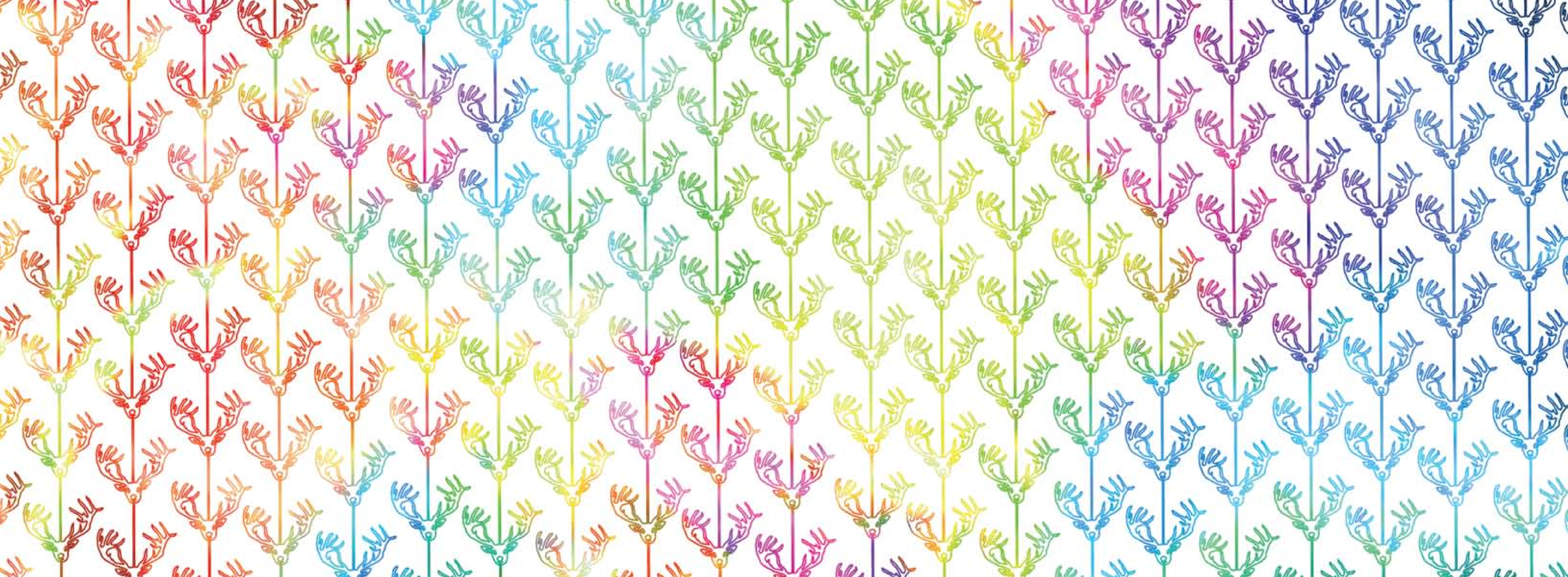


Published by: Ryerson University TAGA Student Chapter

Faculty of Communication & Design
School of Graphic Communications Management
Toronto, Ontario, Canada
http://www.ryerson.ca/gcm

RyeTAGA2008

ADVISOR'S MESSAGE

Dear Ryerson TAGA students,

Unbelievable that another year has gone by!

It was truly amazing to see the activities you did during the last year. There was the "Survival Kit" for 1st year students that included many useful items that a Graphic Communications students needs during his/her time in our program.

The infamous "GCM between the sheets" calendar sold like hotcakes. You put an idea to life that was born during the last Annual Technical Conference of TAGA in Pittsburgh, PA.

Your dedication and hard work brought this student publication to life. You also managed to get some unbelievable support from industry. Without their dedication this publication would not have been possible.

Once again we have a wide variety of topics covered in this publication that will make it a great read.

