Effect of Printing Ink Sequence (KCMY vs. YMCK) of Multicolor Offset Printing on the Color Gamut and Overall Print (image) Quality

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Abstract

This research utilized an experimental research method. The purpose of this research study was to determine the effect of ink sequence (KCMY vs. YMCK) of multicolor offset printing on the color gamut and over print quality. The experiment was conducted in a CTP based workflow for offset printing. A custom layout of 17.5" x 23" test target was used and linear plates were produced by using the CTP device. After the plates were made for the KCMY and YMCK printing sequence respectively, a pilot test was conducted to achieve the target solid ink density (SID) values according to GRACOL SID standard (or in-house SID standard). During the pilot test of KCMY printing, 500 sheets were printed. This pilot test of printing is only to bring the SID values to a standard level. Once density values had been achieved according to the standard ink density (SID) values, the press was run continuously without operator interference and another 100 (N) test sheets were printed, from which a total of 80 (n) sheets were randomly selected for the analysis. The sample size was selected in order of the specific confidence interval ($\alpha = 0.05$). A random sampling technique was used to identify the sample size because of the large size (N = 100) of total population. The findings of this research, comparing

color gamut volume of KCMY vs. YMCK ink sequences revealed that there is no significant major difference of which ink sequence is better over the other. However, in comparing, the YMCK sequence gamut consists of higher gamut volume, and smoother gamut shape than the KCMY sequence. The findings make it difficult to draw conclusions regarding dot gain, because each printing sequence was executed by using the same printing conditions (press, paper, inks, etc.).

1. Introduction

In the process of multicolor offset printing, a paste ink of a given color – yellow, magenta, cyan, and black (CMYK) is transferred from the ink fountain to the series of inking rollers and then to the image areas of the plate (image carrier). The inked image area of the plate is then transferred to the blanket, and from the blanket, it is transferred to the paper. A continuous tone color, or black and white photograph, is composed of a full spectrum of shades and color, from near white to dense black. The method by which continuous tone of photograph is transformed to a printable image is called halftoning, in which varying percentages of the press sheet are covered with halftone dots to represent the varying tones in the image. In the conventional halftoning process these dots are equally spaced. However, the size or diameter of the dots will vary according to the different amounts of light that are reflected from the different tones in the original photograph. The ink printed by each dot, of course, has the same density. At normal viewing distance, the dots of a printed image create an optical illusion of a continuous tone image.

In every day print operations, the multicolor printing sequence is black, cyan, magenta, and yellow (KCMY). Review of numerous reports also revealed the alternative option of ink sequence is inverse fashion (YMCK). In order to print a quality halftone image, the printer (or press operator) must carefully manage several variables and attributes which are associated with the printing process. The print attributes are individual characteristics within the printing process that can be monitored during the production process so as to maintain the color consistency. The commonly monitored attributes include solid ink density (SID), dot gain (DG) and print contrast (PC). For this study, the attributes of dot gain (DG), color gamut's of ink sequence, were used to examine the significant differences that exist in the print ink sequences (KCMY vs. YMCK). A color gamut analysis would reveal the effect of ink sequence in the range of colors produced by the devices (or inks).

2.0 Review of Literature

Anderson (2007) focused on the printing of black ink in different sequences and to understand the concept of ISO 12647-2:2004 standard. The aim of the experiment was to examine the two ink sequences of CMYK and KCMY for both digital printing and offset printing. The results of the test show that the need for a standard may not be needed, due to only slight changes in appearance. It is more important to have consistent sequences while printing. K first, for offset printing, the test resulted in slightly more density and larger gamut. K last, for digital, produced similar findings. The standard of ISO 12647-2:2004 does not need to be changed based on the test results. Furthermore, distribution, ink spreading and ink penetration are the underlying physical process that determine the quality of the image (Li Ying 2003). In printing terms, “color gamut is defined as a measure of the color capacity that the device can deliver.” Rousu et al. (2005) conducted a study to investigate the “distribution of offset ink components in coated paper.” The experiment showed that higher sheet gloss gave rise to higher print gloss. Finer pores are desired in this type of printing because it immobilizes the ink, allowing for a shorter time for the ink filament leveling after the ink was applied. The distribution of offset ink influences ink setting rate and final print quality constituents as the ink comes in contact with a coated paper during printing. Sudarno (2006) investigated the effect of press and paper variables on linting during offset printing of newsprint to find out that lint accumulation on blanket follows a linear relationship with the number of copies, yet pressure was not considered a major component on the effect of lint on the print.

