Visual Communications Journal

Fall 2020 Volume 56 Number 2

Sarah Anderson | Pittsburg State University

VISUAL COMMUNICATIONS JOURNAL

VCJ

VOLUME 56 NUMBER 2 FALL 2020

GRAPHIC COMMUNICATIONS EDUCATION ASSOCIATION

Acknowledgements

About the Journal
The Visual Communications Journal serves as the official journal of the Graphic Communications Education Association, and provides a professional communicative link for educators and industry personnel associated with design, presentation, management, and reproduction of graphic forms of communication. Manuscripts submitted for publication are subject to peer review. The views and opinions expressed herein are those of authors and do not necessarily reflect the policy or the views of the GCEA.

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Reference Sources
The Visual Communications Journal can be found on EBSCOHost databases.
ISSN: Print: 0507-1658 Web: 2155-2428

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Aiming for G7 Master Compliance through a Color Managed Digital Printing Workflow (CMDPW)

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Introduction

A simple digital image could be a binary picture, [h(x, y)], with each point being either completely black or completely white (Pnueli & Bruckstein, 1996). A digital halftone is a pixel map, with an expanded bit depth, that gives the impression of a continuous tone image with multiple shades of gray. An 8-bit grayscale image contains 256 different levels of gray from white to black. A 24-bit image is a combination of three, 8-bit images of the Red, Green, and Blue primaries yielding a continuous-tone color image composed of a full spectrum of shades and color, from near white to dense black. In a traditional printing (offset, digital offset, gravure or flexography) workflow, the method by which continuous-tone photographic images are transformed to a printable image is called halftoning. In this method, the image on the printed sheets are covered with varying size dots, representing the varying tones in the image. The ink (paste or liquid ink or dry toner) printed which creates the dot, has a uniform density. At normal viewing distance, the dots of a printed image blend to create an optical illusion of a continuous tone-like image.

G7 stands for grayscale (or gray) plus the seven primary and secondary colors known as the subtractive and additive: Cyan, Magenta, Yellow, Black (CMYK) and Red, Green, Blue (RGB). G7 is a method which specifies calibration procedures for printing visually acceptable colors with an emphasis on matching colorimetrically derived aim-points for the print reproduction processes to print with a common visual appearance. Today, the G7 method is used in many applications of printing such as offset lithography, flexography, and digital (color laser or inkjet). It uses a pre-defined one-dimensional neutral print density curve (NPDC) to match neutral tonality/gray balance. G7 specifications are owned by International Digital Enterprise Alliance (IDEAlliance). The colorimetric formulas of the G7 are defined in the American National Standards Institute and the Committee on Graphic Arts Technology Standards/Technical Report

(ANSI/CGATS TR015). Published reports reveal there are three ways G7 master compliance can be achieved: a) output device NPDC to G7 NPDC [P2P251x target image], b) use of output device ICC profile, and c) the use of device link profile (DLP = source as GRACoL2013 ICC profile + the destination device ICC profile). G7 master compliance includes three levels in the G7 master qualification: G7 Grayscale, G7 Targeted, and G7 Colorspace. These levels demonstrate G7 master capabilities of a print facility.

G7 Grayscale

This is the fundamental level of G7 commonly seen in most color print reproduction. Regardless of printing process, if a digital printer or printing press reproduces the defined neutral tone ramp as a neutral gray, then all other colors in the reproduction are believed to be without colorcast. This is determined by printing a target specified on a stable printing system and then measuring the target using the correct ink/toner curves to bring the printing system into alignment with the G7 ideal neutral density curve. Aligning the various reproduction processes and obtaining the same neutral aim points is critical for consistent reproduction.

G7 Targeted

The secondary level of G7 is achieved when G7 grayscale is matched, and the solid ink measurements for primary, and secondary (CMY and RGB) are also within the G7 target specifications. This can be achieved through the absolute white point or using the substrate-relative conditions. However, G7 Targeted compliance is not limited to the reference print conditions in ISO 12647-2 or in ISO/PAS 15339. The G7-calibrated dataset can be used as a G7 reference print condition. G7 Targeted achievement certifies that the facility not only conforms to G7 Grayscale, but it can also achieve a higher level of compliance.

G7 Colorspace

The highest level of G7 compliance, and the most stringent is the G7 Colorspace. It includes all the requirements of the G7 Targeted level; and therefore the G7 Grayscale level. This also includes the matching of an entire Reference Print Condition (RPC). This level of control demonstrates that the reproduction maintains an extremely tight tolerance throughout the complete color space. An entire TC1617x target is printed and compared against the specific color space with all 1617 patches held to within a tight tolerance. This assures the printing system will reproduce the entire color space, not just the primary and secondary colors of CMYK and RGB. The G7 Colorspace can also relate to either the absolute white point or the substrate-relative aim values.

Gray balance represents the combination of specific amounts of cyan, magenta, and yellow inks to produce a neutral shade of gray. With slight increases in cyan pigment required to produce a neutral gray, shifts in hue will occur with any imbalance of these three components. In addition to the color gamut, the gray balance is an additional requirement for pleasing color-reproduction. The imbalance is due to impurities of the inks, chromaticity deviation of the substrates, or other attributes. To establish the proper gray balance for a specific process, a full set of tint charts can be reproduced. Careful evaluation of the printed tint charts will provide the specific values for that specific reproduction process. The ISO 12647-7 document states that the gray balance can be printed and measured at the CMY overlap (overlap of C = 50%, M = 40%, and Y = 40%). The deviation can be determined from the calculation of ΔH^* (deviation of hue, h^*) or ΔC^* (deviation of chroma, c^*) and it requires the colorimetric data of CMY overlap printing from the L^* a^* b^* model.

The quality of a color image reproduced through any printing process (digital or traditional) is largely influenced by the properties of paper. While paper is considered a commodity, its properties are a long way from being standardized (Wales, 2009). Additional attributes must be monitored in order to produce quality printed materials; a high quality color image. The press operator must carefully manage several print parameters, such as the source colors (a source profile of ISO or ANSI standard), press calibration, press characterization (device destination profile), and the screening option. Without controlling these parameters to a print job a color mismatch would result.

Purpose of the Research

The purpose of this applied research was to demonstrate the use of a complete color managed workflow (CMW) and to meet the specified G7 master compliance levels by creating and utilizing output device ICC profiles. The experiment was conducted using a color managed digital color printing workflow

(CMDCPW) to determine the effect ICC output device profiles (ODP) have on the G7 master compliance. The experiment utilized an Amplitude Modulated (AM) digital halftone screening process. It was aimed at achieving the G7 master compliance through an ICC based CMW. As previously stated, the G7 master compliance print evaluation can be achieved by using the output device's ICC profile for printing. This experiment adopts this method to achieve the compliance. The compliance of the G7 master includes three compliance levels in the G7 master qualification: G7 Grayscale, G7 Targeted, and G7 Colorspace.

Limitations of the Research

For this research, limitations in the technology of the graphics laboratory were acknowledged. Prior to printing and measuring the samples, the digital color output printing device, and color measuring instruments (spectrophotometer and densitometer) were calibrated against the recommended reference. The print condition associated with this experiment were characterized by, but not restricted to, the inherent limitations: colored images (TC1617x, ISO300, and ISO12647-7) chosen for printing. Additionally, the desired rendering intent applied, type of digital printer, type of paper, type of toner, resolution, screening technique, color output profiles, and calibration data applied are acknowledged. Several variables affected the facsimile reproduction of color images in the CMDPW, and most were mutually dependent. The scope of the research was limited to the color laser (electrophotographic) digital printing system (printing proof/printing), substrates, types of color measuring devices, color management and control applications (data collection, data analysis, profile creation, and profile inspection) used within the university graphics laboratory. Findings were not expected to be generalizable to other CMDPW environments. It is quite likely, however, that others will find the method used and data collected both useful and meaningful. The research methodology, experimental design, and statistical analysis were selected to align with the purpose of the research, taking into account the aforementioned limitations.

