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By Dr. H. Naik Dharavath

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Dr. Dharavath is an Associate Professor of Graphic Communications Management at the University of Wisconsin-Stout. He received a Bachelor of Science in Graphic Communications Technology from Rochester Institute of Technology (1995), a Master of Technology in Graphic Communications from Arizona State University (1998), and a Ph.D. in Applied Science and Technology Education from University of Wyoming (2002). Dr. Dharavath teaches Graphic Communications/Electronic Publishing and Postpress/Distribution Operations Management courses. In addition to teaching, he advises UW-Stout TAGA Student Chapter, which received the First Place Award for overall quality of Non-Print Edition of the Student Journal in 2004. His research interest in Graphic Communications Technology includes Print Manufacturing Management, Curriculum Development, Educational Program Evaluation and Assessment, and Print Quality Management (Color Management, TQM/SPC, and Colorimetric Analysis).

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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 a continuous tone 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 were 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 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, only the SID was used to examine the significant difference that exists in the day-by-day leading national daily newspaper over a period of time (25 days). Also, color variation was examined by comparing the actual color CIE L* a* b* values to the NAA standard CIE L* a* b* values.

Purpose of the Research

The purpose of this research was to analyze the newsprint color reproduction within the Newspaper Association of America Solid Ink Density (SID) and Cyan, Magenta, Yellow, Red, Green and Blue (CMYRGB) Gamut Standards. The following questions were investigated.

1 Is there a difference (variation) in the SID values (CMYK) of the printed newspaper vs. NAA SID (CMYK) Standard values?
2. Is there a difference (variation) in the Average and Range SID values (CMYK) of the printed newspaper over a period of time (25 days)?
3. Is there a color (CMYKRGB) difference (variation) of the printed newspaper CIE L* a* b* values vs. NAA color (CMYRGB) Standard CIE L* a* b* values?

Limitations of the Study

The print characteristics associated with printed newspaper are characterized by, but not restricted to, inherent limitations; for example: type of printing process, type of substrate, type of ink, etc. There are several variables affecting the facsimile reproduction of newspaper color and most of them are mutually dependent on each other. The scope of the research was limited to the offset (lithography) printing systems and instruments and data collection techniques used at the University of Wisconsin-Stout's graphic communications laboratory, and the findings were not expected to be generalizable to other printing environments. Only the print attributes that utilize solid ink patches were examined, as it is an important attribute that represents overall color coverage in the printing. 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. The NAA and others would find this study meaningful and useful.

Review of Literature

The Newspaper Association of America (NAA) is a nonprofit organization representing the US $55 billion newspaper industry. It was established in 1992. NAA members represent nearly 90 percent of the daily newspaper circulation in the United States (U.S.) and a wide range of non-daily U.S. newspapers (NAA, 2006)

In 2005, NAA published the Specifications for Newsprint Advertising Production (SNAP). It was developed by a committee formed by the NAA to develop a document containing general guidelines and recommendations that could be used as a reference source across the newspaper industry for quality printing (SNAP, 2005). The SNAP standards provide a broad spectrum of recommendations and standards regarding the production of newsprint production (SNAP, 2005). It consists of guidelines and charts giving aim points and tolerances for a variety of print attributes (SID, CIE L* a* b*, DG, and PC). Print attributes are defined as the individual characteristics within the printing process that can be measured and monitored during the production so as to maintain the quality consistency. The most commonly monitored print attributes, and the ones concentrated on by the researchers, include solid ink density, CIE L* a* b* values, dot gain, and print contrast (Lustig, 2001). Stanton & Hutton (1999) stated that some attributes are not monitored because they are not readily measurable. SNAP standards are limited to coldset web offset reproduction on uncoated groundwood paper only (SNAP, 2005). A majority of the newspapers in the country are printed by using the coldset offset printing process (NAA, 2006)

Offset Printing Process

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.

Densitometric Measurements

A densitometer is a scientific instrument which is designed to determine, indirectly, the light absorbed by a surface (Brehm, 1992). There are two types of densitometers: transmission and reflection densitometers. Transmission densitometers measure the amount of light that is transmitted through a transparent material such as a halftone film or color negative. Reflection densitometers measure the amount of light reflected from printed material or continuous tone photographs (Brehm, 1992). In the prepress and printing/press areas of the industry, densitometry allows us to find a balance for accurate tone reproduction. Hseih (1997) stated that a densitometer can measure either incident light reflected from a substrate (reflection density), light transmitted through a film (transmission density), or both. In prepress and printing/press areas, the Status T densitometers have been used extensively for measuring densities. Status T is the ANSI/ISO (American National Standard Institute/International Organization for Standardization) standard for wideband densitometer response for measuring print attributes (Brehm, 1992). These instruments are important quality control tools for the industry. In the printing/press area, a reflection densitometer allows us to measure characteristics of print attributes such as solid ink density, ink trap, dot gain, print contrast, gray balance, etc. In the prepress area, a transmission densitometer allows us to measure halftone film density and dot area values, which are used to linearize the filmsetter (see Figure 2).