Offset printing is a planographic printing process, also known as chemical printing. It uses a flat aluminum plate (image carrier) on which image and non-image areas are generated photochemically or electronically. The basic principle of offset printing is that water (or dampening solution) and ink (or oil) do not mix. The image area of the plate is receptive to ink and the non-image area of the plate is receptive to water (Hseih, 1997). The dampening solution is a mixture of chemical concentrate in a water-based solution. The basic configuration of a single color offset press consists of three cylinders – plate, blanket, and impression. The plate, which holds image areas in readable direction, is mounted on the plate cylinder, dampened all over its surface, and then the plate surface is contacted by a series of inked rollers. The inked areas (image areas) transfer onto the surface of the blanket cylinder where they become non-readable, and then onto the paper where they become readable. The paper passes between the impression cylinder and blanket cylinder (see Figure 1). Quality printing is a primary objective during the press run. The press operator will manage and monitor several variables and print attributes.

2.1 Solid Ink Density (SID)

Density is defined as the ability of a material to absorb light, and it is a function of the percentage of light reflected from that material. The reproduction of printed images during the press run is susceptible to tonal and color variations primarily because of the dot size, ink trap and ink film thickness (Hseih, 1997). Generally, the darker a process color is to the eye, the higher the density. Density measurements of solid ink CMYK patches are used to monitor the ink film thickness applied during a press run. Density values indicate to the press operator whether the amount of ink should be increased or decreased (X-Rite, 2003). This solid ink density directly

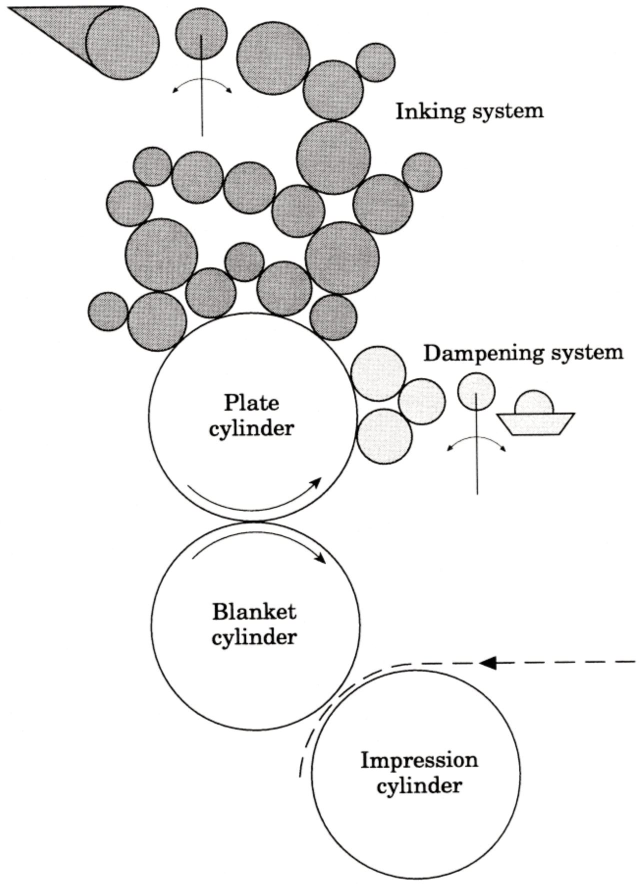

Figure 1: *Schematic Diagram of Offset Printing Unit Design (Courtesy of GATF)*

affects dot gain, print contrast, and apparent trap. Generally, these values will vary as the solid ink density changes. When printing with CMYK inks, it is especially important that the CMYK ink densities are in balance. If ink densities are not in balance, color (hue) of the red, green, and blue (two color overprints) will shift (X-Rite, 2003). Therefore, monitoring solid ink density during a press run is essential when comparing any printed material in terms of quality. The following equation is used by the densitometers to calculate the reflection density (ANSI/CGATS.4-1993, Reaffirmed 1998, p.3).