Research Methodology

The digital color printing device used in this experiment is a Konica-Minolta bizhub C6000 Digital Color Press, with a Creo IC-307 raster image processor (RIP) for its front-end application. A two-page custom test image (12" x 18" size) was created for proofing and printing and used throughout this experiment, (See Figures 1 & 1A). The test target contained the following elements: an ISO 300 generic images for subjective evaluation of color, an ISO 12647-7 Control Strips (2013, three-tier), and a TC1617x target for gamut/profile creation (Figures 1A & 1B). Table 1 presents the variables, materials, conditions, and equipment associated with this experiment. The analysis of the printed samples provided colorimetric, densitometric, and spectrophotometric data extracted through the use of an X-Rite Eye-One Spectrophotometer and an X-Rite i1iO Scanning Spectrophotometer.

In the chosen screening technique, a total of 100 samples of target color images were printed (N = 100). Of 100 samples of each group, 80 samples (n = 80) were randomly selected and measured, noted by the letter "n" (n = 80). This sample size is needed to make the reliability of data is accurate. It is well documented that a large sample size is more representative of the sampling population (subjects). Each printed sheet is measured by using the scanning spectrophotometer, data was then saved, and later combined in the Chromix/IDEAlliance Curve 4 application. 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 following formula was used to determine the required sample size, which was 80 (n) printed sheets for this study:

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

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 population size

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

d = the degree of accuracy expresses as a proportion (.05)

Figure 1A: Test Image for the experiment

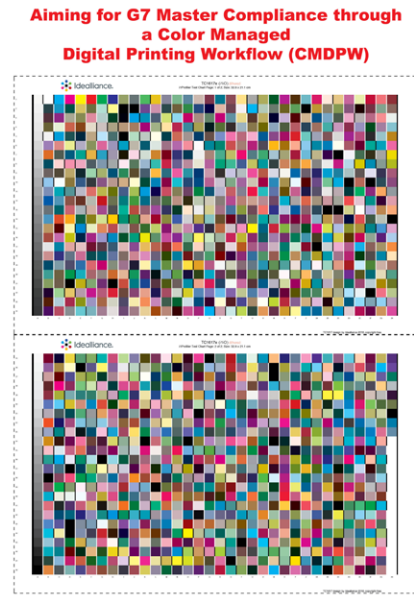


Figure 1B: Test Image for the experiment

Table 1

Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Test image	Custom Test Target, 2 pages
Control strips/targets	ISO 12647-7 (2013), TC1617x
Other Images	B/W and Color for Subjective Evaluation
Profiling Software	X-Rite i1PROFILER 1.8
Profile Inspection Software	Chromix ColorThink-Pro 3.0
Image Editing Software	Adobe PhotoShop-CC
Page Layout Software	Adobe InDesign-CC
Source Profile (RGB)	Adobe 1998.icc
Destination Profile (CMYK)	Custom, Konica-Minolta.icc
Reference/Source Profile (CMYK)	GRACoL2013.icc
Color Management Module (CMM)	Adobe (ACE) CMM
Rendering Intents	Absolute
Computer & Monitor	Dell OPTIPLEX/LCD
Raster Image Processor (RIP)	Creo IC-307 Print Controller
Printer	Konica-Minolta bizHub C6000 Color Laser
Achieved CMYK SID for all print runs (AM vs. FM)	C = 1.47; M = 1.37; Y = 0.90; and K = 1.79
Type of Screen and Screen Ruling	AM, 190 LPI
Print Resolution	600 x 600 DPI
Toner	Konica-Minolta Color Laser
Type of Paper Weight/thickness	Hammermill 100LB Matte Coated, Sheetfed
Type of Illumination/Viewing Condition	D50
Color Measurement Device(s)	X-Rite Eye-One PRO Spectrophotometer with Status T, 20 angle, and i1iO Scanning Spectrophotometer
Data Collection/Analysis Software	IDEAlliance/Chromix Curve 4.0

G7 Compliance for Digital Color Press (printer)

Prior to printing the patches/target image, the printer was calibrated for amplitude modulated (AM) screening technique with 600 x 600 dots per inch (DPI) resolution as per the manufacturer's specifications. This is designed to assure repeatable results; standardizing the performance of the devices according to the device manufacturer specifications. The calibration curve consists of the maximum printable densities of each color (CMYK) used for the printing (Figure 2). The calibration data (range of CMYK densities) were saved in the calibration lookup tables of the RIP and a calibration curve was created. Test target TC1617x was used for the output device profile creation process.

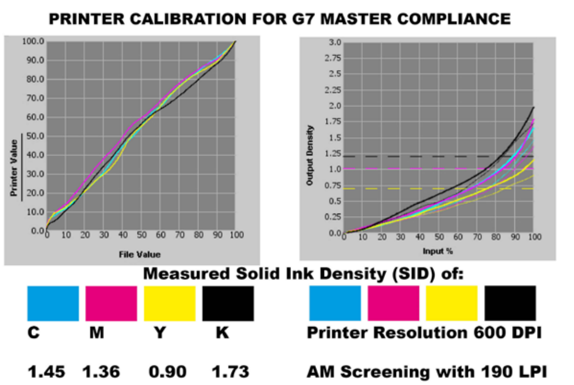


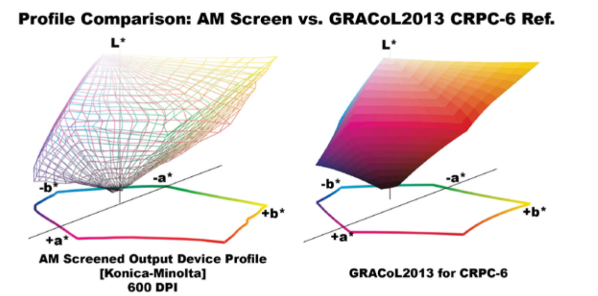
Figure 2: Calibration of a Digital Printing Press

In a generic color managed digital printing workflow, the digital front-end (DFE) platforms (raster image processor or RIP) of digital presses offer opportunities for the operator to manipulate the output color quality to meet the expected demand of the customer. In order to print a quality color image, the user must carefully manage several print parameters, variables, and attributes, associated with the digital printing process.

Output Device Profiles (ODP) for G7 Compliance

The test target image (TC1617x) was placed into an Adobe InDesign-CC layout of 12" W x 18" H size and a PDF file was created devoid of any image/color compression (Figures 1 & 1A). Hammermill brand, 100 LB matte-coated digital color printing paper 12" x 18" was used for printing the research samples. A total of 100 sheets/copies of TC1617x were printed with the calibration curve attached. Also, an amplitude modulated (AM) halftone screening technique with 190 lines per inch (LPI) and 600 DPI as the printer resolution was applied during the printing. No color management or color correction techniques were applied during the printing.

Printed patches of TC1617x were measured in CIE L* a* b* space using the i1PROFILER application with an X-Rite i1iO spectrophotometer. The printer profile was then created and stored. The profile format version is 4.00 and it is considered as the Output Device Profile (ODP) of AM screening. This profile was used as a destination profile (DP) in the workflow. The source profile (SP) used in the experiment is a GRACoL2013 for characterized reference printing conditions-6 (CRPC-6). See Figure 3 for an output device profile comparison of GRACoL 2013 profile vs. AM Screened profile, gamut volume of the profiles, and L* a* b* values of each profile used (Figure 3).



Gamut Volume 537,413					Gamut Volume 389, 023				
Colors					Colors				
L*	53	52	93	11	L*	56	48	89	16
a*	-30	78	-10	1	a*	-32	75	-4	0
b*	-58	-4	1	1	b*	-50	-4	93	0

Figure 3: Output Device Profiles Comparison of AM Screened vs. GRACoL2013 CRPD-6 Ref.

Printing with ODP for G7 Compliance

As stated earlier, AM screening technique was applied during the printing in the experiment (see Figure 4) and was considered a group within the experiment, noted by letter "K" (K = 1). A group involves a set of print parameters, such as: a digital halftone screening technique [amplitude modulate (AM)], the calibration curve (of AM screened), a color source profile [General Requirements for Applications in Commercial offset Lithography for characterized reference printing conditions-6 (GRACoL2013 for CRPC-6)], and a color destination profile of a digital press (AM screened).

