mathematical expression becomes available to help model the process.

Tile 4 is a representation of the scanner interaction. It includes scanner linearity, device compression, and the selection of a particular tone curve from the scanner curve selection menu. In the case of the data discussed in this example the tone curve selected was for normal full tone images.

Tile 5 is a representation of the interaction between separation film and printing plate image. It includes contact vacuum effects, spectral radiance of the source, and the effects of exposure time and source. Each of these could be studied separately and imposed on this diagram as several different Tile 5 planes.

Tile 8 depicts the interaction between the plate image and the final ink on paper image. This interaction encompasses different factors involving paper and ink characteristics and aspects of press operation.

Although this set of tiles lie in one plane, additional steps in the tone reproduction cycle can be considered to be in adjacent or vertical overlapping planes. The three dimensional nature of the 'GRATR' model allows this diagramatic depiction of a set of 4 color separations. Figure 5. The 'GRATR' model also allows depiction and comparison at different levels, in this case, Figure 6, level 1 depicts the information for a one level of GCR and levels 2 and 3 depict different GCR percentages. Figure 7 indicates the use of a 'GRATR' model to study the other aspects of process change such as different film to plate exposures.

<u>GCR/UCA Print Reproduction Process;</u>
Sigg [9] provided the standard definition of GCR. He described GCR as a technique in color reproduction where in any given image location "the least predominant of the three

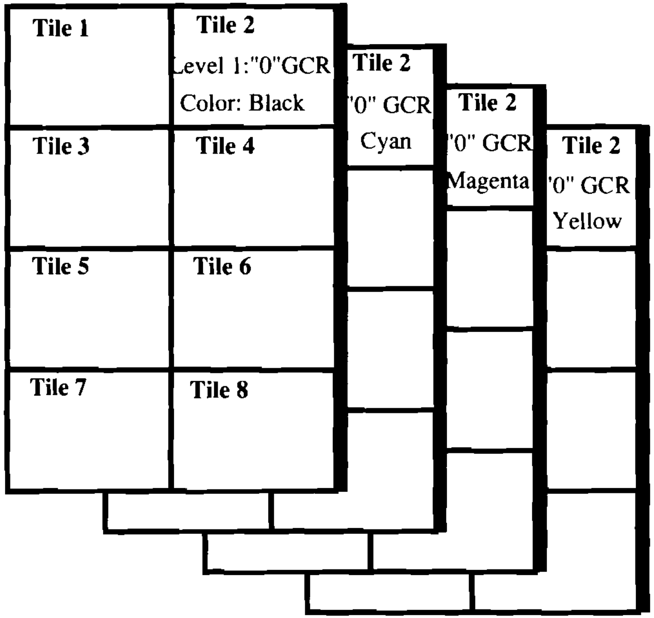


Figure 5

The 'GRATR' Model

Showing 4-Color Reproductions

One Level of GCR/UCA

"Zero"(Conventional) GCR/UCA

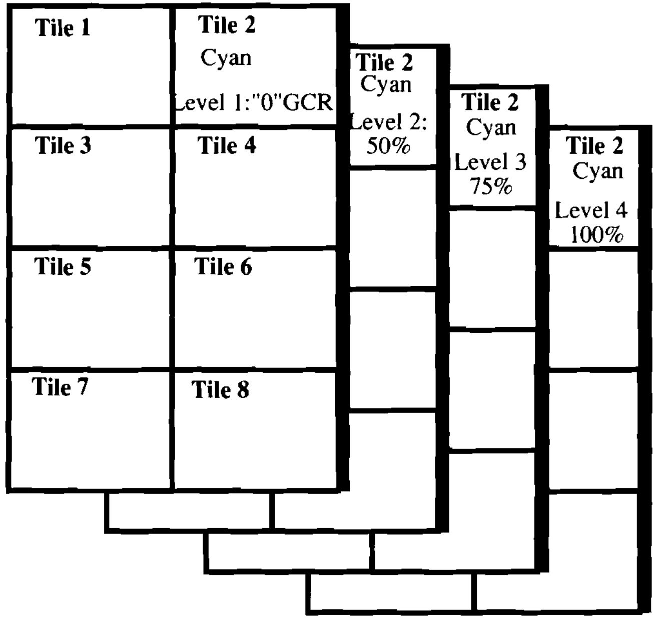


Figure 6

The 'GRATR' Model

Showing Different Levels
of GCR/UCA

Color: Cyan

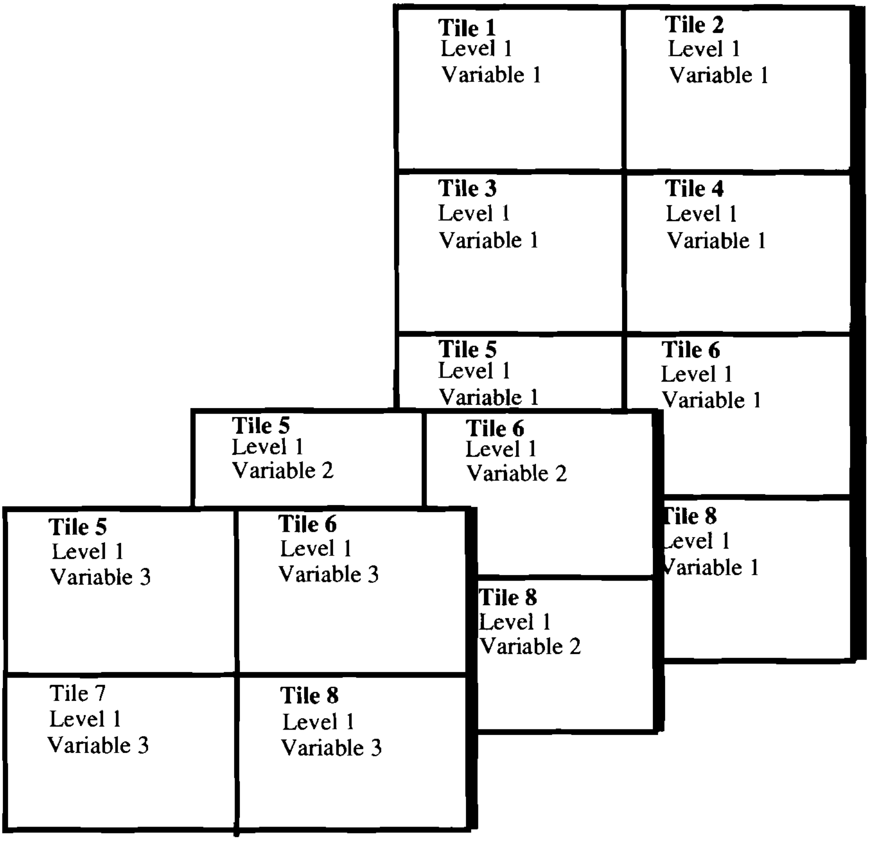


Figure 7

The 'GRATR' Model

Showing the Change in a Variable
(ex. Plate Exposure)

primary printing inks is used to calculate a partial substitution for some or all of the primaries by black".