$$\text{Density}_R = \log_{10}(1/R) \quad (1)$$

where: R = Reflectance

2.2 Calorimetry and Color Gamut

Review of numerous reports reveal that a color gamut is defined as range of colors producible by a device or a color system. The most used definition of gamut in cross-media reproduction system is given by CIE TC 1-42 as “gamut is the total range (scope) of information about color which is possible to reproduce in the given medium under the determined condition of viewing – this is the volume in color space.” A spectrophotometer measures the amount of light reflected from a surface. The result will be a dataset of reflectance values that represents the spectral distribution of the light reflected from the point of the measurement. This means that the starting point will be at 380 nanometers (nm). The spectrophotometer then controls how much of the particular wavelength is reflected. The result will be in terms of percentage value. This procedure is then repeated for the entire spectrum (each wavelength), and the resulting dataset can be visualized as a spectral curve. The visible spectrum normally ranges from 380 nm to 780 nm, and most spectrophotometers sample it every 10th nm (see Figure 2). These data are general and can vary depending on the device being used. When comparing data in colorimetry, it is important to consider both the structure of the device and the illumination source. A spectrophotometer is the most accurate instrument to measure color. The spectral distribution curve can also be used to calculate densitometric and colorimetric values. Spectral response values can be obtained in CIE XYZ and L* a* b* or c* h*scales.

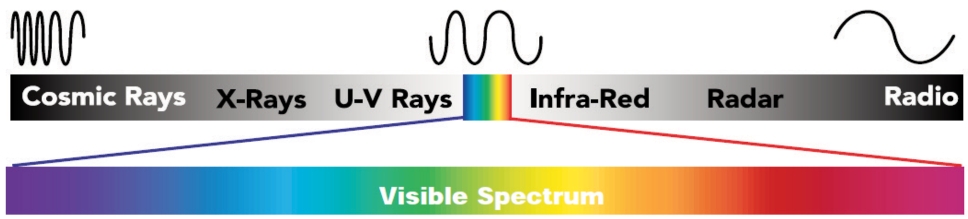

Figure 2: *Schematic diagram of visible spectrum (Courtesy of X-Rite)*

2.3 CIEL*a*b*Color Model

The Commission Internationale de l'Eclairage (CIE), also known as the International Commission on Illumination, is responsible for international recommendations for colorimetric measurements (ANSI/CGATS.5-2003). In 1976, the CIE developed the CIE L*a*b* or CIELAB color model (scale) for quantifying color values numerically. It was intended to provide a standard, approximately uniform color model that could be used by the industry so that color values could be easily compared or expressed (ANSI/CGATS.5-2003). The CIE color model utilizes three coordinates to locate a color in a color model. In a uniform color model, the difference between points plotted in the color model corresponds to the visual differences between the colors plotted (Hunter Lab, 1996). The CIELAB color space is organized in a cube form. The L* axis runs from top to bottom. The maximum for L* is 100, which represents a perfect reflecting diffuser. The minimum for L* is zero (0), which represents black. The +a* and +b* axis have no specific numerical limits. A +a* is an indication of red color and –a* is green color in the color model. Additionally, +b* is yellow and –b* is blue (Figure 3). The center of this model represents the neutral or gray colors. These color scales are based on the opponent color theory of color vision, which means that two colors cannot be both green and red at the same time, nor blue and yellow at the same time. As a result, single values can be used to describe the red/green and the yellow/blue attributes (X-Rite, 2002). The following equations are used by the spectrophotometer to calculate the CIE L* a* b* values (CGATS2003, p. 28).