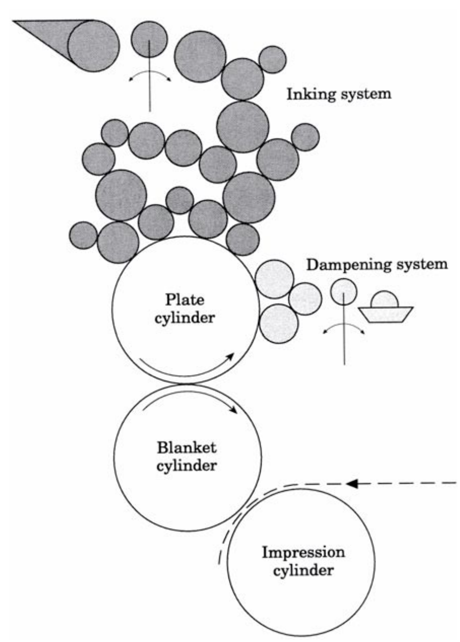


Figure 1: Schematic Diagram of Offset Printing Unit Design (Courtesy of GATF)

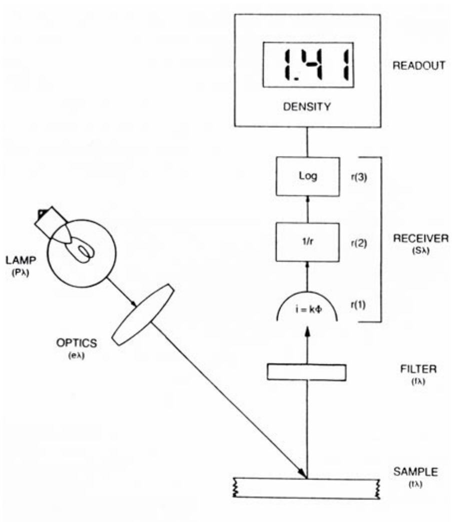


Figure 2: Schematic of a Densitometer (Courtesy of GCA)

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 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).

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

where: R = Reflectance

Colorimetric Measurements

A spectrophotometer measures the amount of light reflected from a surface. The result will be a dataset of reflectance values that represent the spectral distribution of the light reflected from the point of the measurement. This means that the starting point will be at 380 nanometer (nm). The spectrophotometer then controls how much of the particular wavelength is reflected. The result will be a percentage value. This procedure is then repeated for the entire spectrum and the resulting dataset can be visualized as a spectral curve. The visible spectrum is normally considered to range from 380 nm to 780 nm and most spectrophotometers sample it every 10^{th} nm. These data are of course general and can vary depending on the device being used. When comparing data in colorimetry, it is important to consider the structure of the device as well as the illumination source. A spectrophotometer is the most accurate instrument to use when it comes to color measurement. 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* scales.

Hue, Chroma, and Lightness

Each color has its own distinct appearance based on three elements: hue, chroma or saturation, and value or lightness (X-Rite, 2002). By describing a color using these three attributes, one can accurately identify a particular color and distinguish it from any other. When asked to identify the color of an object, you'll most likely speak first of its hue. Quite simply, hue is how we perceive an object's color — red, orange, green, etc. (X-Rite, 2002). Chroma or saturation describes the vividness or dullness of a color — in other words, how close the color is to either gray or the pure hue. For example, think of the appearance of a tomato and a radish. The red of the tomato is vivid, while the radish appears duller (X-Rite, 2002). The luminous intensity of a color — i.e. its degree of lightness — is called its value. Colors can be classified as light or dark when comparing their value. For example, when a tomato and a radish are placed side by side, the red of the tomato appears to be much lighter. In contrast, the radish has a darker red value (X-Rite, 2002).

CIE L 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 differences between points plotted in the color model correspond 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 indication of red color and –a* is green color in the color model. Additionally, +b* is yellow and –b* is blue (see 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 (ANSI/CGATS.5-2003, p.28).