Those of you in your final year at the Graphic Communications Management program at Ryerson I wish you all the best for life after university. You will be sorely missed! Before you leave, pass that spark of enthusiasm for the TAGA student chapter onto the next generation!

Congratulations on this great brochure. Enjoy the conference!

All the best to you,

Martin Habekost, Dr. rer. nat.
Ryerson TAGA student chapter advisor

PRESIDENTS' MESSAGE

This past year has been a time of incredible growth in the Ryerson University TAGA student chapter. We now have an established following in the Graphic Communications Management program. Last year, we had the fantastic opportunity to attend the 2007 TAGA conference in Pittsburgh, with six students representing Ryerson. This year we are lucky enough to have twelve students representing Ryerson University at the 60th annual TAGA conference.

The journal is a place for students to explore new ideas and make new discoveries in the Graphic Arts field. This year's edition of the Ryerson University journal is no different, so we welcome you to our journal- Print Your Fantasy. Starting out with a plain black cover you are compelled to enter the bright and exciting world of knowledge and innovation contained within. This journal represents a compilation of student work from third and fourth year. The majority of the papers research-based tests designed and carried out by students, the others are independent research projects. We are proud of all the hard work that has gone into this year's technical writing. Please check out the multimedia component, which holds an interactive PDF of the entire journal, appendices, an FM6 colour model and even a special surprise for those who look hard enough!

As the world continues to become more environmentally aware, our student chapter is no exception. The global concern for sustainability leads us to take strides into becoming more eco-conscious. In order to do our part, we chose to print our 2008 journal on FSC certified paper. Taking small strides towards using paper from responsibly managed forested and verified recycled sources will ensure that our industry continues to flourish well into the future.

We would like to thank everyone who has supported us this past year, including the staff and faculty of GCM at Ryerson University. A big thank you to all of the students who contributed to our efforts along the way and in a perfect world we would all be at the conference. A special thanks goes out to our staff advisor Dr. Martin Habekost for his continued support of our student group, and to Peter Roehrig for his printing expertise and continued patience.

The production of this journal would have also not been possible without the generous donation from Spicers, Webcom and also J&P Steel Rule Dies Co. We are so proud of this year's journal and we would not have been able to do it without your help. Thank you for continuing to support the future of our industry!

As we are both in our final year at Ryerson University, looking back we have so many fantastic memories. Although we might not miss staying in the lab until 2am, we will miss all the laughter and good times we've had together. This student chapter has evolved so much in the last three years, and with the success of the 'Between the Sheets' Calendar, first year kits and TAGAoke it is bound to continue to grow. We are excited to see what the future holds for the Ryerson TAGA student chapter and wish them many successes in the years to come!