$$L^* = 116\,(Y/Y_n)^{1/3} - 1$$
$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \quad (5)$$
$$b^* = 200\,[(X/X_n)^{1/3} - (Z/Z_n)^{1/3}]$$

where: X_n, Y_n, Z_n: Tristimulus Values of XYZ for 2° Standard Observer

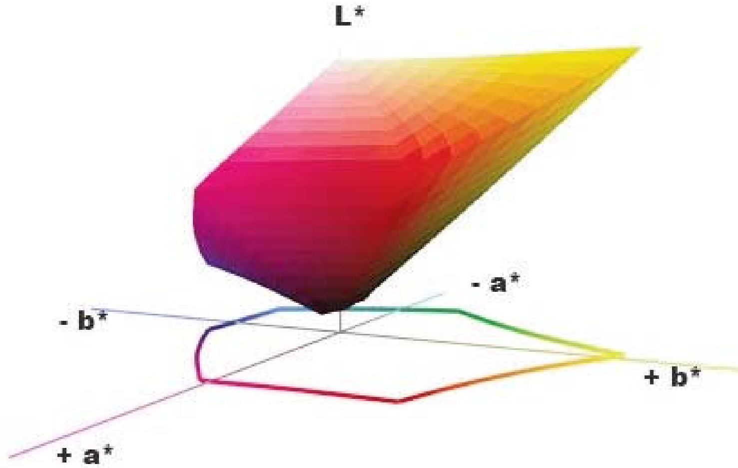

Figure 3: *Schematic Diagram of CIE L* a* b* Color Model*

2.4 CIE Color Difference (ΔE)

Assessment of color is more than a numerical expression. In most cases it is an assessment of the deviation in the color sensation (delta) from a known standard. In CIELAB color model, any two colors can be compared and differentiated. These color differences are expressed as ΔE (Delta E or Difference in Color Sensation). The following equation is used to calculate the ΔE (ANSI/CGATS.5-2003, p.29).

$$\Delta E^* = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \quad (6)$$

where: 1= Color 1 and 2 = Color 2

3. Purpose of Research

The purpose of this experimental research was to analyze and identify the significant differences that exist in the color gamut of printing ink sequence (KCMY vs. YMCK) of multicolor offset printing.

3.1 Limitations of Study

The print characteristics associated with the KCMY vs YMCK images are characterized by, but not restricted to, inherent limitations; for example: type of printing process, type of paper, type of ink, etc. There are several variables affecting the facsimile reproduction and most of them are mutually dependent on each other. The scope of the research was limited to the offset (lithography) printing systems and materials used at the University of Wisconsin-Stout's graphic communications laboratory, and the findings were not expected to be generalizable to other printing environments. Color gamut's of KCMY vs. YMCK were analyzed (or compared). The research methodology, experimental design, and statistical analysis were all selected in alignment with the purpose of the research with full awareness of the aforementioned delimitations. It is quite likely, however, others could find this study meaningful and useful.

4. Research Method

An experimental research method was adopted for this study. The method required two parts: pre-press and press. This method is summarized in the following paragraphs.

4.1 Prepress

A layout was created for a 17.5" x 23" press sheet utilizing a custom Four-Color target. The target contained the following elements: KCMY tone- scale, RGB overprints, IT8.7/4 image with 1638 patches, P2P25X image, color control bars, and other custom multi-color images. During the printing, these elements are used to evaluate the subjective and objective aspects of the image quality (see Figure 5). The layout was processed through Prinergy Evo Raster Image Processor (RIP). The layout was output using a conventional halftone screen at 175 lines per inch (LPI), with elliptical dot shape by using the Creo Trendsetter Computer to Plate (CTP) device and two sets (KCMY and YMCK) of linear CMYK (four) offset plates were made, each set for a each ink sequence. Linear plates were made by not using the previous dot compensation curve at the RIP in order to have input dots equal to output dots. Output dot values on the plates were measured and recorded for the plate curve (see Figure 4) by using Troika LithoCam plate dot reader via LithoCam 2.5 interface application. Table 1 presents the variables, materials, conditions, and equipment associated with the prepress and press areas of this experiment.