In a 4 color reproduction process a black printer is used for several purposes, among these a technique called undercolor removal [10] which allows for ink conservation, better trapping and drying. UCR does this by a reduction of the colored ink levels at the upper portion of the grey tone reproduction curve and replacement of this reduced colored ink by increased black ink. Only grey and near grey colors are affected.

As discussed in this paper, GCR is differentiated from UCR by the fact that in GCR the colorimetric substitution of black ink occurs throughout the image affecting grey and tertiary color images at the smallest picture element or "pixel" stage.

Some older scanners can perform UCR calculations, but are not equipped to perform the GCR inter image calculations. The Graphic Communication Association (GCA) GCR Study Group chose to separate the definitions of GCR and UCR to avoid the conflict and confusion that could occur when defining the capabilities of scanner devices. However, within the definitions of Sigg and Yule, UCR is a subset of GCR.

Although GCR images can be obtained they appear lacking in shoulder contrast. A technique called Undercolor Addition (UCA) is employed to overcome this objection. In UCA additional yellow, magenta and cyan densities are added to each of their respective curves at the shoulder portion. The quantities of the colors added to their respective GCR image must be in such a ratio that they produce a grey. Objectionable color shifts will be apparent in the shoulder and Dmax areas if they do not. GCR plus UCA are a team that allow the GCR process to be successfully applied. This GCR study uses GCR images that contain UCA.

3M conducts GCR research both independently and with many of the trade association GCR study groups. The data from a recent 3M GCR TAGA annual meeting paper detailing the GCR/Scanner interactions [11] was used for the tone reproduction studies reported in this paper.

EXPERIMENTAL

General Background

Under the auspices of the GCA Graphic Communication Association, GCR Study Group, 3M supplied a 3M Custom Ektachrome Scanner Transparency to test the conventional and GCR output of various scanner manufacturers systems and the scanner aim points for the target. Four of the 5 different scanner manufacturers agreed to scan the 3M scanner target and produce a series of color separations at different levels of GCR/UCA. The materials and a series of press runs to print the images were provided by R.R. Donnelley, Torrence California.

The test was conducted in 3 Phases. In Phase 1, the scanner manufacturers provided their own propriety GCR set up targets to evaluate the Donnelley press and ink conditions. They used the results of the first press run to fine tune their devices to Donnelley conditions. Each systems manufacturer was then responsible for optimizing his equipment and producing a conventional UCR separation and an optimum set of GCR/UCA separations. Separations were requested covering a range from 50 to 100% GCR/UCA at set specified levels. These separations were web printed on two separate occasions. The zero GCR level was considered to be a conventional 300% area coverage UCR separation.

For phases 2 and 3 information on the 3M Scanner Target is given in Appendix 1 and details on the instructions to the scanner manufacturers is found in Appendix 2. Details on the ink colors used, the stock and press conditions are offered in Appendix 3. Instructions on the running of the press tests are included in Appendix 4.

The 1988 TAGA presentation reported that photosensor/filter scanner analysis differences existed between scanners made by different manufacturers. These differences result in color output changes that are apparent in conventional as well as GCR/UCA separations. Their study is beyond the scope of this paper. Those differences prevent meaningful scanner to scanner color analysis comparisons. However color and tone rendition analysis between conventional imaging and the various levels of GCR/UCA images for any one scanner is possible.

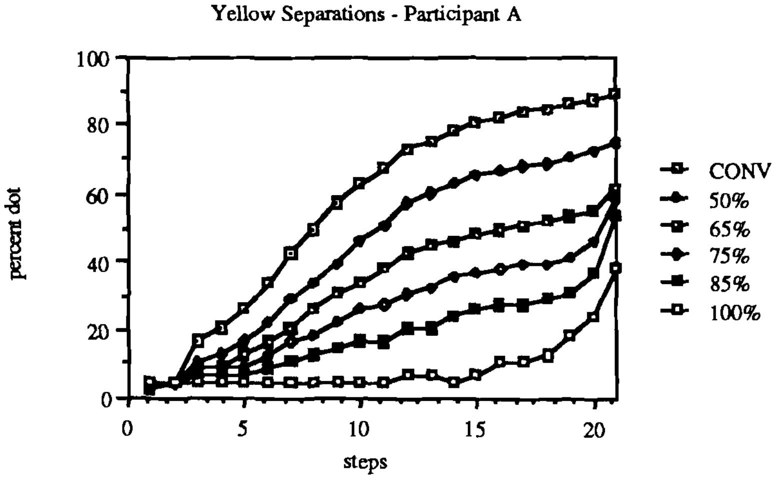


Figure 8

Yellow Separations - Participant D

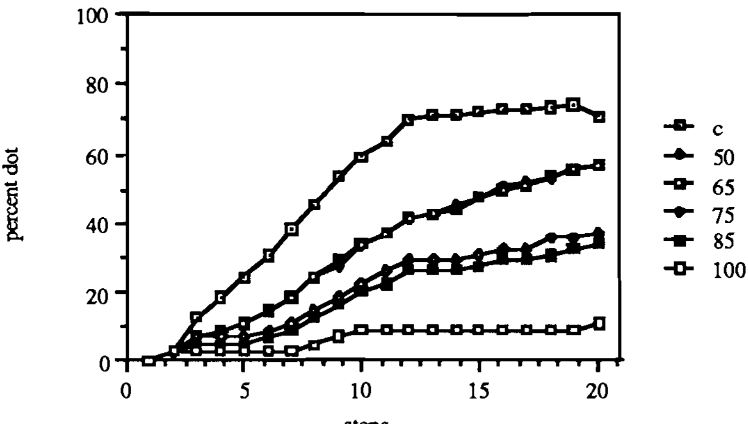


Figure 9

Figures 8 and 9 detail the separation differences between only two of the five different scanners covering the range from conventional UCR separations (or no GCR/UCA) to those containing 50, 65, 75, 85 and 100% GCR/UCA. For brevity, the blue filter, yellow separation films are only depicted. Figures 10A and 10B depict the black separations from that same scanner comparison.