As parameters illustrate in the figure 4 (Schematic Illustration of Sequence of Print Parameters for G7 Compliance), the test target of 12” x 18” was printed for use in the experiment. The test target contained the following elements: TC1617x target, ISO 12647-7 (2013) control strips, an ISO 300 and custom images of color and b/w for subjective evaluation of color. A total of 100 sheets/samples were printed for the screening technique used by enabling the color management technique at the RIP. The digital press AM calibration curve, AM screening destination profile, and the source profiles all were applied during the printing (Figure 4).

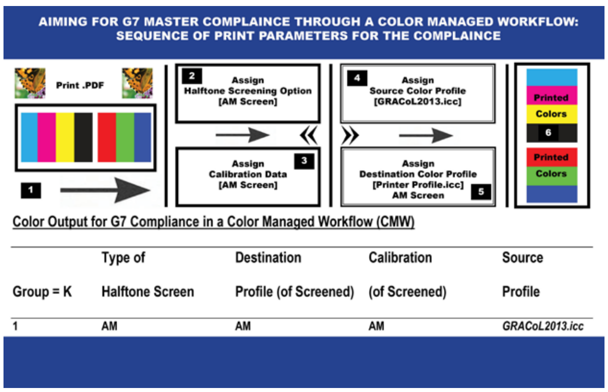


Figure 4: Schematic Illustration of Sequence of Print Parameters for G7 Compliance

A total of 80 randomly pulled printed copies of TC1617x printed target images were measured against G7 ColorSpace GRACoL 2013 (CGATS21-2-CRPC6) in CIE L* a* b* space using an IDEAlliance (Chromix/ Hutch Color) Curve 4.2.4 application interface with an X-Rite i1iO spectrophotometer. The measured data was combined, averaged to run through this application (Curve 4.2.4). The combined data set was then analyzed by using the Verify Tool of the application to determine the pass/fail of G7 master compliance levels using G7 ColorSpace tolerances. Analyzed data from the experiment revealed that the printed colorimetric values (G7 Grayscale, G7 Targeted, and G7 Colorspace) were in match with the G7 master compliance levels (reference/target) colorimetric values (G7 Grayscale, G7 Targeted, and G7 Colorspace).

Test Chart (TC) 1617x is a new CMYK printer characterization target (test chart) combining the unique patch values in the standard IT8.7/4 target with all the patch values in columns 4 and 5 of the P2P51 target. The letter “x” distinguishes the final version from earlier prototype versions circulated during development.

The TC1617x maintains the same patch count as the IT8.7/4 (1,617 – hence the name is TC1617x) by removing 29 duplicate patches from the IT8.7/4 and replacing them with the 29 patches in columns 4 and 5 of the P2P51, absent in the IT8.7/4. Data derived from the TC1617x target image was the difference between the characterization data set (TC1617x) and the printed sample. The reference file content for the image (TC1617x) was the CMYK dot percentage values and nominal CIE L* a* b* characterization data values for the GRACoL2013-CRPC6 reference. Analyzed G7 master compliance levels (reference/target) data (G7 Grayscale, G7 Targeted, and G7 ColorSpace) with G7 colorimetric formulae and formats were presented in the following sections for each of the levels.

Data Analysis & Research Findings

The colorimetric computation methods for G7 compliance were used to analyze the collected data and presented in the following pages/tables. Subjective judgment on color difference or any deviation was not used in this particular study because 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), but 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 (Goodhard & Wilhelm, 2003). Instruments, such as colorimeters and spectrophotometers, eliminate subjective errors of color evaluation perceived by human beings. In comparing the color differences between two colors, a higher deviation (ΔE or ΔH or the ΔC) is an indication that there is more color difference and a lesser deviation (ΔE or ΔH or the ΔC) is an indication of less color difference. In this scenario of the color measuring/evaluation stage, a consistent and standardized light source (D50 or D65) and angle of viewing (2° or 10 °) are important.

CIE L* a* b*, Delta L* Delta E and Delta Chroma (ΔL, ΔE and ΔC)

Colorimetric values of printed colors against original colors and the deviations (Delta’s) can be used to determine the visual variation in overall colors, hue, chroma, and lightness. The a*, b* coordinates correspond approximately to the dimensions of redness – greenness and yellowness – blueness respectively in the CIE L* a* b* color space and are orthogonal to the L* dimension. Hence a color value whose coordinates a* = b* = 0 is considered achromatic regardless of its L* value. Calculation of ΔH* requires colorimetric data from the L* a* b* model.

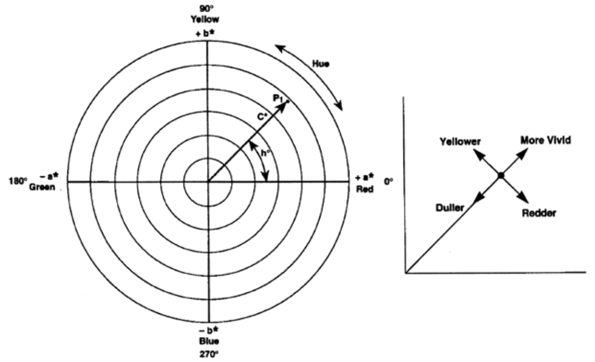


Figure 5: Schematic of L* a* b* & c*, h * Coordinates

Metric hue angle h* and C* are defined by the following formulas [Morovic, J., Green, P., & MacDonald, L. (2002)].

Metric hue angle: $h^*_{ab} = \tan^{-1}\left(\frac{b^*}{a^*}\right)$

Where: a*, b* are chromaticity coordinates in L* a* b* color space

Chroma (C*) = $[a^2 + b^2]^{1/2}$

Where: a*, b* are chromaticity coordinates in L* a* b* color space

Calculation of ΔC* (of two colors) and ΔL* requires colorimetric data from the L* a* b* model. Difference in the chroma C* of two colors (Reference vs. Printed) can be calculated by using the following formula (Green et al., 2002).

ΔChroma (ΔC) = $C^*_1 - C^*_2$

Where: 1 = C* of Reference Color and 2 = C* of Printed Color

Assessment of color is more than a numeric expression. It is an assessment of the difference in the color sensation (delta) from a known standard. In the 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 = Reference Color and 2 = Printed Color

Chromaticness difference (ΔCh) is the difference between the reference chroma (a*1 and b*1) and the measured chroma (a*2 and b*2) of a gray balance control patch (C50, M40, Y40). Weighted Delta Chroma (wΔCh) is the delta Ch value after it is passed through a weighting curve that reduces the significance of Ch errors in the darker regions of the color. The weighting function is defined in the G7 specifications ([Technical Report (TR) 015] and the G7 master pass/fail document as follows:

wΔCh = ΔCh x [1 – max (0, (% - 50) / 50 x 0.75)]

Delta L* (ΔL*) is the difference in the lightness between the reference and measured sample lightness regardless of any color. This makes ΔL* the perfect metric for measuring tonality [Neutral Print Density Curve (NPDC)] error in G7. Colorimetrically, ΔL* is the result of subtracting the L* of measured sample value from the reference L*, as follows:

ΔL* = L*1 – L*2

Where: 1 = L* of Reference Color and 2 = L* of Printed Color

Weighted Delta L* (wΔL*) is the delta L* value after it is passed through a weighting curve that reduces the significance of L* errors in the darker regions of the color. The weighting function is identical to that for wΔCh, as follows:

wΔL* = ΔL* x [1 – max (0, (% - 50) / 50 x 0.75)]

Overall Color Variation (ΔE) of AM Screened (TC1617x image) vs. GRACoL 2013 Ref.

The CIE L* a* b* values associated with the CMYK+RGB colors AM screened image vs. G7 ColorSpace-GRACoL 2013 [CGATS21-2-CRPC6 (reference)] are compiled in Table 2. Numerical color differences (ΔE) were found when comparing the colors of the AM screened printed image vs. G7 ColorSpace within all seven colors (CMYK+RGB). Also, noticeable visual color differences were found in the solid color area [lightness, color hue and chroma]. Overall, both groups of images are similar in colors (See Figures 6), with the exception of the printed image consisting of higher L* for red, magenta, and green, etc. This results in producing the higher ΔE for these colors.