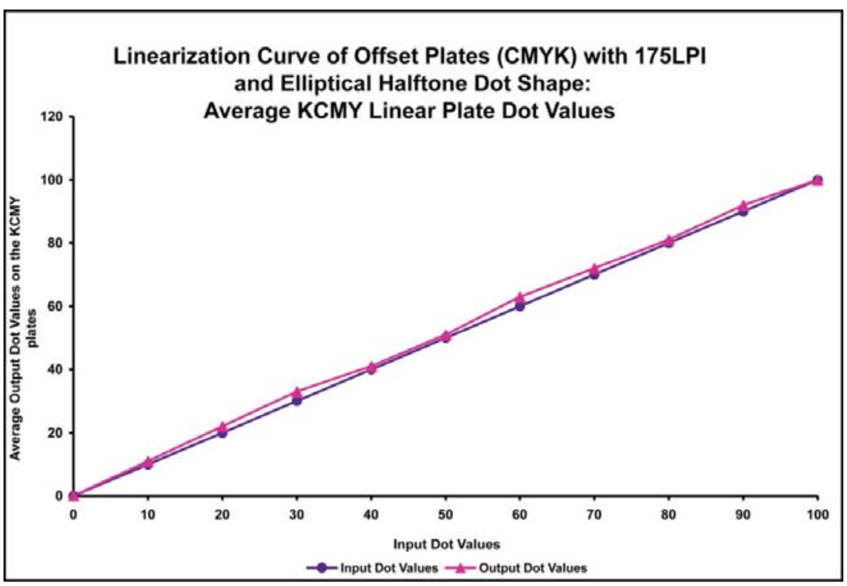

Figure 3: Schematic Diagram of CIE L a* b* Color Model*

4.2 Press

After the plates were made for the KCMY and YMCK printing sequence, a pilot test was conducted to achieve the target ink density values according to GRACol standards. During the pilot test of KCMY printing, 500 sheets were printed. These 500 sheets of printing were only to bring the SID values to a standard level. Once density values had been achieved according to the standard ink density (SID) values, the press was run continuously without operator interference and another 100 (N) test sheets were printed, from which a total of 80 (n) sheets were randomly selected for the analysis. The machine (ink/printing units) was cleaned for the second run of printing YMCK. The same procedures were applied for printing of second press run (YMCK). Table 1 presents the variables, materials, conditions, and equipment associated with the prepress and press parts of this experiment.

Variable	Material/Condition/Equipment
Test Image	GCM Custom 17.5" x 23" Four-Color (CMYK)
Page Layout	Adobe In Design CS-5
RIP	Prinergy EVO 5.1.00
CTP	Creo Trendsetter 400 Quantum
Plate	Kodak SWORD Digital Thermal
Plate Processor	Kodak Polychrome
Plate Chemistry	Kodak Polychrome Developer and Fixer
Dot Reader	Troika LithoCam
Dot Reading Application	LithoCam 2.5.4
AM Screen Line Ruling	175 LPI
AM Screen Dot Shape	Elliptical Dot
AM Screen Angles	C = 105°, M = 45°, Y = 90°, & K = 75°
Target SID values (+/- 0.10)	K = 1.30, C = 1.15, M = 1.15, and Y = 0.90
Achieved average SID values (+/- 0.10)	K = 1.30, C = 1.15, M = 1.15, and Y = 0.90
Paper (Substrate)	Unisource 80 LBS. Matte-coated
Solvent-based ink	Flint Sheetfed Solvent Offset Process Colors
Press	Heidelberg SM-74 Four Color
Press Speed	6000 IMPH
Blanket to Impression Pressure	0.04 to 0.10 mm
Ink Sweeps (KCMY)	53, 53, 55, and 52
Dampening Solution	RBP Fountain Solution
Dampening Solution PH	4.5
Dampening Sweeps (KCMY)	6
On-Press SID Measurement/Control	TECHKON SpectrDrive Scan Spectrophotometer
Data Collection	EyeOnePro with iO-Table
Press Operator(s)	Lab Manager and Students
Data Collection and Analysis Software	MS-Excel, MeasureTool, ColorShop X
Profile Creation	ProfileMAker 5.10.00
Profile Inspection	ColorThinkPro by Chromix