Black Separations - Participants A & D

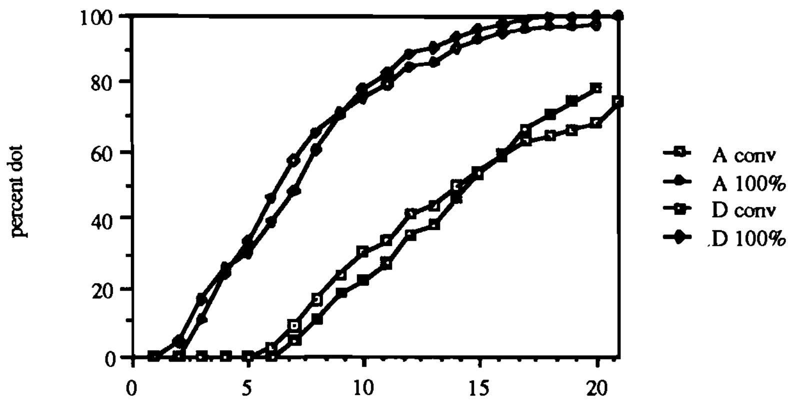


Figure 10A

Black Separations - Participants A & D

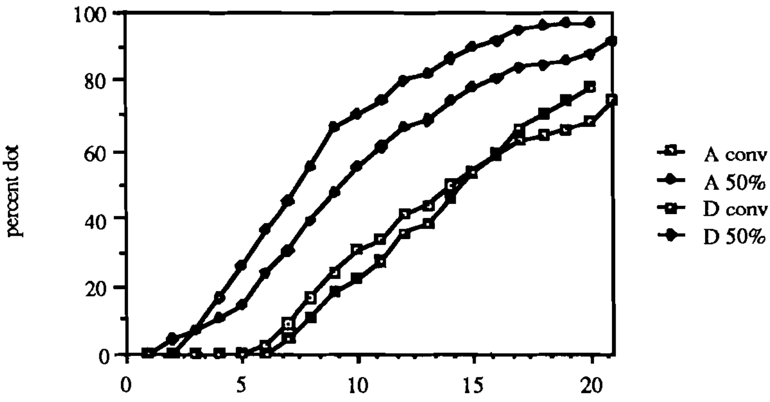


Figure 10B

A 'GRATR' Model study of the Torrence, GCR/UCA Test

For purposes of this study the scanned separations of Participant A in the GCR/UCA test were used. All the curves for both the cyan and black images depicted so far are from the separated color images requested.

A Full 'GRATR' model depiction of all 4 color images at all steps as well as the composite images for the conventional and all the GCR/UCA would overwhelm this paper. For brevity, only the cyan and black separations at conventional (300% UCR) and GCR/UCA levels of 50, 75 and 100% GCR/UCA will be depicted.

Having explained the 'GRATR' model and what what each of the Tiles represent, Figure 11 depicts a full set of 8 Tiles detailing the red filter separations (cyan color image) when a conventional (300% total area coverage UCR) image was requested.

Figures 12a and 12b each depict a full set of 8 Tiles detailing the cyan color image at 50, 75, and 100% GCR/UCA.

Figure 13 depicts a multi image 'GRATR' model with all the levels of GCR/UCA as well as a conventional image. Table 1, details the regression equations and the correlation coefficients (R^2)that describe the 100% level of GCR/UCA and conventional image in the interaction Tiles 5 and 8. R^2 values as high as these indicate excellent correlation between actual curves and the derived equations.