Nicola Kidd & Scott Millward

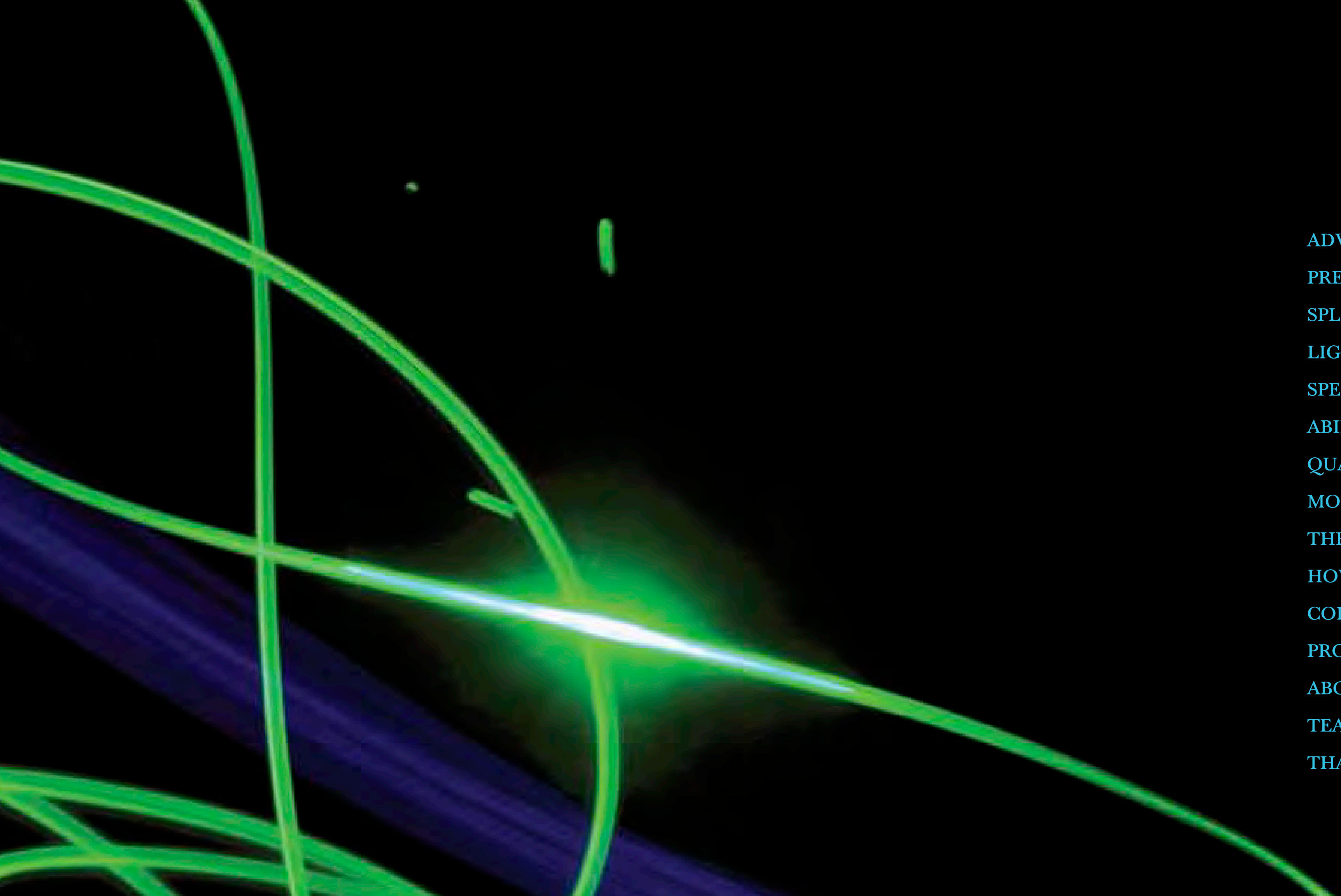


TABLE OF CONTENTS

SPLIT-FOUNTAIN PRINTING

Olayemi Alawiye, Erin Davies, Michael Morneau, Nathan Witt

SCOPE

The main property that is examined in this test is the contamination of one colour of ink into another when the oscillation of the inking rollers is set to full oscillation (25mm) and to minimum oscillation (~4mm) while implementing the split-fountain printing technique. The property is tested on a sheetfed offset press using process colours. By taking density readings throughout a press run, we can determine at which point contamination occurs when the press is at full and minimum oscillation. This is done primarily by taking readings from the ink zones of a press sheet that are in line with a lead splitter that is separating two colours of ink in the same fountain. A more subjective, but also valuable evaluation can be made by viewing the press sheets under controlled lighting conditions of an industry standard viewing booth.

Another important consideration is how the split-fountain technique is used in the print industry. Split-fountain printing is most often applied during security printing processes for rainbow prints or guilloches, which is slightly different from our experiment, as they normally blend spot colours as opposed to process inks. However, process inks should still illustrate realistic results. Separating inks in a single fountain has also been used to increase the amount of colours printed in a single press run, but the technique is very uncommon, especially in today's industry.