Table 1: *Prepress and Press: Experimental and Controlled Variables*

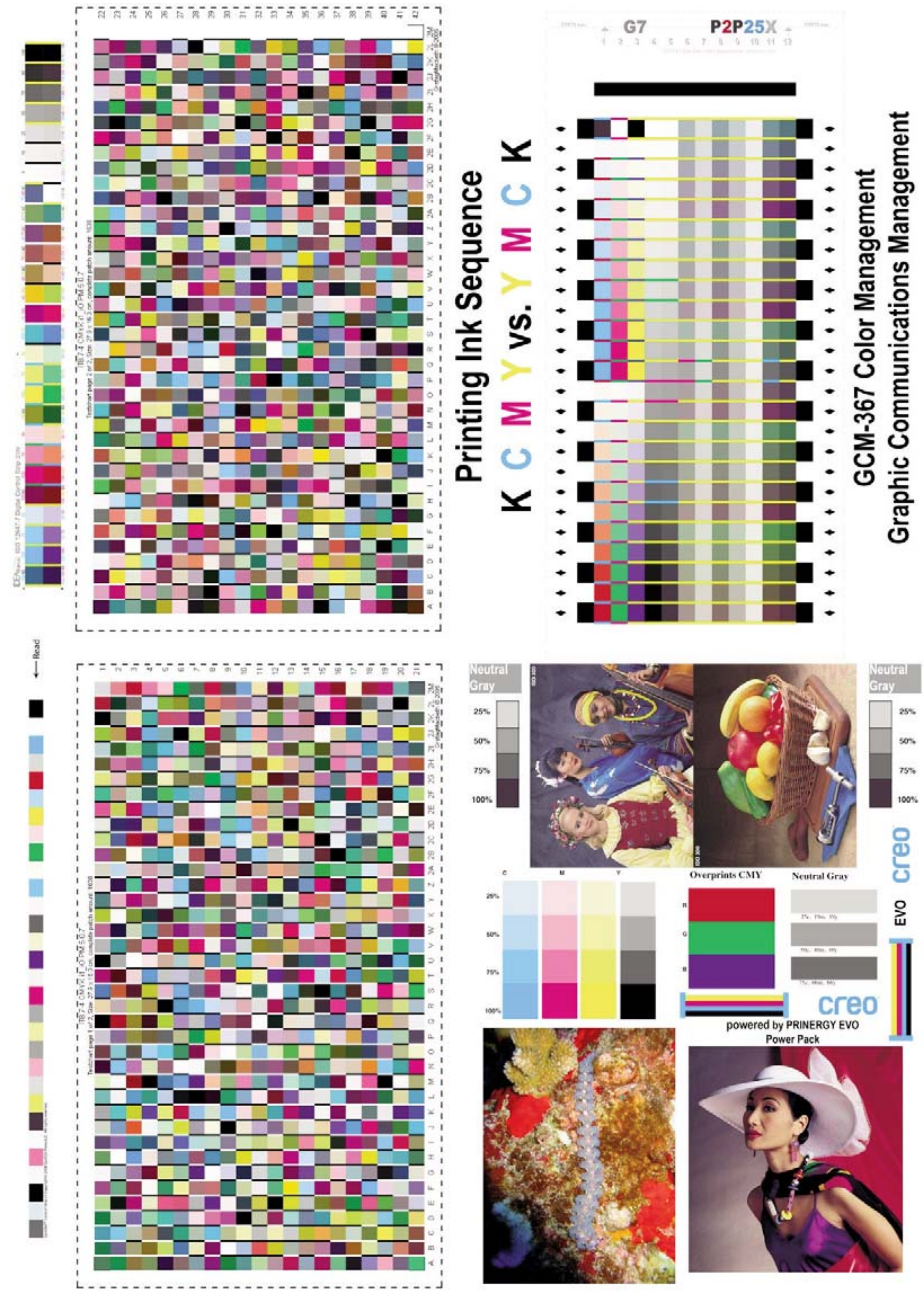

Figure 5: *Custom 17.5" x 23" Four-Color (CMYK) Test Target*

The sample size was selected in order of the specific confidence interval ($\alpha = 0.05$). A random sampling technique was used to identify the sample size because of the large size (N = 100) of the total population. During the printing, a Techkon SpectroDrive Spectrophotometer was used to control the solid ink density on the press. After the printing, an X-Rite EyeOne-Pro spectrophotometer was used to collect the colorimetric data from the sample. Glass, G.V. & Hopkins, K.D. (1996), provides an objective method to determine the sample size when the size of the total population is known. The total population for this study was 100 (N) printed sheets. The following formula was used to determine the required sample size, which were 80 (n) printed sheets for this study.