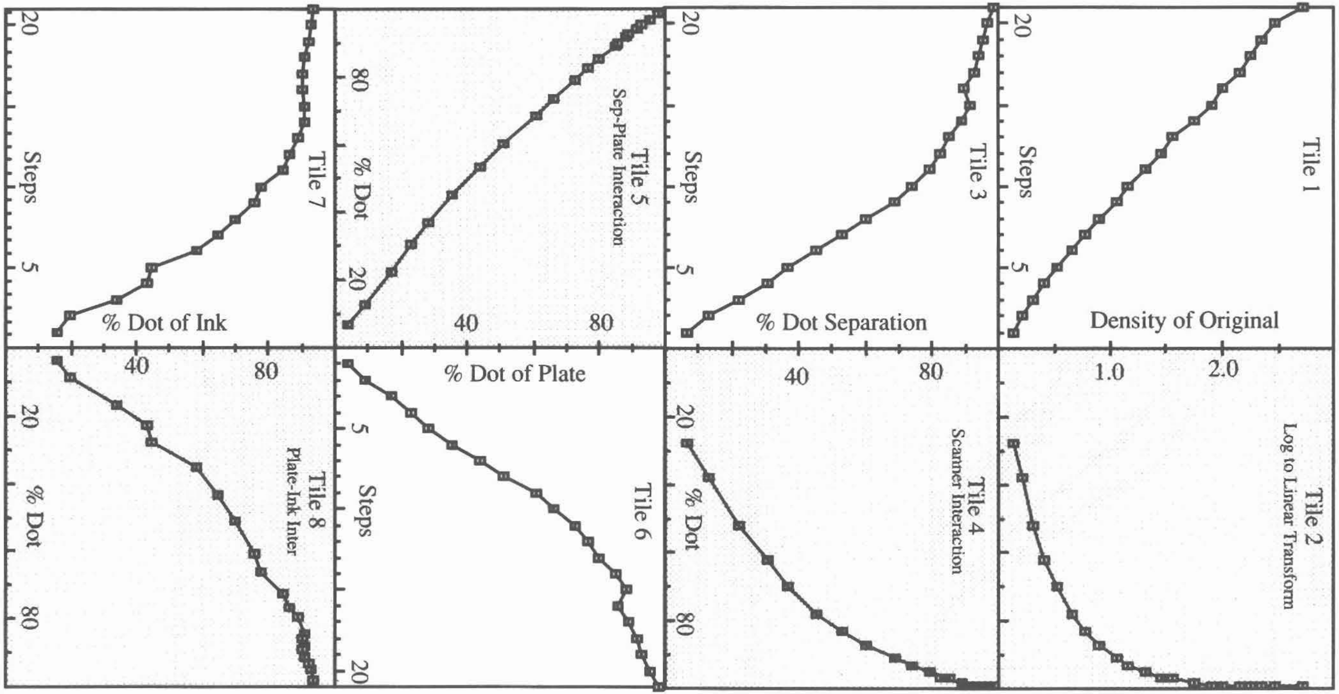


Figure 11

A 'GRATR' Model Representationof the Conventional Web Offset Printing Process

Red Separation, Cyan Image

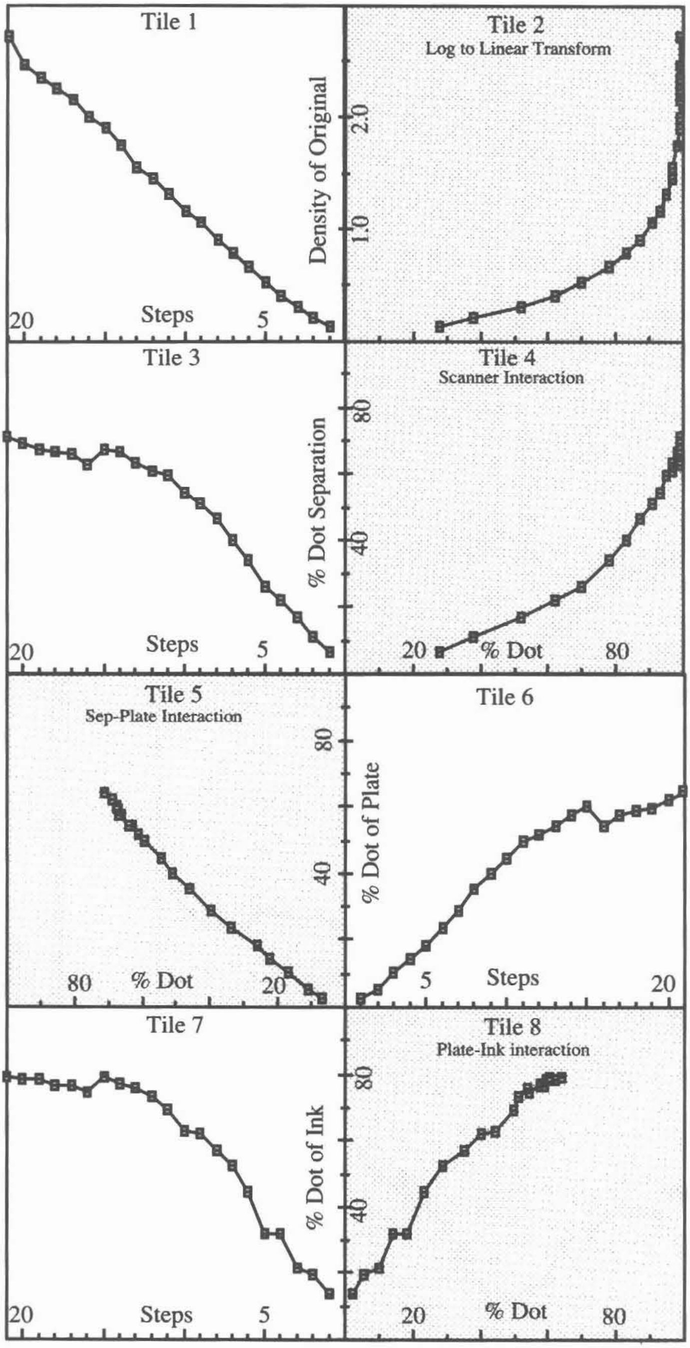


Figure 12 A

A 'GRATR' Model Representation of the 50% GCR/UCA Web Offset Printing Process

Red Separation, Cyan Image

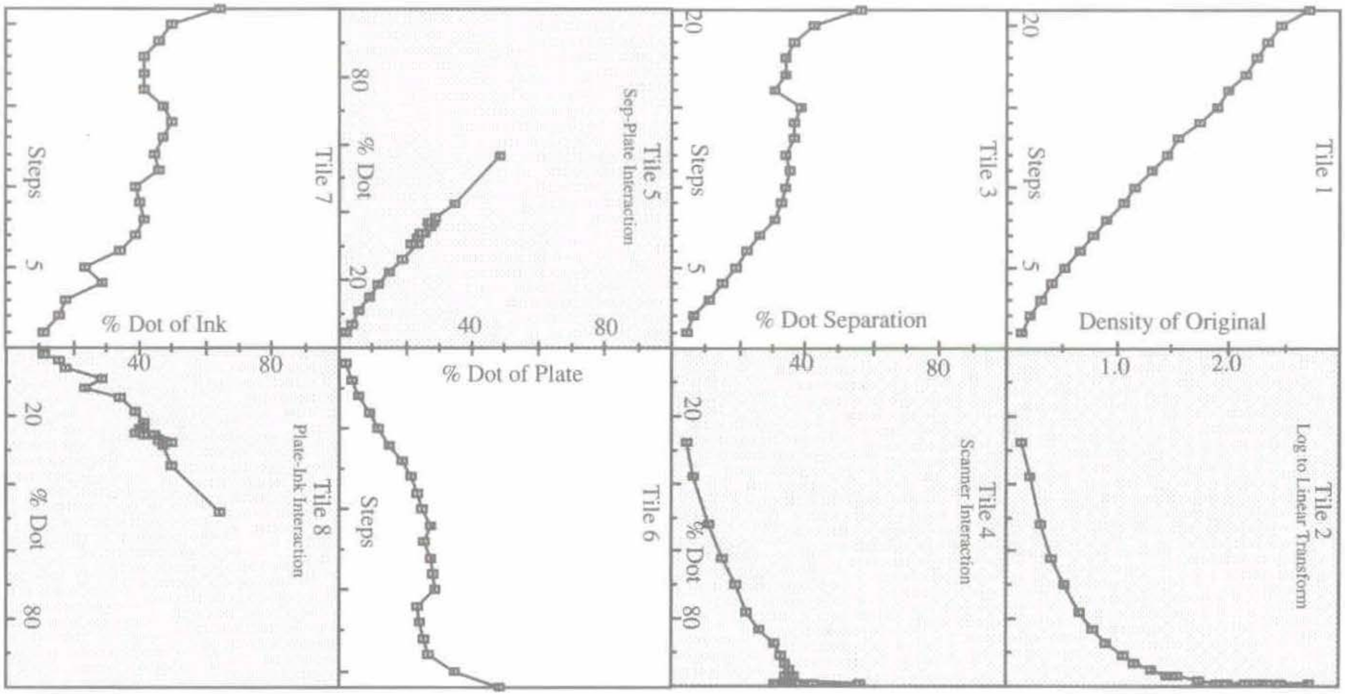


Figure 12 B

A 'GRATR' Model Representation of the 75% GCR/UCA Web Offset Printing Process

Red Separation, Cyan Image

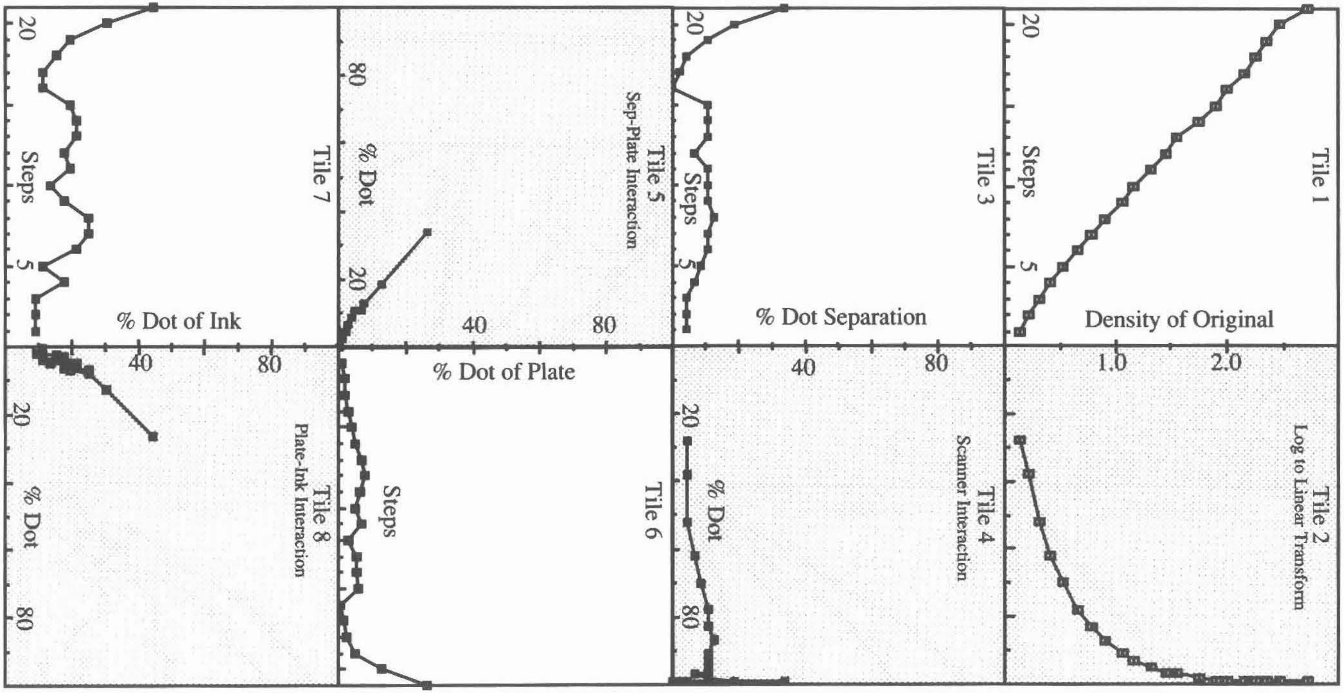


Figure 12 C

A 'GRATR' Model Representation of the 100% GCR/UCA Web Offset Printing Process

Red Separation, Cyan Image

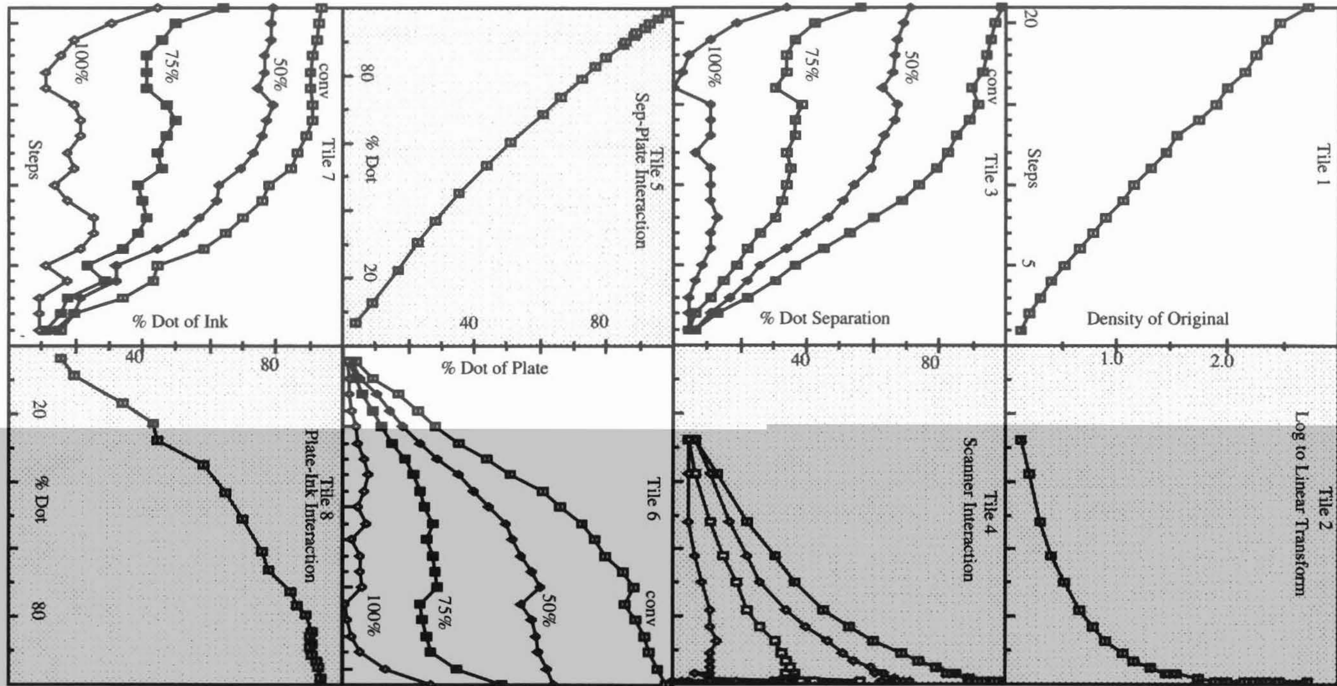


Figure 13

A 'GRATR' Model Representation of the Conventional, 50%, 75%, 100% GCR/UCA

Web Offset Printing Process Red Separation, Cyan Image

TABLE 1

CYAN

SCANNER INTERACTION

Conventional Image

$$y = -62.241 + 3.9305\,X - (6.6086 * 10^{-2})\,X^2 + (4.2656 * 10^{-4})\,X^3 \qquad R^2 = 0.997$$

SEPARATION TO PLATE

$$y = -0.41155 + 0.67068X + (2.6667 * 10^{-3})X^2 + (6.1643 * 10^{-6})\,X^3 \qquad R^2 = 1.00$$