This higher color deviation (red, magenta, and green) might be the result of the substrate (paper) or inks used (age, condition, quality, etc.). These are the darker colors which produced lower L* value and in turn affected the higher deviation. The 2D color gamut comparison (Figure 6) reveals that the colors of the printed image closely match the reference colors. The goal was to determine the deviations among various attributes of color between these two groups of colors. The comparison is an indication that, in a color managed workflow (CMW), color matching of a target image can be achieved from device to device regardless of device color characterization and original colors. Subjective judgment was not used for the color comparison.

In addition to the colorimetric comparison of individual colors (Table 2), AM screened printing G7 ColorSpace

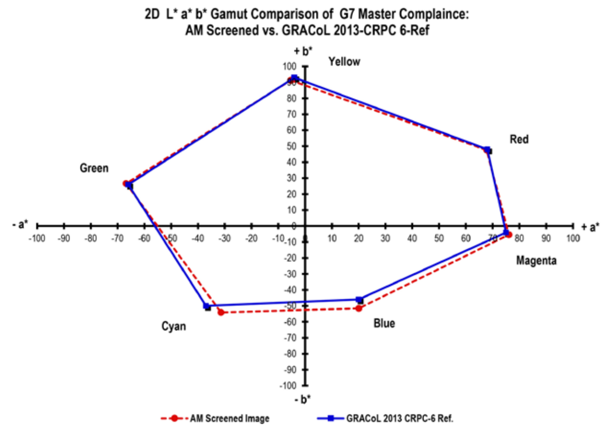


Figure 6: AM Screened Image vs. GRACoL 2013-CRPC-6 Ref.

Table 2

Overall Color Variation of CMYK+RGB: AM Screened Image (TC1617x) vs. G7 ColorSpace

	AM Screened Image			**G7 ColorSpace / Target**			**Color**
	L*	**a***	**b***	**L***	**a***	**b***	**Difference**
Color(s)	**Color 1**			**Color 2**			**ΔE**
	N = 80*			**N = N/A**			
White (W)	97.22	2.79	-9.47	97.22	2.79	-9.47	0.00
Cyan	57.44	-31.30	-54.11	57.39	-36.88	-55.85	1.99
Magenta	51.49	76.06	-5.38	49.21	77.92	-7.10	2.40
Yellow	90.98	-5.36	91.29	91.09	-2.44	92.91	1.62
Black (K)	13.46	0.34	-0.11	16.30	0.24	-0.74	1.97
Red	50.64	67.72	47.65	48.19	70.73	48.27	2.59
Green	53.39	-66.80	26.68	51.25	-66.87	24.48	2.29
Blue	26.79	20.05	-51.57	25.62	21.18	-50.24	1.60
TAC 300	24.33	-0.07	-1.73	23.56	0.45	-1.35	1.02
TAC 400	9.74	0.55	-0.97	8.99	0.17	0.61	1.72

and the G7 master compliance colorimetric deviation (wΔCh and wΔL) values for all the three levels (G7 Grayscale, G7 Targeted and G7 Colorspace) were a close match with the established tolerances for the G7 (see Tables 3A, 3B, and 3C), including the Neutral Print Density Curve [NPDC (CMY)] and NPDC (K).

Table 3A: G7 Master Compliance Levels
G7 Grayscale of AM Screen vs. G7

All Metrics	Black (K)	CMY (Overlap)		G7 Tolerance
	wΔL*	wΔL*	wΔCh	
G7 Grayscale of AM Screened Image (Tonality/Gray Balance)				
Average	0.90	0.39	0.89	1.50
Maximum	2.37	1.18	1.72	3.00

Table 3B: G7 Master Compliance Levels
G7 Targeted of AM Screen vs. G7

All Metrics	ΔE 2000	G7 Tolerance	Maximum	G7 Tolerance
G7 Targeted of AM Screened Image				
Substrate	0.00	3.00		
K	1.97	5.00		
CMY			2.40	3.5
RGB			2.59	4.3

Table 3C: G7 Master Compliance Levels
G7 Colorspace of AM Screen vs. G7

All Metrics	ΔE 2000	G7 Tolerance
G7 Colorspace of AM Screened Image		
Average	1.28	3.5
95%	2.33	5.0

Summary/Conclusions

This experiment used an output device ICC profile to achieve compliance. G7 master compliance includes three compliance levels in the G7 master qualification: G7 Grayscale, G7 Targeted, and G7 Colorspace. These levels demonstrate G7 master capabilities of a print facility. The experiment was conducted in a Color Managed Digital Printing Workflow (CMDPW). It was aimed at achieving the G7 master compliance through an ICC based color managed workflow (CMW). The G7 calibration method, using the P2P251x target, was NOT used to derive the device NPDC to compare with G7 NPDC for print (or press) runs 1, 2, 3, etc.

The conclusions of this study are based upon an analysis of colorimetric data, visual assessment, and associated findings. The guiding objectives of this study allowed testing of an accepted color management practice to gain a better understanding of the presumptions associated with the application of an output device profile (ODP). The experiment examined the importance of calibration, characterization and the color evaluation processes of the digital press which was capable of printing colors to match or be in proximity of G7 master compliance levels.

Printed colorimetry from the experiment was compared against G7 ColorSpace GRACoL 2013 (CGATS21-2-CRPC6) in CIE L* a* b* space using an IDEAlliance (Chromix/Hutch Color) Curve 4.2.4 application interface with an X-Rite i1iO spectrophotometer. The measured data was run through this application (Curve 4.2.4). The data was then analyzed by using the Verify Tool of the Curve 4.2.4 application to determine the pass/fail of G7 master compliance levels using G7 ColorSpace tolerances (G7 Grayscale, G7 Targeted, and G7 Colorspace). Analyzed data from the experiment revealed that the printed colorimetric values (G7 Grayscale, G7 Targeted, and G7 Colorspace) were in match (aligned) with the G7 master compliance levels (reference/target) and colorimetric values (G7 Grayscale, G7 Targeted, and G7 Colorspace). Therefore, the press run was passed by the Curve 4 application.

It is evident that integration of device profiles is important in a CMW and it also enables/allows the workflow process to meet the G7 compliance levels via an ICC based CMW, instead of using G7 calibration methodology. This study represented specific printing or testing conditions. The images, printer, instrument, software, and paper that were utilized are important factors to consider when evaluating the results. The findings of the study cannot be generalized to other digital printing workflows. However, the result of this research may be of interest to others when exploring similar methodologies to other printing workflows.

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Online Workflow Game

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Abstract
This paper introduces an online game for teaching graphic arts workflow. The game is hosted on Ryerson University's server at https://ryerson.ca/~wdp/workflow-game. The game currently includes four workflows for print, including a stitched brochure, RIPping process, deck of cards, and user-definable workflow; and one web workflow.

Glossary of Terms

- JavaScript — A programming language for the World Wide Web that adds interactivity to web pages, first introduced by Netscape in its Navigator browser in 1995 (Duckett, 2014; W3Schools, n.d.). Script statements are enclosed in <script> tags and placed in the <head> or <body> of a page.

- jQuery — A curated library of Javascript functions started by MIT in 2006, it aims to make Javascript programming easier through the use of predefined functions. Used in 73% of popular web sites (Open JS Foundation, n.d.).

- JSON — Javascript Object Notation, a standard file format for data interchange (JSON.org, n.d.). JSON is a compact and easy-to-read textual data format. The JavaScript function 'importJSON' can import straightforwardly JSON data inside a file, which is stored on the HTML server.

- MP3 — Standard format for music and audio files (Musmann, 2006).

Significance of Workflow in Graphic Arts Education

Prior to the "democratization" of design and prepress workflows with desktop publishing, producing a printed product required a certain number of steps, many requiring specialized equipment and expertise that were not easily accessible to the lay person.

Desktop publishing procedures that developed in the 1980s and began with the graphical user interface, PostScript page description language, laser printer, and page layout software, made more of the production steps accessible to designers and novice users.