$$n = \chi^2 NP (1-P) / d^2 (N-1) + \chi^2 P (1-P)$$

where: n = the required sample size

χ^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.84)

N = the total known population size

P = the population proportion that it is desired to estimate (.50)

d = the degree of accuracy expresses as a proportion ($\alpha = 0.05$)

Of the 100 (N) printed sheets for each ink sequence (KCMY and YMCK), 80 (n) sheets were pulled randomly for the analysis. For KCMY ink sequence, all the 80 sheets were measured for the colorimetric analysis. Data of colorimetric values were extracted by using EyeOne-Pro and iO-Table with MeasureTool as an interface application. A total 80 data files were saved. The data files consisted of measured CIE L* a* b* values of IT8.7/4 (1638 patches) test image. With the use of all these 80 files, data was averaged into one data file by using the “average” option from the MeasureTool. The average data file was run through the ProfileMaker 5.10 application in order to create the color gamut (or .ICC profile) of the KCMY printing sequence. The same procedures were applied to 80 printed sheets from printing ink sequence of YMCK. Analyzed colorimetric data of both printing sequences (KCMY vs. YMCK) were presented in the following section.

5. Data Analysis

A total of 80 randomly selected samples (printed sheets) were analyzed for each set of printing ink sequence (KCMY vs. YMCK). Using an X-Rite EyeOne-Pro the printed sheets were measured to generate the colorimetric data. Descriptive and colorimetric were the statistical procedures used to analyze the data. In comparing the differences between two ink sequences (colors), a higher ΔE indicates a greater color variation while a lower ΔE is an indication of less color variation. However, the subjective judgment of color difference could differ from person to person. For example, people see colors in an image, not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003). In addition, people see colors by mentally processing contextual relationships among colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (A New Test Method, 2003). The results of analysis are presented in the following section.

5.1 Color Gamut Analysis

Two color gamuts (ICC profiles) of ink sequences KCMY vs. YMCK were analyzed. An IT8.7/4 image consists of 1638 colored patches. In comparison, the average ΔE between the two gamuts were found to be ΔE 7.50. The color gamut volume, a volume in CIE L* a* b* space, can be interpreted as the number of colors that can be discernable within the tolerance of ΔE = √3. Thus the highest number of colors that could be produced by the KCMY ink sequence was 369, 474, while with the YMCK sequence was 381, 843 colors. The larger gamut volume resulted from YMCK printing ink sequence. It is only a numeric indication of higher gamut volume. Gamut volume reveals only the size of the gamut, not the shape. In order to determine the shape of the gamut visual assessment is required (Figure 6).