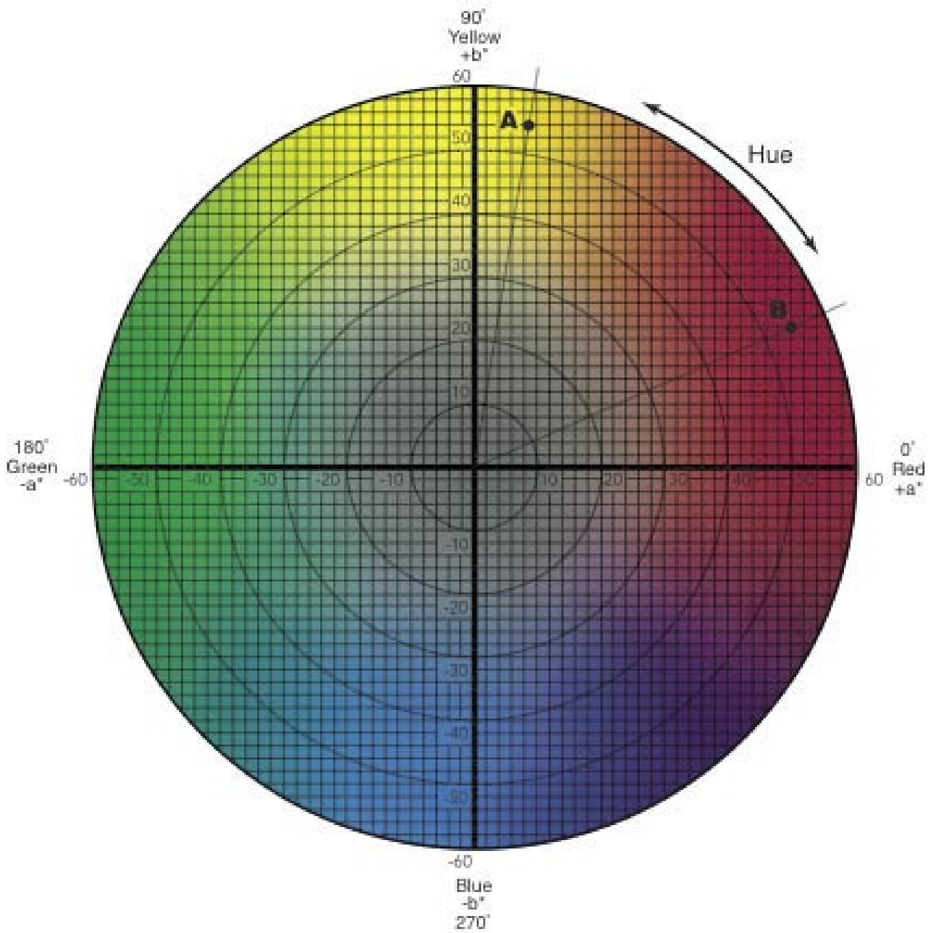


Figure 3: Schematic Diagram of CIE L a* b* Color Model (Courtesy of X-Rite)*

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

$$a^* = 500 [(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$

$$b^* = 200 [(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

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

CIE Color Difference (ΔE)

Assessment of color is more than a numeric expression. Usually it's an assessment of the difference in the color sensation (delta) from a known standard. In CIELAB color model, two colors can be compared and differentiated. The expression for these color differences is 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)

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

where: 1 = Color 1 and 2 = Color 2

Application of Control Charts in the Newsprint Color Reproduction

A control chart is the best tool for determining whether a process is in-control or not in control. An in-control process is one that lacks "assignable causes" or "special causes" of variation. This means that the processes output will be consistent over time. This is not to say that the process will be capable of meeting your needs or your customer's expectations, just that the results will be relatively consistent (Blevins, 2001).

Good color reproduction in the newspaper industry requires consistency in the pressroom. Accurate color reproduction is dependant upon several factors. One of the factors is the CMYK ink density. To achieve acceptable printing results, it is important to establish density aim points (density target values or control limits of the process) and monitor the aim points consistency during the whole press run. With the use of a specific process control techniques, one can determine if the consistency is in-control or not in control. If the average density and range of the process fall between the UCL x-double bar/UCL r and LCL x-double bar/LCL r, the process is said to be within the specific process control. Conversely, if the density is outside the upper and lower boundaries, they would be out of control (Blevins, 2001).

Research Method

This research utilized an experimental research method. The purpose of this research was to analyze the newsprint color reproduction within the NAA Solid Ink Density (SID) and Cyan, Magenta, Yellow, Red, Green and Blue (CMYRGB) Gamut Standards. A leading national daily newspaper was selected for the analysis. Everyday, one sample of the same titled newspaper was pulled and kept aside to analyze. A total of 25 daily newspapers of the same title were collected over a period of 25 days.

An X-Rite DTP-22 Spectrophotometer was used to collect the CIE L* a* b* values from the CMYKRGB colors printed on the newspaper. Gretag D19C Densitometer was used to collect the SID values from the CMYKRGB colors printed on the newspaper. Table 1 presents the variables, materials, conditions, and equipment associated with this experiment (see Table 1).

Data Analysis and Research Findings

A total of 25 selected printed newspaper samples were analyzed. Data was generated by using an X-Rite DTP 22 and Gretag D19C instruments to measure both SID and CIE L* a* b* values. Descriptive, Control Charts Statistical techniques and Colorimetric computations were used to analyze the data. Analyzed results are presented in the following section.

SID Average Variation

The control limit (CL x-double bar), upper control limit (UCL x-bar) and lower control limit (LCL x-bar) values associated with the SID (CMYK) average variations of the newspapers are compiled in Table 2. Differences were found in the SID values of printed colors when comparing with the NAA standards. Printed colors CMK average SID values were lower than the NAA standards. However, yellow color density value is almost equal to NAA standard yellow color SID.