PLATE TO INK-ON-PAPER

$$y = 7.7135 + 1.7097\,X - (1.0653 * 10^{-2})\,X^2 + (2.1832 * 10^{-5})\,X^3 \qquad R^2 = 0.997$$

BLACK

SCANNER INTERACTION

100% GCR

$$y = 1.4480 * 10^{(1.8079 * 10^{-2})\,X} \qquad R^2 = 0.976$$

SEPARATION TO PLATE

$$y = 4.2507 * 10^{-2} + 0.6261\,X + (3.6648 * 10^{-3})\,X^2 \qquad R^2 = 1.000$$

PLATE TO INK-ON-PAPER

$$y = 5.9188 + 1.7172X - (6.5116 * 10^{-3})\,X^2 - (1.3366 * 10^{-5})\,X^3 \qquad R^2 = 0.998$$

REGRESSION EQUATIONS for TILES 4, 5, and 8

Tile 4 depicts the interactions produced by the transparency, scanner program and the photographic characteristics of the output film.

Tile 5 details the interactions between the separation films and the plate characteristics at a given exposure level. The differences here have been referred to a representing "dot gain" however how can one express dot gain at a 50% level when some of the GCR/UCA images do not obtain these values?

Tile 8 represents the interactions between the plate characteristics and the ink/press interactions at a given exposure level. The differences here have been referred to a