Today those without formal training in the graphic arts can complete many design and production steps on their own, however processes like imposition, trapping, and file output still require specialized software and the knowledge to operate it. Platemaking, printing, and binding then require capital-intensive equipment that could easily be damaged and cause injury if improperly used, thus putting them out-of-reach of the lay person and therefore unfamiliar to the beginning student of graphic arts.

Consider the church volunteer who wants to print a newsletter. Such a person may have a US letter-size (A4) laser or inkjet printer, or possibly a US tabloid (A3) printer, and can easily procure letter-size and tabloid paper from an office supply store. The person could design a one- or two-page letter-sized newsletter or, with some planning, impose a four-page 5½×8½-in. (A5) folded newsletter from the letter-sized paper. A larger and more complicated document, like a church magazine, would require larger paper not easily accessible to the consumer, along with knowledge of bleeds, imposition, and trapping, and then capital-intensive press and bindery equipment. These concepts and skills that are out-of-reach of the lay person are the most challenging to teach, thus the value of the Online Workflow Game.

Moreover, the authors noticed in their graphic communication classes, that most students know a lot about single processes and resources, but often lack the knowledge to put those in a proper order. For example, it is hard for them to answer questions like "should color management come before or after trapping" or even "should gathering go before or after folding?" This game might make them aware of the sequence of actions and trigger a discussion between the students. Since also resources have to set, they learn the "missing links" or "interfaces" between two processes, i.e. what is the outcome of one process and in the same time the input of the next one.

History of the Game

The Workflow Game was conceived by Thomas Hoffmann-Walbeck around 2015 for use as a teaching tool in his classes at the Hochschule der Medien (HdM). The original cards were designed in Adobe InDesign, using the "Data Merge" functionality and a CSV database. The latest version was designed as a proper card deck, imposed onto a press sheet, printed on HdM's six-color Heidelberg Speedmaster press, and die cut. The card decks were packaged in boxes that were also designed and printed at HdM. The card decks were used in one or two classes each semester for perhaps nine semesters and also handed out as a give-away for the participants at HdM's annual Workflow Symposium. Different versions of the printed cards were created for various print products and in German and English (Figure 1).

Figure 1: Print versions of the Workflow Cards include (left) an early German version for the step "printing content" and (right) the most recent version in English designed for HdM's Tenth Workflow Symposium.

How the Game Works

When users access the Workflow Game, they get an explanation of the site and can then choose print or web workflows, along with descriptions of each. A separate developer page describes how to customize the workflow.

In the Print workflow page, users can choose one of four workflows (Stitched Brochure, RIPping, Deck of Cards, and customizable Your Workflow). Each workflow includes a set of "puzzle pieces" labeled with operations necessary to complete the finished print product. Hovering the mouse over a piece shows a description of that step at the bottom of the page. Steps representing resources (e.g., final product) are shown in blue, while processes (e.g., printing) are yellow. This so-called "process-resource model" is the base of the print production specification of the Job Definition Format (CIP, 2018a; CIP, 2018b; Gehman, 2003; Hoffmann-Walbeck, Riegel, & Dobrowits, 2012; Kühn & Grell, 2005; Marin, 2007; Romano, 1999).

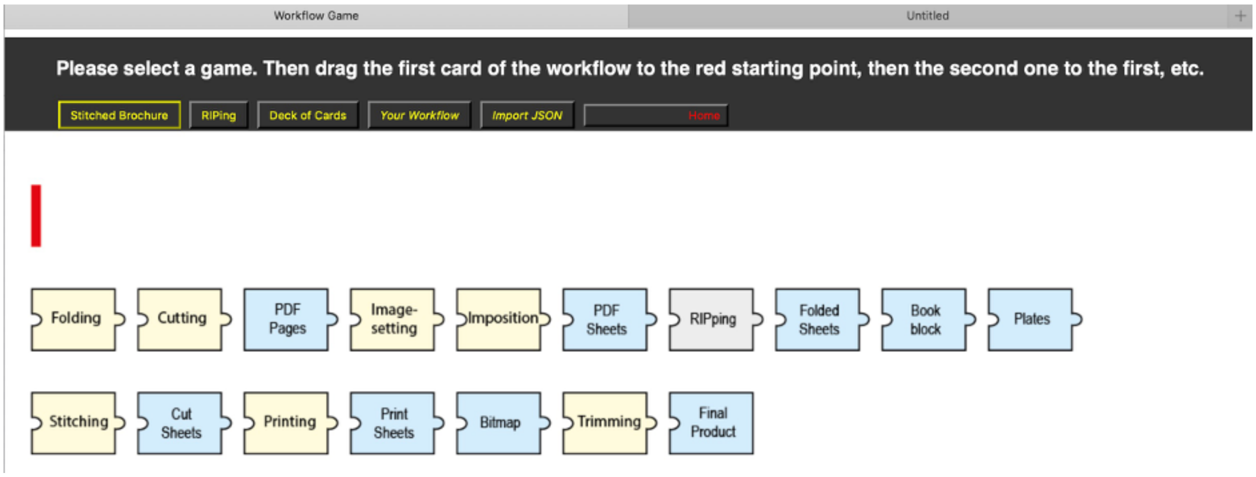

Figure 2. Print workflow page for "Stitched Brochure." Users can arrange the 17 "puzzle pieces" in the correct order, placing the first piece (PDF Pages) at the red line.

The objective is to drag-and-drop the workflow steps up to the red starting line and in the correct sequence. Each piece that is correctly placed produces a "chime" sound. The above-mentioned descriptions of the puzzle piece should help the player to find the correct one. When the entire sequence is completed, a "siren" sounds. Currently the only method of preserving the completed workflow is to print the page. When the page is reloaded, the puzzle pieces are reshuffled into a random order (Figure 2).

Execution

The workflow game currently consists of six web pages. Puzzle pieces are portable network graphic (PNG) files drawn and exported from Adobe Illustrator. The graphics have been programmed in JavaScript to be "draggable" around the page using the jQuery JavaScript library (Sharkie, 2012; Open Js.Foundation, n.d.). The user-selectable workflows on the Print page have been programmed in JavaScript when the respective button is pressed.

Customization

The workflow game can be easily customized with some knowledge of the hypertext markup language (HTML) and cascading style sheets (CSS) used for web pages, as documented on W3Schools.com and numerous other online references. The site's Developer page provides step-by-step instructions on how to customize the workflows. Three illustrations of puzzle pieces can be downloaded in Adobe Illustrator (.ai) format, labeled as desired, then exported to PNG format using the File > Export > Save for Web dialog box. Further instructions tell how to edit the JavaScript to reproduce the card ID, image name, image width, image height, name of the following piece, and interactive information text. The bell and siren sounds are MP4 files and can likewise easily be changed (Figure 3).

Future Direction

There many potential ways to enhance this game, which so far is really a prototype. The UI and the gaming experience might be improved. Moreover, we are planning to simplify the customization by importing external JSON data. Finally, we would like to extend the functionality, so that many processes

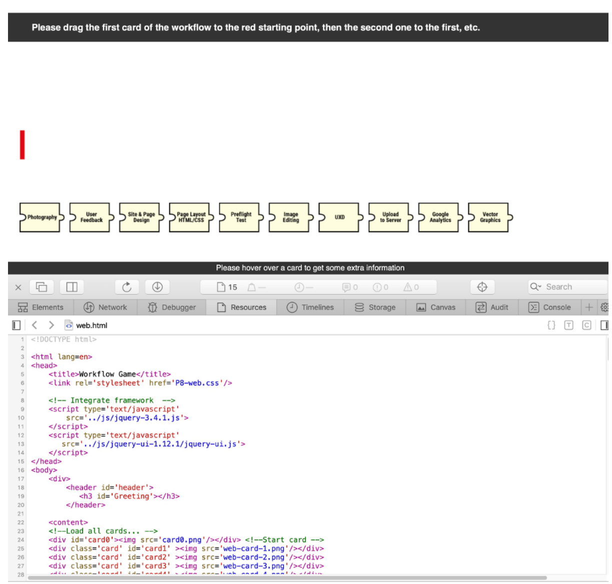

Figure 3. Web game shown in Safari's Web Inspector view, where the code can be copied and customized according to instructions on the Developer page.

and resources can be joined together, more or less freely. Thus, players could model not only a predefined print product but also their own one. In the background, however, a few independent rules still need to be checked, like "the process printing outputs a print sheet" or "folding first, then gathering."