SUMMARY

We found that maximum oscillation of 25mm produced wider, more-noticeable blends of contamination. However, the levels of contamination between neighbouring colours on our test form were very consistent throughout a press run of 1,000 sheets. The minimum oscillation setting of roughly 4mm produced shorter, less-noticeable blends with irregular levels of contamination between neighboring colours throughout a press run of 1,000 sheets.

INTRODUCTION

Split-fountain printing is a technique used in the printing industry mainly in the area of security printing, and is commonly referred to as rainbow printing. Rainbow printing is used to create a blend of colours; not by printing one transparent ink on top of another, but by separating them in a single ink fountain and allowing the colours to blend in the inking system of the press. It is used for security documents as these types of blends are diffficult to reproduce. The split-fountain method is also used to print more than one colour from a single printing unit at the same time. This is beneficial for jobs that require two or more colours on smaller one- or two-colour presses. The objective of this topic is to see how quickly the contamination of inks that are split on one fountain occurs. The significance of this test is to see how efficiently colours can stay separated by splitters on the fountain for a method that requires no blending, and to see how quickly and consistently the contamination occurs for the method that requires the blending of colours (rainbow printing). Both of these methods are tested under full oscillation and zero oscillation on a Heidelberg Printmaster GTO 52-2P.

DEFINITIONS

For the explanation of this test, the two printing techniques that utilize split-fountain printing will be referred to as follows:

RAINBOW PRINTING

Where the ink is separated in the fountain only. The desired result is a unique, consistent blending of two colours on the press sheet.

GAP-FOUNTAIN PRINTING

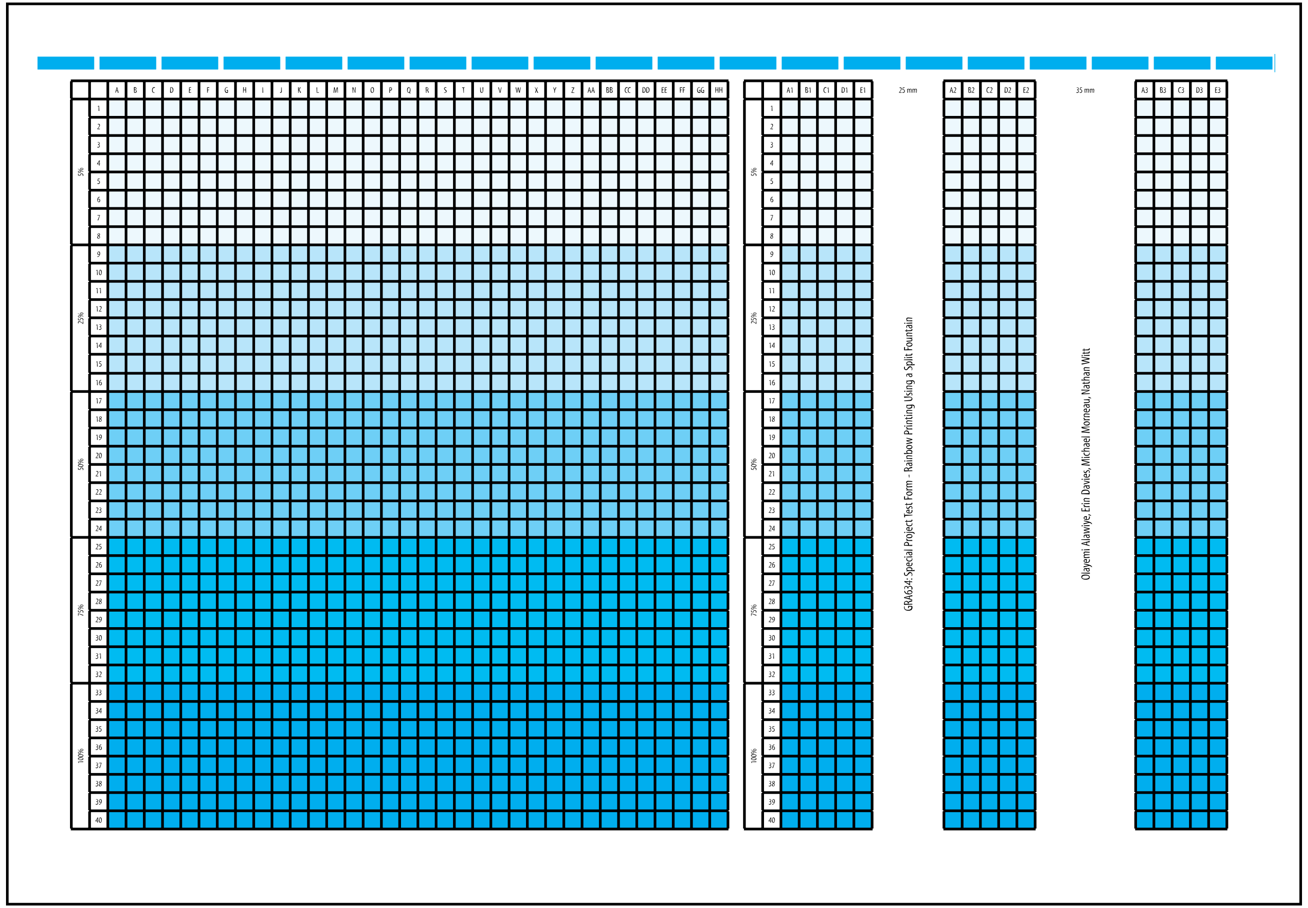
Where the ink is separated in the fountain and on the plate, by a gap of non-image area that is the same width as the splitter in the fountain. The desired result is two separated colours on the press sheet.