Newsprint printed colors do not match with the NAA standards. However, the SID average variations of CMYK printed colors over a period of time are in control. It suggests that the newspapers were produced with consistent SID density values every day (see Figures 4 to 7).

SID Range Variation

The control limit (CL r-bar), upper control limit (UCL r) and lower control limit (LCL r) values associated with the SID (CMYK) range variation of the newspapers are compiled in Table 3. The SID range variations of CMYK printed colors over a period of time are in control. It suggests that the newspapers were produced with consistent SID density values every day (see Figures 8 to 11).

Newsprint Printed Color Gamut vs. NAA Standard Color Gamut

An X-Rite DTP 22 Spectrophotometer was used to collect the CIE L* a* b* (spectral response) values from CMYKRGB colors. Newsprint printed colors average CIE L* a* b* values (color 1), NAA Standard CMYRGB color CIE L* a* b* values (color 2), and ΔE between the two colors are compiled in table 4.

In comparing the color differences between two colors, a higher ΔE is an indication that there is a more color variation and lesser the ΔE is an indication of less color variation. However, the subjective judgment of color difference could differ from person to person. For

Table 1. Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Product	National Daily Leading Newspaper
NAA Standard SID values	K = 1.05, C = 0.90, M = 0.90, Y = 0.85
Actual Printed average SID values	K = 0.81, C = 0.67, M = 0.79, Y = 0.87
Substrate	Newsprint Uncoated
Printing Process	Coldset Web Offset
Print Measurement Control	X-Rite DTP-22 Spectrophotometer, and Gretag D19C Densitometer
Type of Filtering	Wideband Status T
Angle	2° Standard Observer
Data Analysis Software	X-Rite ColorShop X, Quick Read and MS-Excel

Table 2. Solid Ink Density Average Variation

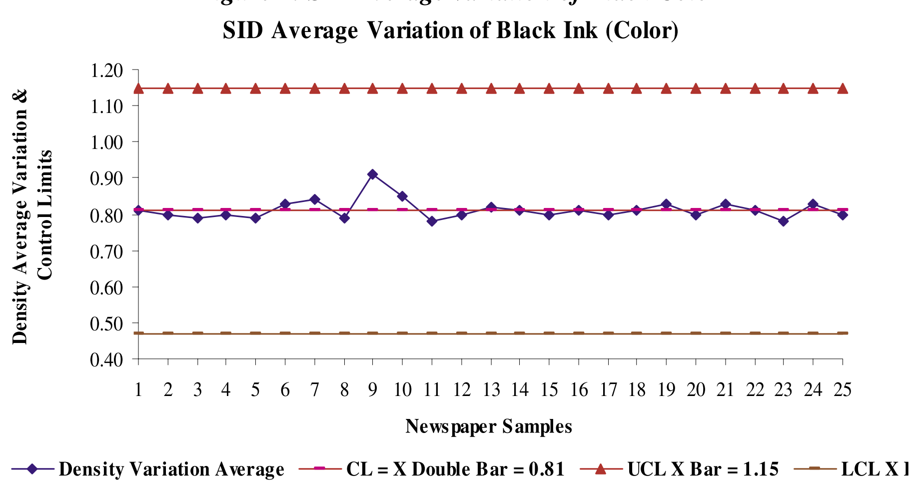
Color	NAA Density Standards	Printed Newspaper Values $CL_{X\ double\ bar}$ N = 25	$UCL_{X\ bar}$ N = 25	$LCL_{X\ bar}$ N = 25
Black	1.05	0.81	1.15	0.47
Cyan	0.90	0.67	1.40	0.03
Magenta	0.90	0.79	1.32	0.26
Yellow	0.85	0.87	1.33	0.41

Source for NAA Density Standards: SNAP, 2005 (Tolerance +/- 0.10)

Table 3. Solid Ink Density Range Variation

Color	Printed Newspaper Values CL_{r-bar} N = 25	UCL_r N = 25	LCL_r N = 25
Black	0.33	0.86	0.00
Cyan	0.71	1.83	0.00
Magenta	0.52	1.34	0.00
Yellow	0.45	1.16	0.00

Figure 4: SID Average Variation of Black Color



example, we see colors in an image not by isolating one or two colors at a time. We see colors by mentally processing contextual relationships between colors where the changes in lightness (value), hue and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image.

The NAA states that ΔE tolerance of +/- of 5.00 between the NAA standard CIE L* a* b* values and printed CIE L* a* b* values for each color (CMYRGB) is acceptable (SNAP, 2005). In this case, printed colors cyan and magenta produced a higher ΔE. This indicates that there is a noticeable color difference. Also, there is a difference in the overprint colors of RGB. This could be because of press condition, paper and ink (see Figure 12).