Tile 5

Separation to Plate Interaction

Conventional and GCR

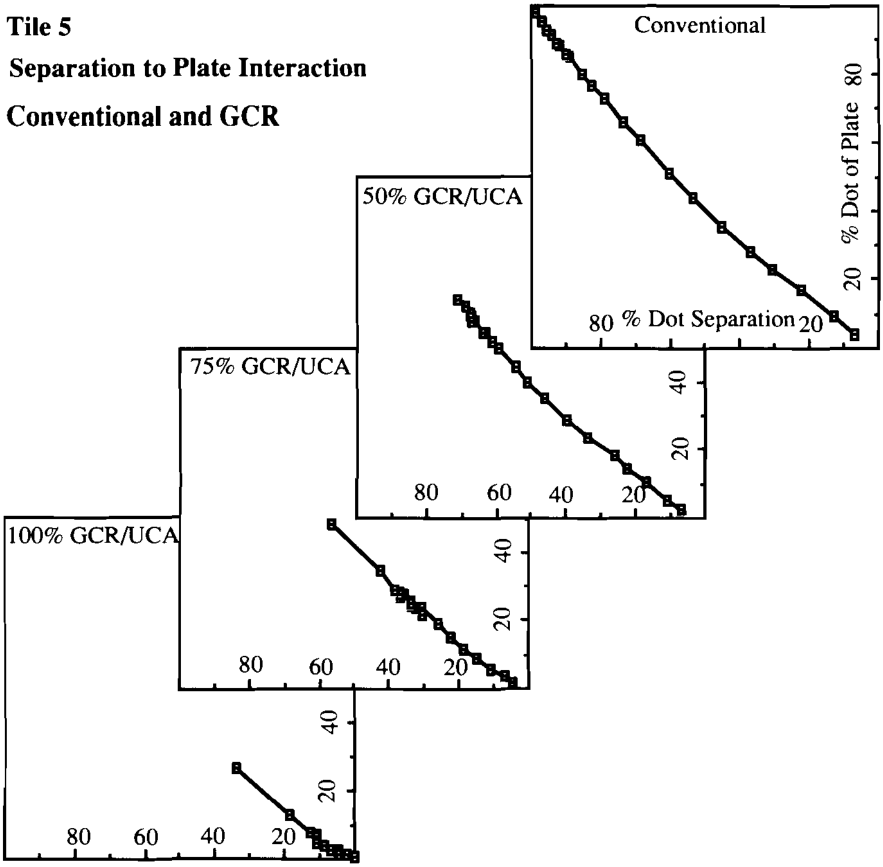
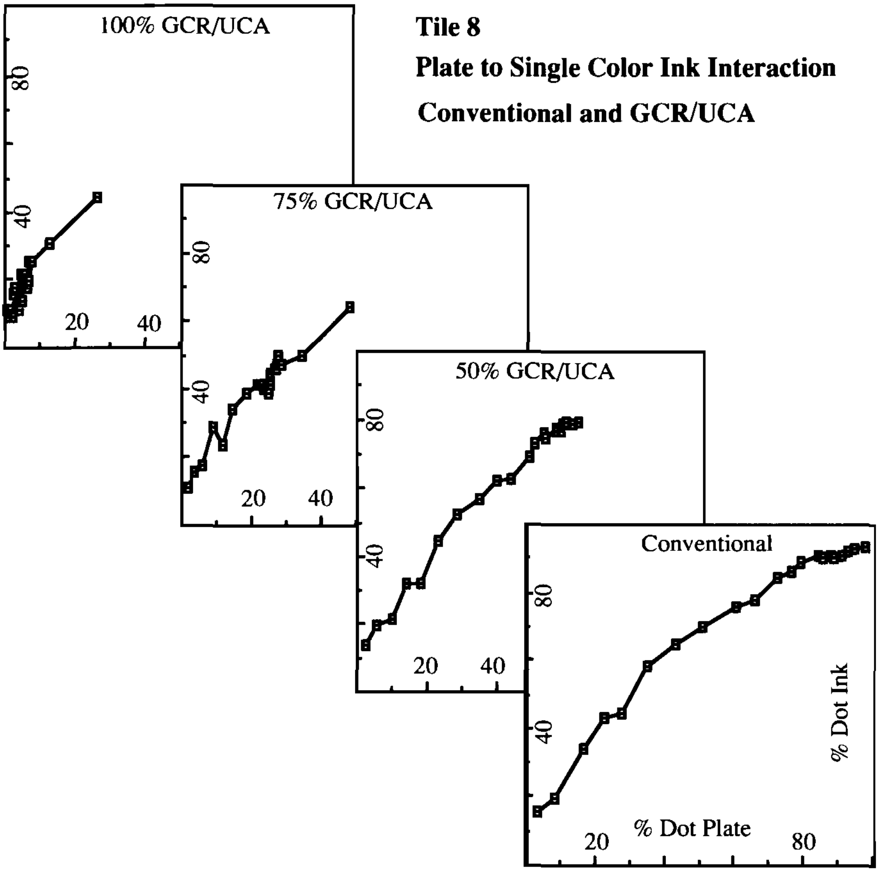


Figure 14 A



Tile 8
Plate to Single Color Ink Interaction
Conventional and GCR/UCA

Figure 14 B

representing "dot gain". Again as in Tile 5 how can one express dot gain at a 50% level when some of the levels of GCR/UCA level images do not reach these values?

A 45 degree line from the lower left corner of any of the interaction tiles 4, 5, or 8 depicts a transition with no change which represents a dot for dot image. The difference between the actual result and the 45 degree line is dot gain. If you look at the 45 degree line as horizontal you will visualize the curve as we see it when we draw dot gain curves. Our routine depiction of dot gain is the difference in dot size from a dot for dot reproduction.

Note the information displayed in Figures 14A and 14B. Tiles 5 and 8 of the 'GRATR' model indicates that the general curve shape of the conventional image still holds but in the GCR images it is only used at certain portions.

Figure 15 represents a full 8 Tile set for the black separations including conventional and GCR/UCA images. Tiles 5 and 8 are different than the corresponding curves for the cyan image (Figures 16A and 16B). The black image does extend up to and pass the 50% dot area coverage level. It would appear from these findings that the dot gain from such GCR/UCA images as represented from this test come basicly from the black image.

CONCLUSION

An improved technique for tone reproduction analysis called the 'GRATR' model has been presented. Such a representation recognizes the different metrics used to describe images in the reproduction train. The use of regression analysis to facilitate this technique and resultant mathematical expressions for assisting in modelling have been detailed. A step by step analysis of the conventional and GCR/UCA printing techniques using the 'GRATR' model has been demonstrated. Some observations on aspects of GCR imaging have been noted.

Tone reproduction diagrams have been depicted for a conventional UCR image as well as several levels of GCR/UCA. All the images have been obtained from the same target, scanner, film, inks, paper and press run.

Such techniques when used to compare changes in the routine steps of reproduction employing the concept of dimensional tiles can assist in the understanding of the lithographic printing process as well as in trouble shooting difficulties.

An expression of appreciation must be included in a job such as this as it not done by one person alone. I want to expressly thank Sharon Bartels without whose help this work would not be possible.

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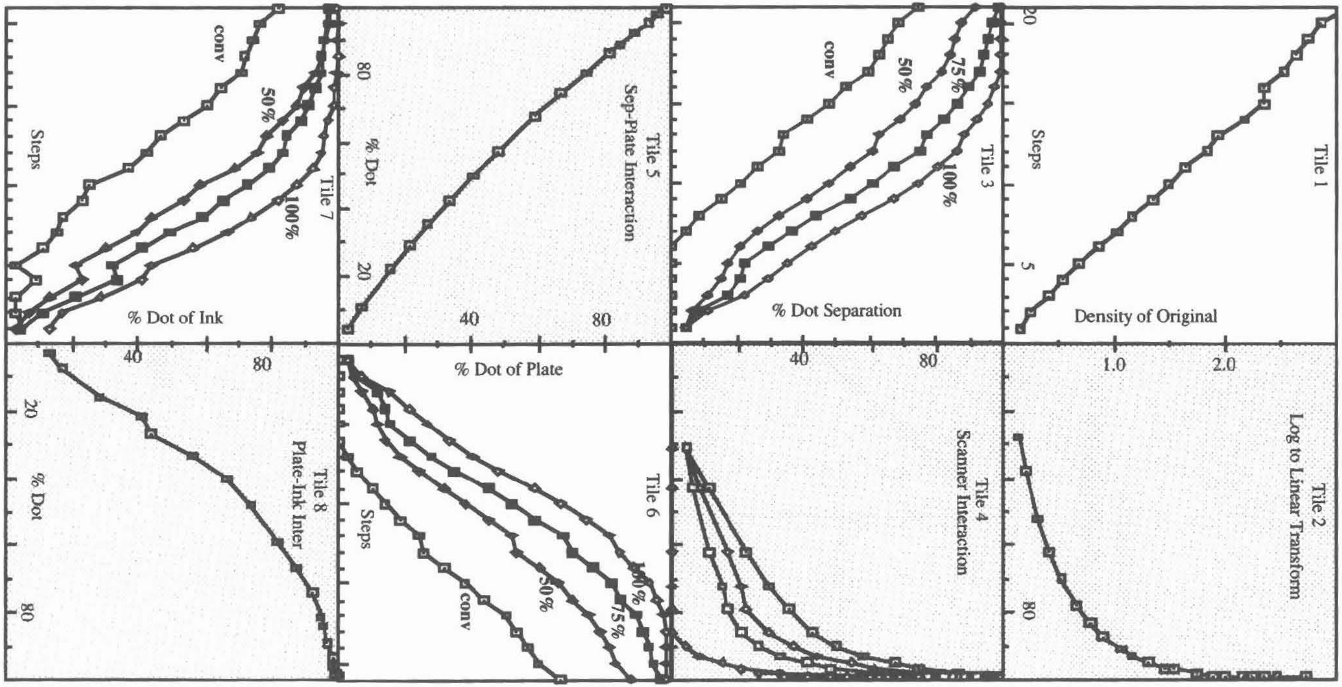