The authors are curious to see how end-users customize and make use of the Workflow Game. Our emails are included in the About the Authors page of the website.

Conclusions

Like the "workflow game" of physical cards that came before it, this online game provides a way of modeling entire production workflows in the graphic arts industry, which could help students and industry professionals alike in the planning of new production lines and automation of workflow. The online version provides a simple method to make students familiar with this topic in an interactive approach

Acknowledgment

Thanks to Graham Maclean, MLIS at Ryerson University for his help in formatting the references.

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Color Correction in Video: Testing the Accuracy and Efficiency for Achieving Brand-Correctness using DaVinci Resolve

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Introduction

The use of video is an increasingly popular form of communication, and the technologies for production such as cameras, editing software and display systems are continually evolving and improving. Broadcasting live events is a very popular use of video, especially for college and professional sports. Broadcasting live sporting events is much different than the production of video in a controlled environment, as there are many factors susceptible to change: subjects and movement of subjects, weather, and lighting conditions. Because of the continuously changing environment during live broadcasts, color grading and correcting are done in real time by a colorist. A colorist will shade and paint the recorded footage so that the colors appear visually consistent, and their adjustments are what is seen broadcasted on television and on the jumbotrons inside the event. The process of color grading and correction in video does not yet have standardized measures for accuracy and are therefore very subjective in practice. Standardizing color for static images or printed graphics is managed both numerically and visually, but for video there are best practices, but currently no industry standard for measuring and determining color accuracy.

This study explores the current methods available for color correction to provide a quick and efficient way to display brand-accurate colors on displays. The current color correction procedures for a non-linear editing software program were examined to determine whether it is possible to color-match for brand accuracy.

Review of Literature

Capabilities of Output Display Monitors

Display devices have a much smaller dynamic range of color than what the Human Visual System (HSV) is capable of seeing (Kunkel et al., 2013). Figure 1 shows the range of the Rec. 709/sRGB color-space in comparison to the range that human eyes can see. In other words, humans can see many more colors than what display devices are physically capable of producing. When considering the accuracy of a color, or whether two colors match, there is a geometric referencing system: CIELAB Values. The International Commission on Illumination (CIE) is an international scientific and standardization organization that established the most essential standard for color matching: a way to quantify colors and compare color difference (Hung, 2019). When two CIELAB values are compared to one another, their difference is calculated as a ΔE value (Kunkel et al., 2013).

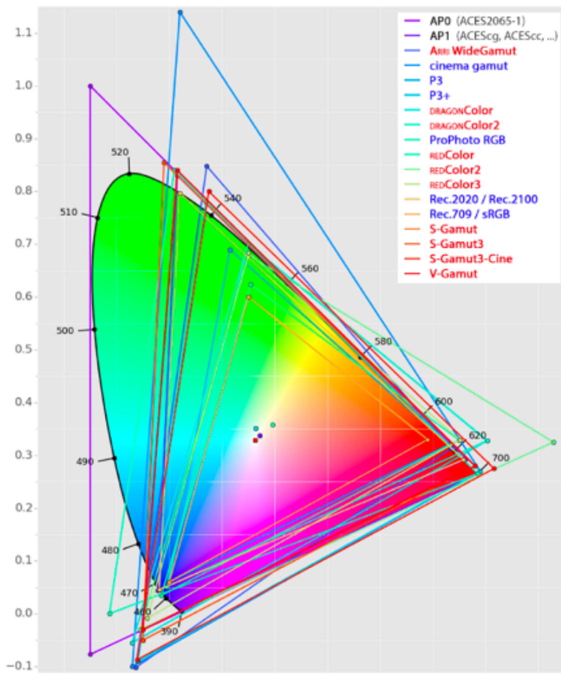

Figure 1: "CIE 1931 chromaticity diagram (y axis shown) with comparison between ACES (black), professional digital motion picture cameras (red) and reference cinema/display (blue) color gamuts" (Arrighetti, 2017).

Color Processing In-Camera

Every camera processes color differently. The sensors on different makes and models of cameras will capture different RGB values of the same scene, when compared to one another (Bilodeau, 2017). For example, if two cameras made by different manufacturers were placed side-by-side and recorded the same scene, there will be a visible difference in color between the two shots. All cameras have their own agnostic color space or Log (logarithmic) file formats/colorimetries "designed to account for camera sensors' characteristics" (Arrighetti, 2017). An agnostic or Log color space captures much more color data than linear color spaces do. Many cameras have the capability to capture footage in both linear and Log color spaces, but some cameras (such as the Panasonic AK HC-5000 used in this study) can only capture footage in Log formats. Footage recorded in a Log-

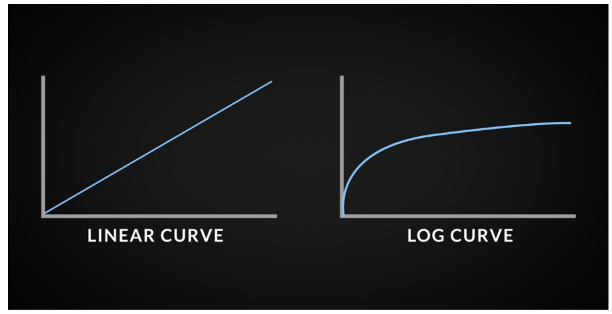

Figure 2: The curves above display the differences between linear and Log color spaces. Just like other color curves, the bottom-left represents shadows/black points and the top right represents highlights/white points (Blankenship, 2017).

format color space has more compressed shadows, and the highlights are pushed up. Footage with a Log color space appears to have very muted colors before editing occurs, but allows for more color manipulation in post-production (Blankenship, 2017). Examples of different camera manufacturers' raw formats are: Sony S-Log and S-Gamma, Panasonic V-Log, GoPro CineForm/ProTune, Canon C-Log, ARRI LogC Wide Gamut, RED DRAGONColor and REDLogFilm, etc. (Arrighetti, 2017).

Figure 3: An example of Log footage before and after color correction (Blankenship, 2017).

Color Grading Workflow

Although the camera provides an initial color space, for television broadcasts color grading does not occur in-camera but in an entirely separate process during post-production. Color grading is typically "set in a TV grading room, dimly lit and equipped with one or more monitors… that are all color-calibrated according to their own reference color standards, dynamic ranges, and viewing environments" (Arrighetti, 2017). The footage has a raw format or log color space, which was embedded from the camera. The footage was read from this proprietary format and color corrected from there. The colorist first performs a "master grade" in the widest-gamut color space possible (Arrighetti, 2017).

Rec. 709 is the current standardized color space that most high-definition television displays adhere to; the majority of display monitors are only capable of displaying this range of colors (Kunkel et al., 2013). The Rec. 709 color space is demonstrated by the triangle in Figure 4. At this point, there are no universally accepted standards for the practice of color grading/correction; the look of the colors is dependent on the colorist's perception and artistic choices while grading (Arrighetti, 2017).

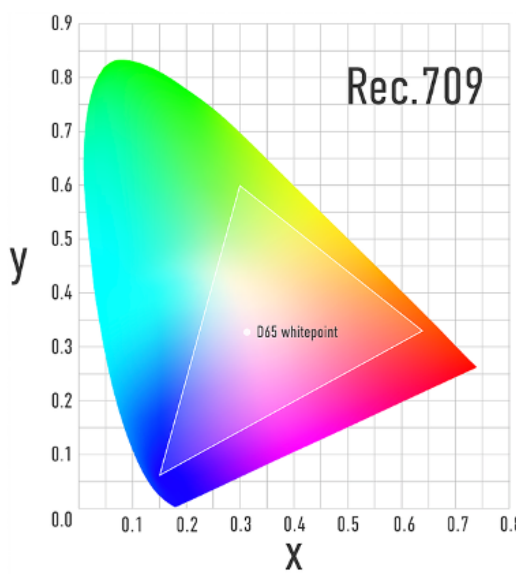

Figure 4: The Rec. 709 color space in reference to the CIELAB 1931 color space (https://www.unravel.com.au/understanding-color-spaces)

Once colorists adjust the footage, it is exported to the display. The viewing environment of the display has an impact on the way viewers will see the color. The surrounding lighting combined with the light emission and limited color-space of the display impact how colors are perceived (Arrighetti, 2017). The appearance of a color changes "when the viewing environment is changed" (Kunkel et al., 2013).