Applications, Conclusions and Discussion

This study was based on the preprinted samples that were collected over a period of 25 days. The conclusions of this study were based upon an analysis of the data and major findings. The findings of the study cannot be generalized to other printing conditions. However, others may find this study meaningful and useful. The findings of this research, comparing NAA standard color gamut vs. printed newspaper color gamut were in close match. The SID of CMYK colors average and range variations are within the control limits of the process. However, there is a fluctuation of average and range density levels day-by-day in all CMYK colors. This can be due to several technical and non-technical variables, such as press speed, ink, instrument error, etc.

Of the CMYKRGB colors, some of the printed colors values (SID and L* a* b*) do not match with the NAA standards. NAA standards were based on thousands of sample newspapers, and the values were obtained from the wet ink density. This research utilized a small number of samples to confirm the known standards (NAA standards). The values were derived from the dry ink density. This could have led to a significant decrease in the values collected in

Figure 5: SID Average Variation of Cyan Color

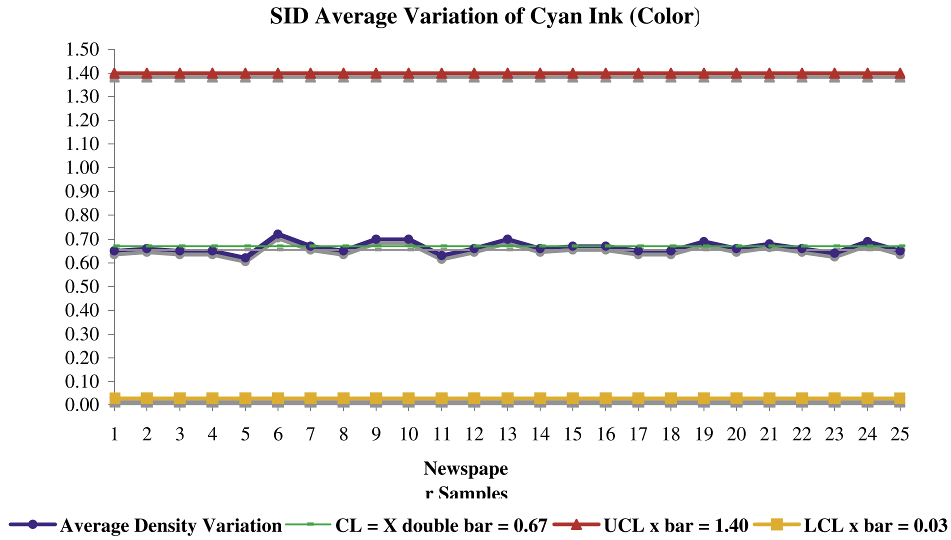


Figure 6: SID Average Variation of Magenta Color

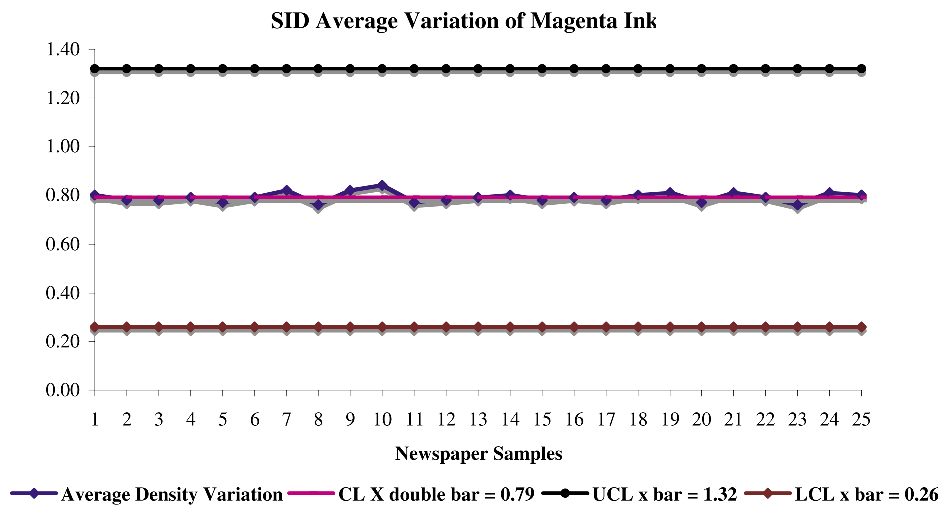
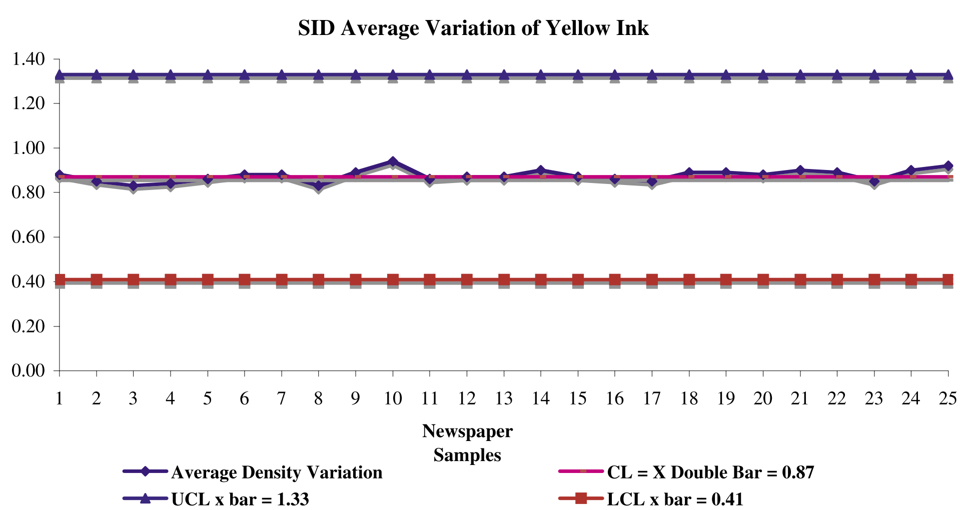