Figure 15

A 'GRATR' Model Representation of the Conventional, 50%, 75%, 100% GCR/UCA

Web Offset Printing Process   Black Separation

Tile 5

Separation to Plate Interaction

Black - Conventional and GCR/UCA

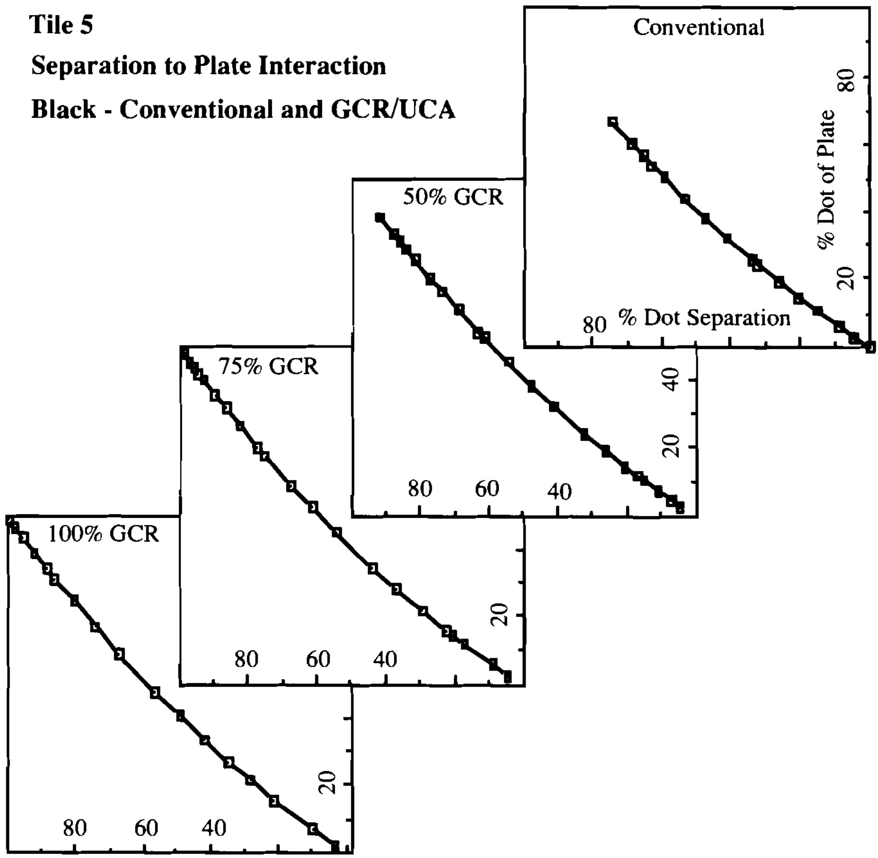
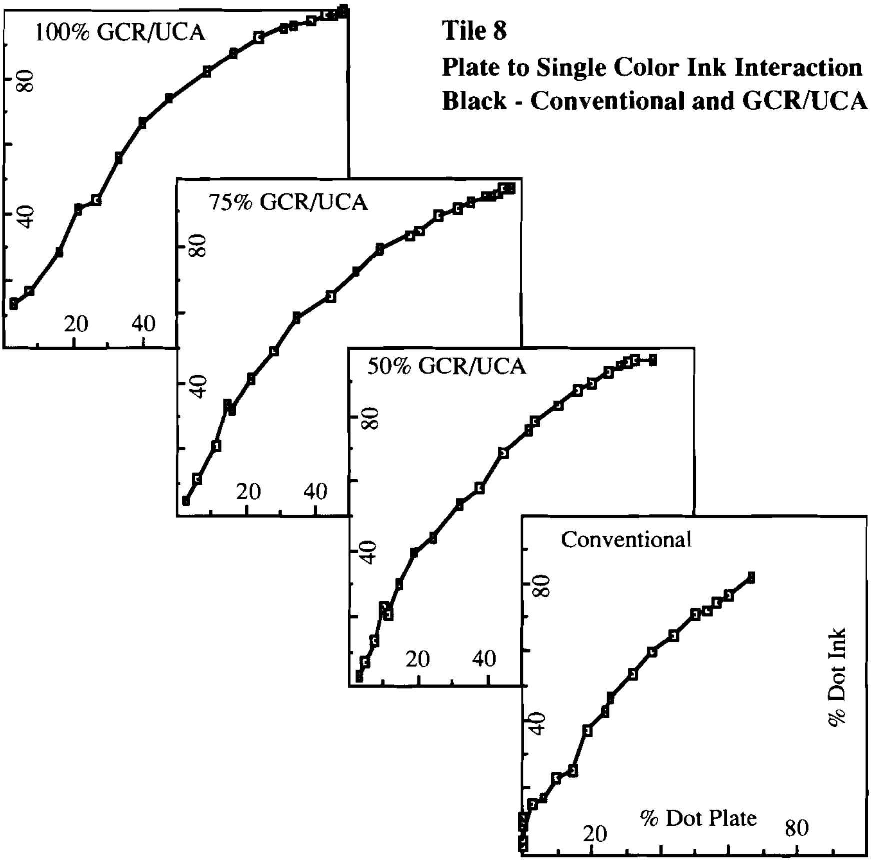


Figure 16A



Tile 8
Plate to Single Color Ink Interaction
Black - Conventional and GCR/UCA

Figure 16B

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APPENDIX 1

THE 3M SCANNER TRANSPARENCY TARGET
A 3M custom made 4x5 Ektachrome transparency was used as a scanner target. The following scales of that target were used for the color and tone GCR/UCA and conventional image analysis.

SCALE A - A linear scale of visual grey densities covering a range of from 0.03 to 3,00 Status A densities.
SCALE A1 - The A Scale in a continuous mode.
SCALE A2 - The A Scale in a 21 step mode.
Figure 17 depicts the relationship between the Status A densities and the 21 grey scale steps of the A2 scale.