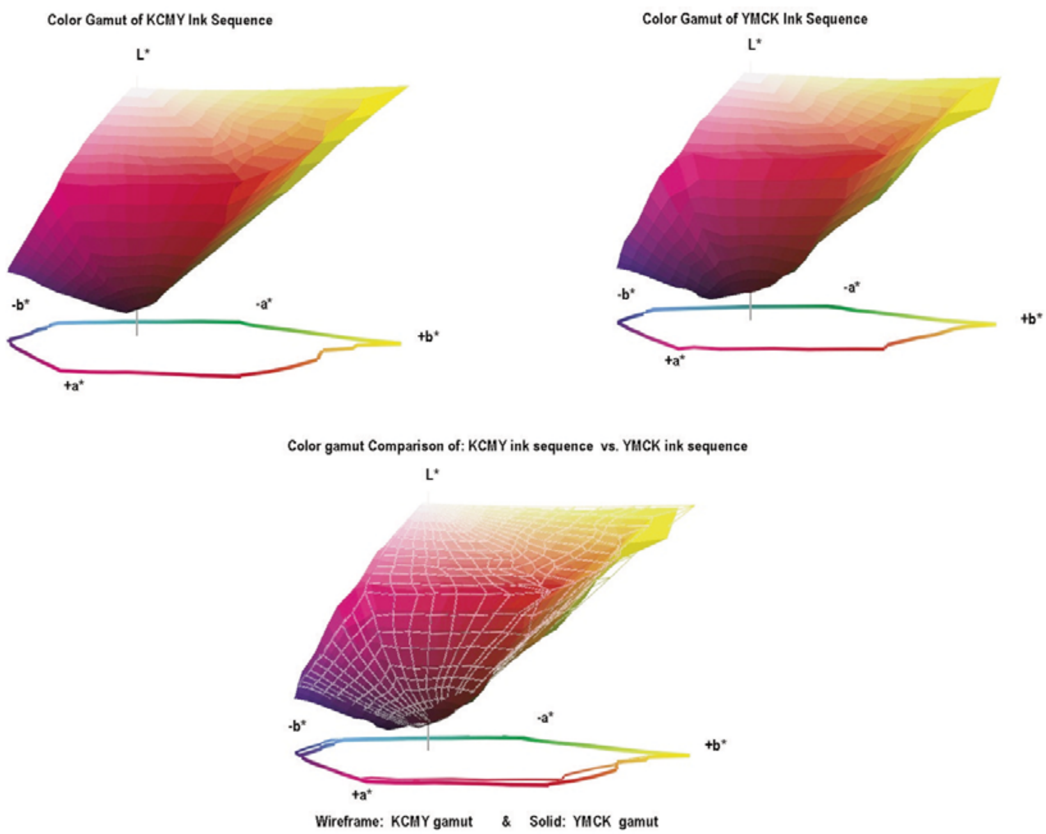

Figure 6: *A 3D Visual representation of Color gamut's of KCMY vs. YMCK ink sequence*

6. Summary/Conclusions

The conclusions of this study are based upon an analysis of the data and major findings. The findings of this study represent specific printing or testing conditions. The technologies, paper, ink, dampening solution, and plate imaging system, and printing process that were used are important factors to consider when evaluating the results. The findings of the study cannot be generalized to other printing conditions. However, others may find this study generally meaningful and useful. In this study, no solid colors (KCMY vs. YMCK) were compared. Outcome of overlap of solid process colors were compared. Also, printed images were evaluated based on the visual assessment (subjective judgment).

Ink trap of magenta and yellow (red color) in the printing sequence of KCMY was 54%, while the higher trap (62%) was resulted for the same color in the printing sequence of YMCK. No significant trap differences were found in the remaining overlap of colors for green and blue between the two printing sequences.

L* a* b* values of neutral gray balance (overlap of CMY at highlights, mid-tones, and shadows) of both printing ink sequences were used to examine the significant differences that exist, as these gray balance patches were made up of halftone dots or screened tint percentages. The gray balance of both ink sequences revealed significant differences. In comparison (KCMY vs. YMCK), at a quarter-tone gray area ΔE 5.41 was found, at mid-tone area ΔE 12.62, and at a shadow area ΔE 16.03 was found. The ΔE values indicated that overlap of CMY inks have significant effect on producing neutral gray balance. Visual assessment concluded that there were no significant differences.

The findings of this research, comparing color gamut volume of KCMY vs. YMCK ink sequences, reveals that there is no significant major difference of which ink sequence is better over the other. However, in comparing, the YMCK sequence gamut consists of higher gamut volume, and smoother gamut shape than the KCMY sequence. The findings make it difficult to draw conclusions regarding dot gain, because each printing sequence was executed by using the same printing conditions (press, paper, inks, etc.). Further study is needed to attempt greater control of variables. A more deliberate process of press calibration would also be recommended in a future study of this topic. Qualitative analysis may also be pursued. A panel of experts may be utilized to provide qualitative analysis regarding their preference for one sequence over the other.

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