Figure 7: SID Average Variation of Yellow Color



the experiment.

The primary goal of the research reported here was to compare the newsprint color values with NAA standard color values. Previous studies show that newspaper industry often struggled to maintain the quality, largely due to the production difficulties inevitably associated with the printing process and printing newspapers at multiple locations. The findings of this study represented specific printed samples: i.e. the substrate, ink, plate imaging system, and printing process that were used were important factors to consider when evaluating the results. A newspaper publisher that tries to print according to NAA standards to achieve higher quality will be required to evaluate their production equipment, raw materials, and staffing capabilities. The ability to produce quality newsprint color reproduction encompasses many different areas of expertise in computers, scanning, image editing, ink control and pressroom skills. Also, a periodic evaluation of newsprint color reproduction is needed in order to determine whether or not the product is meeting the NAA standards. This study illustrates how to evaluate printed newspapers to determine the quality of color reproduction. Previous research studies also show that only a handful of newspapers, such as the New York Times, the Oregonian, USA Today, Washington Post, and the Wall Street Journal are very successful in meeting the quality standards. The success of these companies is based on the careful periodic evaluation of the quality of their products.

Managing and controlling color from a wide range of input devices (digital cameras and scanners) to multicolor output devices (digital printers and printing presses), are major concerns for the graphic communications and imaging industries. Accurate or facsimile color control from beginning to end in a printing or imaging process is important for quality output (display or printed). Advancements in science and engineering in the recent years, allow printing and imaging professionals to apply scientific applications in the