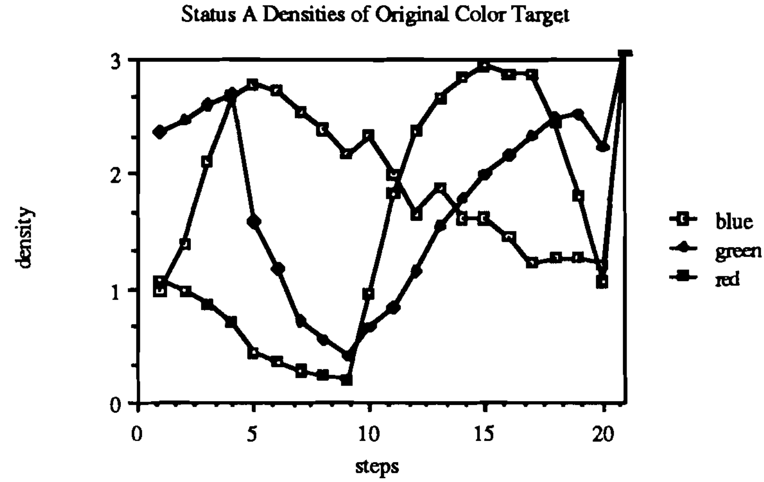

Figure 17

SCALE B
A series of color blended patches wherein a near constant level of cyan is overprinted with a combination of magenta is changed by increasing quantities of yellow until a yellow maximum density is achieved, and then that yellow with an increasing amount of cyan until a maximum cyan density is achieved, and then at that cyan level increasing amounts of magenta density is achieved.
SCALE B1 - These color patches at a minimum color brightness level.
SCALE B2 - These color patches at a medium brightness level.
SCALE B3 - These color patches at a high brightness level.
Figure 3 depicts the STATUS A, red, green, and blue filter density readings.

SCALE C - Individual 11 step scales of yellow, magenta, cyan, red, green, blue and black colors.

APPENDIX 2

Information given to the scanner manufacturers.

PHASE 2 SCANNER OUTPUT TESTING
Five scanner manufacturers were invited to use their data from Phase 1 to produce color separations from a custom 3M machine readable Ektachrome color transparency (details in APPENDIX 1)

The following operational instructions were given the scanner manufacturers for Phase 2:

1. Standard scanner linearity and control procedures were requested.
2. Since each scanner manufacturer provides a variety of output tone curves, the "normal" output curve was requested.
3. To standardize scanner input, a white point and Dmax was specified for the 3M Scanner Grey Scale Target (A2)

4. An Eastman Kodak pictorial was included as a visual indication of GCR/UCA.
5. Each manufacturer was asked to produce a GCR/UCA set of 300% total area coverage color separations (at the manufacturers' selected UCA level appropriate for the GCR conventional (300% UCR total area coverage) separation. The GCR levels were specified at 100%, 85%, 75%, 65%, and

Unfortunately only 2 of the manufacturers chose to participate in this phase. These separations were quality checked at 3M using a Watchprint system then stripped up and again web printed at R. R. Donnelley at Torrence, Ca.

In the interest of accommodating the greatest scanner manufacturer participation, as well as provide a measure of data reliability, phases 2 and 3 were repeated twice. Experience being the greatest teacher some small changes in instruction were communicated to the manufacturers for phase 3.

PHASE 3 CHANGES

1. To ensure a specified input curve, the curve of the 3M transparency grey scale (A2) was additionally specified by detailing 25%, 50%, and 75% points as well as white point and Dmax.
2. A 3M practical transparency mated to the 3M Scanner Target was included in the test to be scanned under the same conditions as the Scanner Target.
3. The magnification of the 3M Target and practical was specified at 200%. This insured a final image size that could be analyzed by colorimetry.
4. The levels requested for Phase 3 were restricted to 50, 75, and 100% as well as the conventional (UCR 300% Total Area Coverage)
5. A request was made to produce GCR separations with and without UCA. This was to ascertain where UCA correction was applied.

A transparency formally used in a live advertisement was contributed by and included with the readable 3M Scanner Target.

Appendix 3

Spectrophotometric curves of the yellow, magenta and cyan inks used are reproduced in Figure 18. Spectrophotmetric curve of black ink used is reproduced in Figure 19.

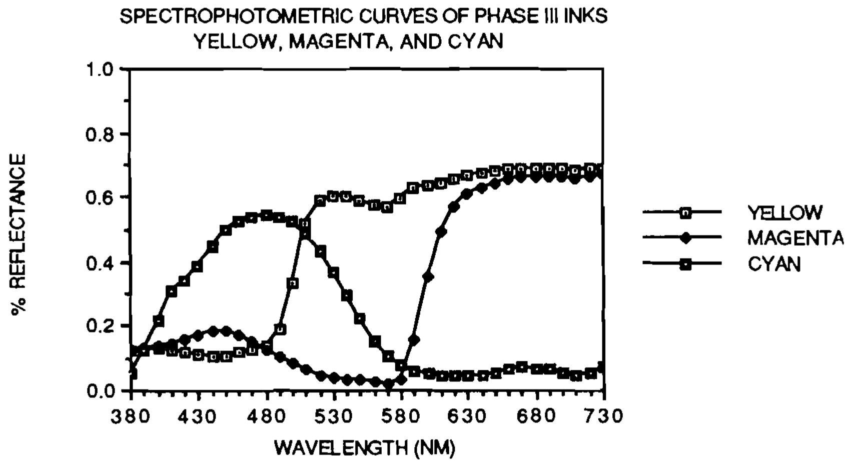

FIGURE 18

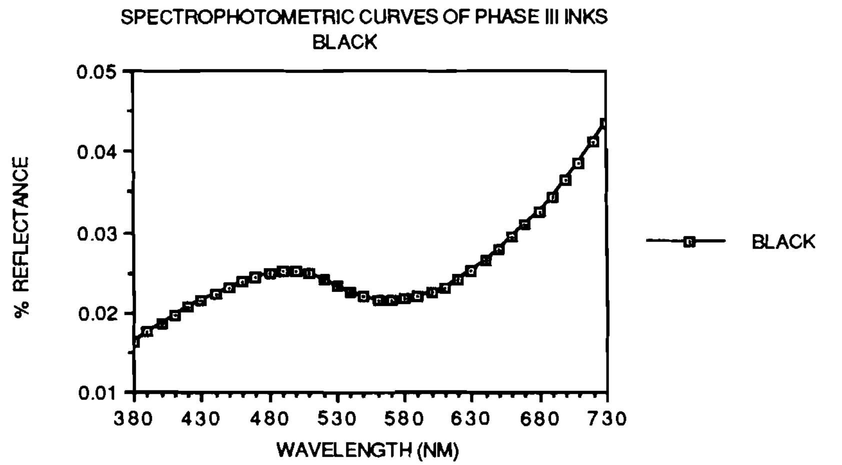

FIGURE 19

APPENDIX 4

PHASE 3 PRESS RUN Press and ink details

The following instructions were provided for the press runs of Phases 2 and 3.

1. The GCR/UCA and conventional separations were to be printed on the same plates side by side.
2. Information on which image came to an OK stage (GCR or Conventional) faster and makeready data was to be collected.
3. Selected sheets were to be sampled during the run.
4. Single color images of yellow, magenta, cyan and black were to be obtained.