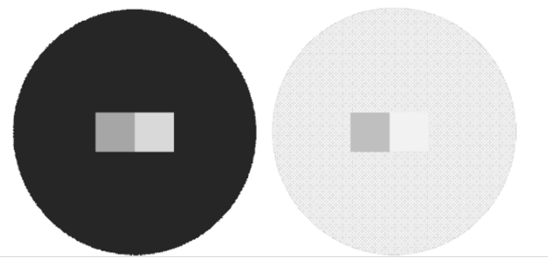

Figure 5: "Simple visual experiment how the background affects the appearance of the identical set of grey patches" (Hung, 2019).

Methods

In order to simulate accurate, real-time video comparable with broadcasted game footage, this study was conducted at a home baseball game on May 17th, 2019. The test was done at Doug Kingsmore stadium, Clemson University's baseball field, using the current cameras and infrastructure for broadcasting and color management. The materials used include: X-Rite Video Color Checker Palette, six Panasonic AK HC-5000 cameras, and DaVinci Resolve software.

The research was conducted at an early evening Clemson baseball game using an X-Rite Video Checker color palette. Each Panasonic camera was placed at a different angle along the outskirts of the field. Two of the HC-5000 cameras were right next to each other, so a total of five separate angles to the sun were captured. Each of the HC-5000 cameras recorded video of the target for a few seconds.

It was important to capture footage from each of the six cameras because baseball games are normally recorded from those angles (Figure 6). In addition, the varying angle of sunlight on a subject, or in this case a color target, can skew color appearance in the video footage.

The current infrastructure for broadcasting sporting events at Clemson University was not manipulated or changed during the testing, due to it being a live baseball game and a real TV broadcast. The footage was recorded at the camera's base-level color settings and incurred no shading and painting by the colorist before it was exported. The Panasonic AK HC-5000s do not record any footage to the actual camera itself; they have no input for an SD card. Each camera has an HD-SDI output on the back which transmits the footage via an underground cable to a large computer in the broadcasting room. The footage is transmitted from the camera to the broadcasting room passing

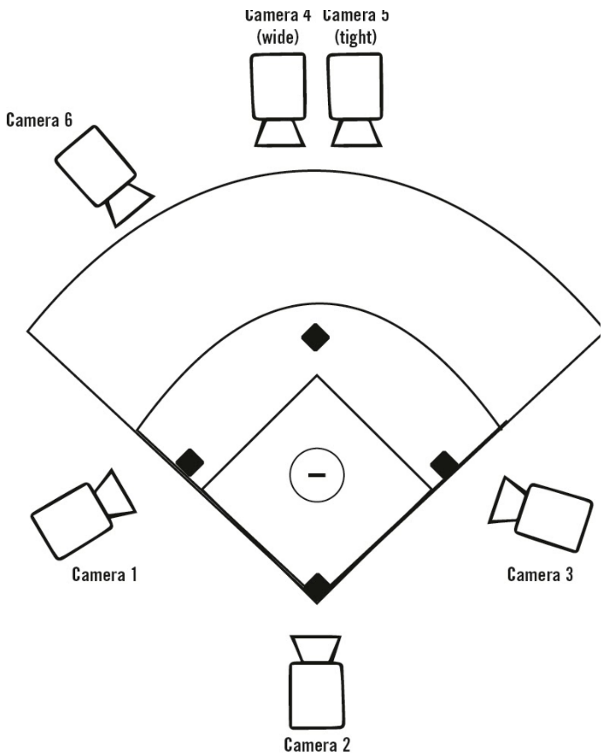

Figure 6: Panasonic AK HC-5000 placement on field at Doug Kingsmore Stadium during this test

through the colorist’s shading and painting board. For this research, the colorist was not actively adjusting the color as they would be during the game. The coloring station was left at standard settings. After the footage passes through the coloring room, it is then transmitted either to the jumbotron in the stadium or to the TV channel broadcasting the game. This transmission of footage from the field and out to broadcast or on-field displays happens in a matter of seconds; the cables used transmit footage at a rate of 1.5 GB/second. The footage that passes through the color room and onto the jumbotrons or television broadcast can also be exported as an mp4 file. Those mp4 files were used for the next steps in this study.

The footage recorded from each of the six camera angles was compiled into one file. The video file was then brought into DaVinci Resolve which is a color correction and non-linear video editing application that can create profiles using footage that contains the X-Rite color palette. To apply color correction, the user is prompted to select the source gamma of the original footage, target gamma, and target color space of the final color corrected footage, and color temperature of the original footage (Figure 7).

The source gamma for this footage was set to “auto,” because the source gamma was the automatic color settings from the camera. The source gamma of an input device “is all the colors it can record” (Chamorro-Martínez et al., 2017). The target gamma of an output device “is all the colors it can show” (Chamorro-Martínez et al., 2017). Both the target gamma and target color space for this footage were Rec. 709, because both the jumbotron in the stadium and standard TV displays us a Rec. 709 color space.

A measurement of the Clemson Orange color was taken for each of the color-corrected photos. The Digital Color Meter application on Apple computers was used, using an eyedropper tool to dial into one pixel on the orange shirt. The CIELab value for an orange pixel in each photo was read using the Digital Color Meter, and then compared to the CIELab value

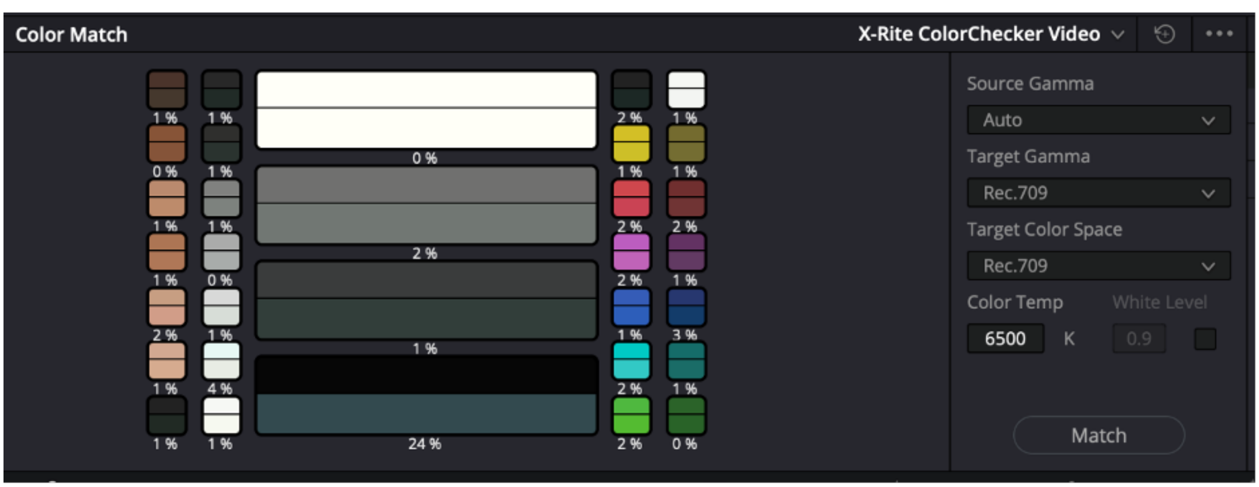

Figure 7: Example of DaVinci Resolve’s X-Rite Color Match window after correction has taken place, showing the percentage differences between the X-Rite Color Checker Palette and colors in the frame.