Figure 8: SID Range Variation of Black Ink

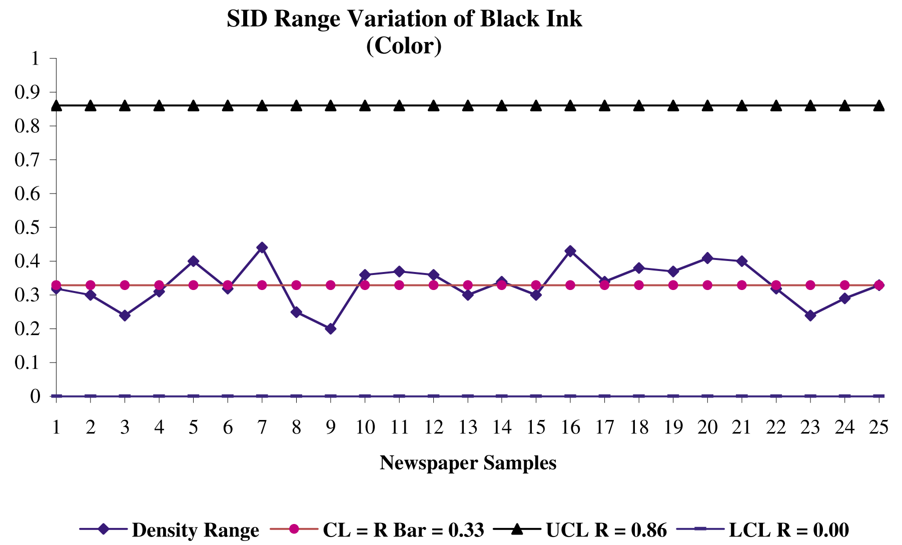


Figure 9: SID Range Variation of Cyan Ink

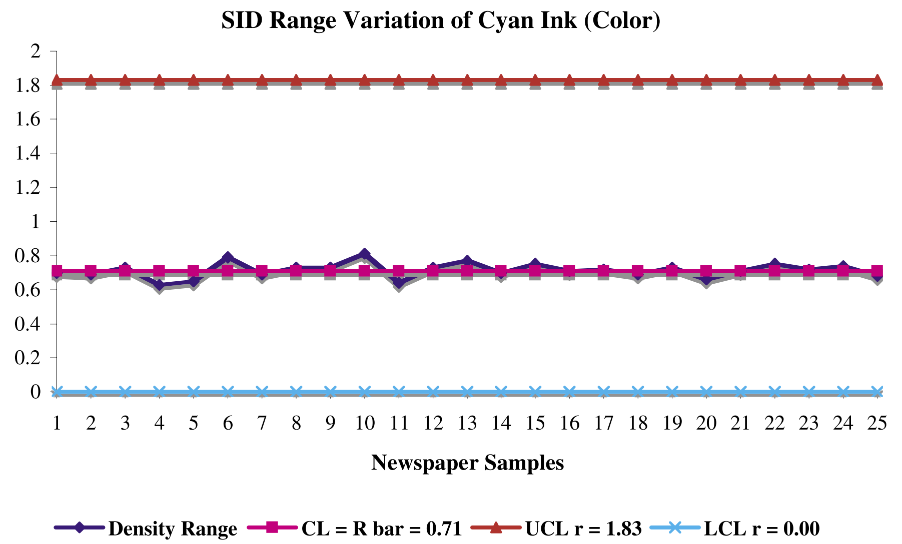
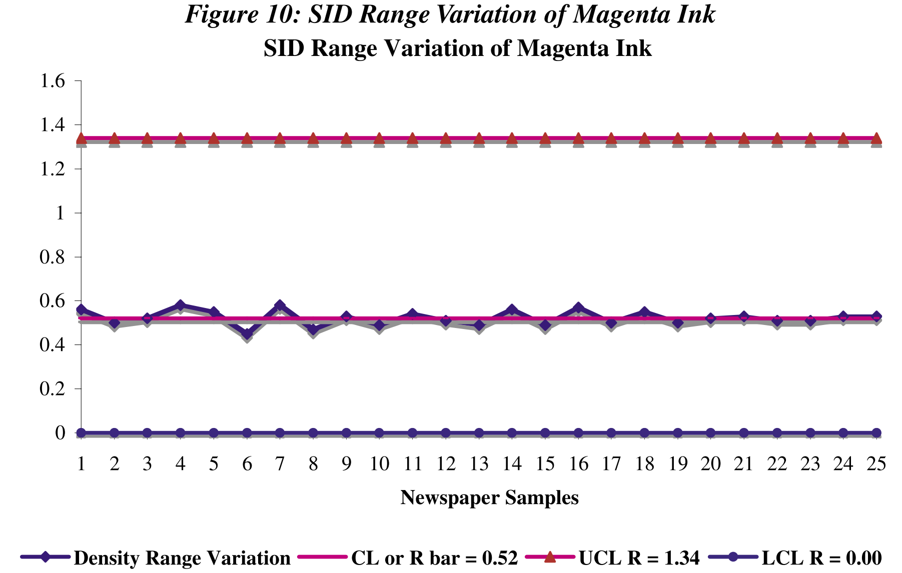


Figure 10: SID Range Variation of Magenta Ink



prepress, pressroom and quality control areas of the industry. Modern printing technology has evolved from the craft oriented field to more of a color imaging science. This allowed the industry to control the color between the various devices more accurate than before. The study of color is a science and the optical aspects of color only are quantitatively analyzable and measurable. The human eye perceives color more subjectively. It is true when determining the color capabilities of different input (scanners or digital cameras) and output devices (monitors, printers, and presses). These devices produce colors differently because they depend on their own color capabilities. Previous research shows that it is impossible to match original color to reproduced color.

Final subjective or objective judgment of color occurs once the job is printed. Prior to the final printing, a specific job would go through several production steps. There are several variables affecting the facsimile reproduction of newspaper color and most of them are mutually dependent on each other. Subjective evaluation of this newspaper is acceptable. Printed colors have pleasing effect on the reader. The findings of this research show that the printed colors are in close match with acceptable tolerances for CMYKRGB. The researcher is not in a position to decide whether the printer should print their newspaper or not because they are not matching 100% with the standards. Though, this newspaper is not matching 100% with NAA standards, the colors printed on the newspapers are consistent day-by-day. That indicates it is a quality newspaper and it has its own set of standards throughout the process. Accurate application of color to colored printed images sells the printing. Color attracts readers. A majority of the newspaper advertisement inserts are printed in color. Previous research studies shows that advertisement inserts printed in colors lead to greater likings for the advertisements, and this feeling is mediated by the greater feelings of relaxation elicited by the higher value of color. In the recent years, improvements in newspaper color printing have made it possible for newspapers to offer quality color printed advertisements. The most difficult task of this experiment has been the ability to collect reliable measurements from the preprinted samples. The density level in the newsprint varies frequently due to several technical and non-technical factors. This made it impossible to obtain accurate data values that match with NAA standards.

Figure 11: SID Range Variation of Yellow Ink

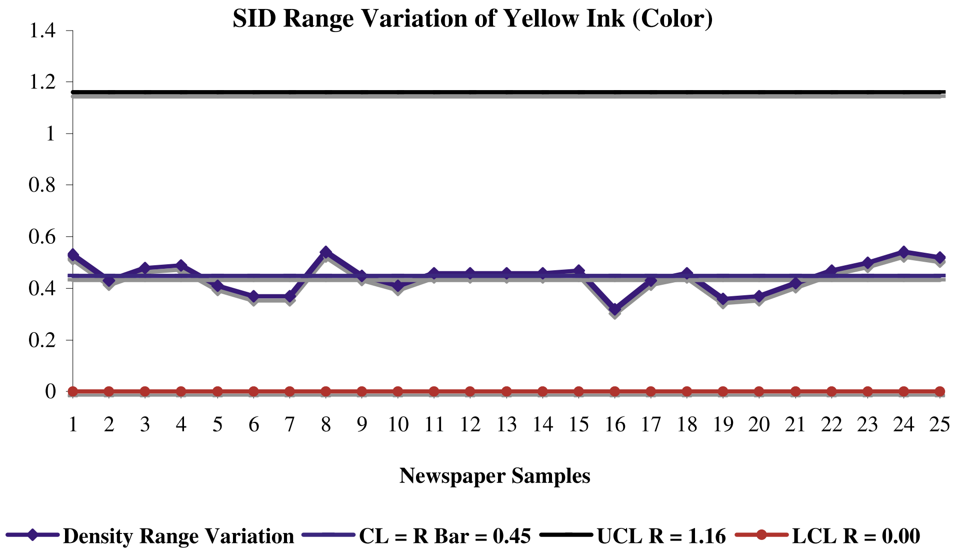


Figure 12: CIE L a* b* Model for Color Comparison*

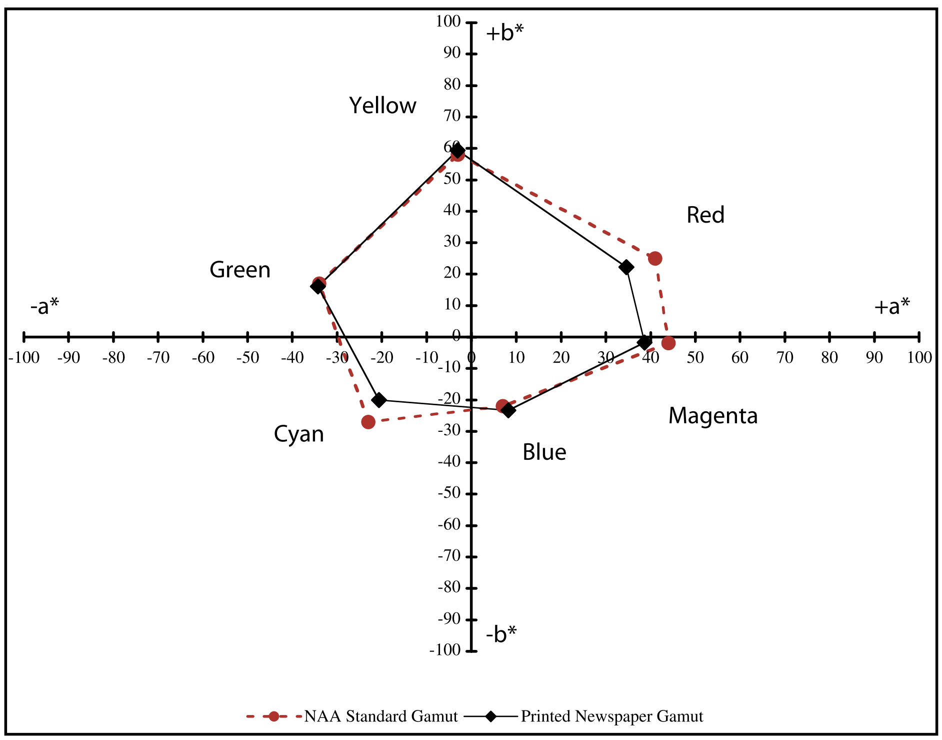


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Table 4. Color Comparison of Printed Color Gamut vs. NAA Standard Color Gamut

Color	Printed Color Gamut			NAA Color Gamut			Color Difference
	L*	a*	b*	L*	a*	b*	
	Color 1			Color 2			ΔE
Cyan	54.00	-20.65	-20.01	57.00	-23.00	-27.00	7.96
Magenta	47.40	38.62	-1.75	54.00	44.00	-2.00	8.52
Yellow	79.83	-3.07	59.36	78.00	-3.00	58.00	2.28
Black	27.77	0.77	3.08	36.00	1.00	4.00	8.28
Red	55.09	34.61	22.26	52.00	41.00	25.00	7.61
Green	58.61	-34.30	16.08	53.00	-34.00	17.00	5.69
Blue	40.66	8.19	-23.34	41.00	7.00	-22.00	1.82

Source for NAA Color Gamut Standards: SNAP, 2005 (Tolerance +/- 5.00)

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