Figure 8: Before and after color correction in DaVinci Resolve. Photos on the left are original frames, photos on the right are after Color Match has been applied.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

Figure 9: Delta E equation (Konica Minolta, 2019).

for Clemson Orange, Pantone 165 (L*64.76, a*58.52, b*67.92). The CIELab values were then compared to one another using the equation for ΔE (Figure 9).

There is currently not a standard for measuring color accuracy in video or motion graphics, so the ΔE comparison was used for this research. ΔE is one of the standard methods for measuring color correctness and tolerance in print. Color tolerance is the range in which the sample or printed piece can differ in color from the target while still being acceptable. The tolerance value is fluid, and typically a decision made between the supplier and the brand. The human eye can typically spot a color difference of a ΔE value of 1.0, depending on the color. While there is not a set number for a pass/fail range in color tolerance and correctness in printing, the ΔE value for acceptance is a number agreed upon between a printer and the brand. In the print world, the acceptable range for color tolerance is typically set anywhere from a ΔE of 2.0 to a ΔE of 6.0, depending on the client's desires and printer's capabilities. When determining a color tolerance value, it should also correlate to what the human eye can see. The correct color should be both "visually and numerically correct" (Konica Minolta, 2019). When measuring CIELab values for printed pieces, the print being measured is typically placed in a D50 lighting booth; D50 lighting closely mimics the white point of natural daylight. Color swatches are measured either with a colorimeter or spectrophotometer. The ΔE comparison method was deemed relevant because even though it is primarily used to compare physically printed pieces, it can be used to measure the color accuracy of digital soft proofs when they are viewed on a calibrated LCD screen. The Digital Color Meter was used in place of a spectrophotometer, and the D50 lighting is not applicable because the image is being viewed on an LCD computer screen.

Findings

Results of the experiment are shown in Tables 1 and 2. With an average ΔE value of 22.72, this color correction is not within an acceptable range for brand color correctness. This method was not effective in correcting colors for brand accuracy, as the lowest ΔE value was 10.57. While the numbers were not in coherence with Clemson's orange, the visual appearance was also inconsistent. Depending on

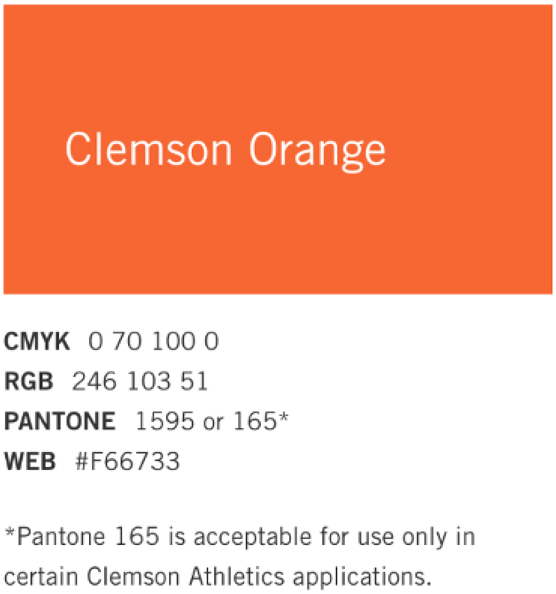

Figure 11: Clemson Orange

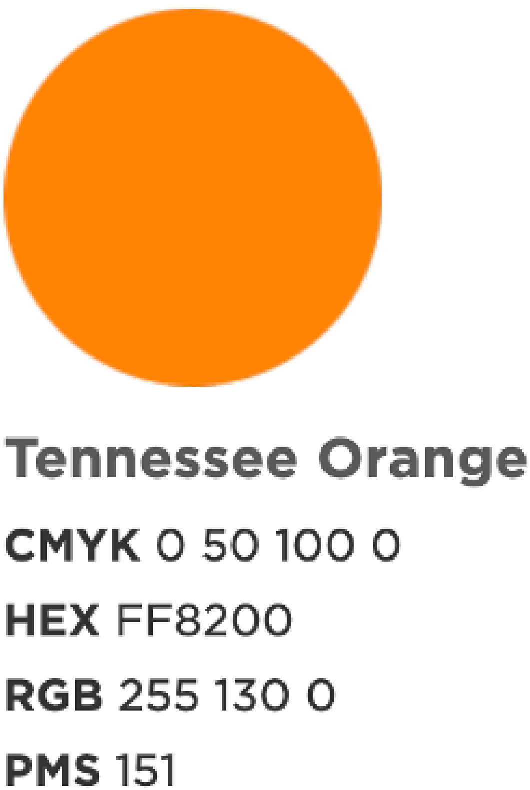

Figure 12: Tennessee Orange

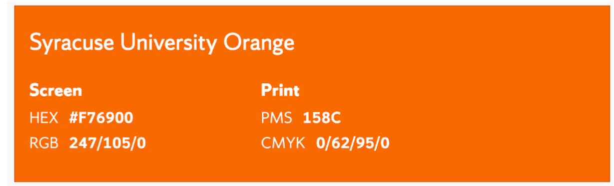

Figure 13: Syracuse Orange

Table 1

The ΔE calculations comparing Clemson's Pantone 165 LABCIE values to an orange pixel in the frame from Color Match.

File (Photo #)	L*	a*	b*	ΔE (Pantone 165 C)
1	63.42	71.90	90.54	26.32
2	58.49	81.30	92.32	33.96
3	64.42	69.58	74.46	12.85
4	61.91	76.59	87.49	26.79
5	63.02	74.34	64.29	16.32
6	59.9	81.75	89.70	32.21
7	69.79	54.04	76.07	10.57
Average ΔE				22.72

Table 2

The ΔE calculations when comparing the various orange brand colors of UT, Syracuse, and Clemson

Color	L*	a*	b*	ΔE (Pantone 165 C)
Clemson Orange	64.76	58.52	67.92	0.00
Tennessee Orange	68.54	44.24	75.23	16.48
Syracuse Orange	62.46	53.32	71.78	6.87

the color, a human eye can detect a color difference with a ΔE of just 1.0. ΔE values of 10.57 and upwards translate to very large visible differences. For example, the difference between Tennessee orange, Syracuse Orange, and Clemson orange are noticeably different to the human eye. To put into perspective the visible difference of varying ΔE values, the other colors of orange are visibly different with ΔE values of 16.48 and 6.87 from the original Clemson CIELAB values.

Conclusion

In many instances, color accuracy in video is less important than obtaining an overall "look" for a production piece, but there are instances where color correctness matters. When it comes to branding, color accuracy is of utmost importance across all mediums. This is especially important for large companies who put heavy investments into marketing efforts. Companies with colors like Coca Cola red, McDonalds yellow or Facebook blue for example would not want to put out any deliverables that were not on-brand. Considering the success in brand recognition of companies who enforce strict guidelines for color control, it would be interesting to explore the connection between color control and brand recognition for colleges and universities. An area to explore could be whether color control can increase brand equity and brand recognition. This study found that the standard method for color correction is not effective for quickly and accurately maintaining brand correctness for broadcasting live sports.

Therefore, the current color correction methods for brand-correctness using DaVinci Resolve and an X-Rite color palette, are neither efficient nor accurate for this application. Using the Color Match software is not effective because once the target has been selected and matched, the user would have to go in and additionally adjust the curves (in each lighting scenario) in order to achieve a color that more closely represents the correct brand color. More research would need to be done in order to test whether other color palettes would bring a closer match, as DaVinci Resolve has Color Match software for many color palettes. However, based on the findings of this research, color correction using this color palette is not the best solution to ensure brand color accuracy. The Color Match software is better suited to ensure that all colors within the frame are consistent, especially between cameras shooting the same scene, rather than specifically adjusting for the accuracy of one color. There is currently not an option to set a focal point of a specific color or color-match within this software system.

As of current practice, color correction is a balancing act of these three things: the way the camera processes color, the workflow of the color grading, and the capability of the output monitor or display. Finding a quick, accurate, and efficient way to color grade for brand correctness needs to be further researched.

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GRAPHIC COMMUNICATIONS EDUCATION ASSOCIATION

Visual Communications Journal Fall 2020 Volume 56 Number 2