TESTING PRINCIPLE

The main principle of this experiment is to test the two split-fountain techniques, rainbow and gap-fountain, under two different amounts of oscillation. By examining the maximum oscillation, which is the normal amount for our press, and minimum oscillation, we can see its affect on blending and separating different ink supplies in the fountain as they make their way to the substrate. The main method of quantifying the results of this test will be through densitometric readings. As contamination is a part of the split-fountain method, the contamination which occurs between neighboring inks is the main focus of this experimentation.

Split-fountain printing is used to create special on-press blends for security or artistic means, or to print two or more colours on one printing unit (ie. increase colours down per unit). The test form that is used for this test is set up to allow for both blending and non-blending methods to be tested, so that the effectiveness of controlling oscillation can be seen and the rate of contamination can be observed.

TEST FORM



MATERIALS TESTED

INK SET

- BASF Corp. Printing Systems Group
- Cyan - Novavit 4F 713
- Magenta - Novavit 2F 713
- Yellow - Novavit 1F 713
- Black - Novavit 738

PAPER

- Euro Art Gloss DI - 14 X 20 60M
  102 lb, 150.79 g/m^3

EQUIPMENT USED

- Heidelberg Printmaster GTO 52-2P
- 1 X 25mm Lead Cast Ink Fountain Splitter
- 1 X 35mm Lead Cast Ink Fountain Splitter
- 2 X 0.5” Lead Cast Ink Fountain Splitters
- IHARA R710 Colour Reflection Densitometer

PROCEDURE

1. Use the created test form to create a dylux proof and then plates for the Printmaster GTO.
2. Mount the rainbow multi-colour plate in the first printing unit, and a second plate with a grid that divides the colours into quantifiable cells in the second printing unit.
3. Align the grid on the second unit to print in black over the rainbow pattern, with the lines of the grid intersecting the points at which the colours are separated in the fountain.
4. Measure the locations to place the lead splitters in the fountain. Do this by putting the dylux proof up to the fountain and placing the splitters in line with those areas on the plate where colours are desired to be separated.
5. Split the ink fountain of the first unit into five sections to print multiple colours side by side for the rainbow. The colour sequence from drive side to operator side is cyan, magenta, yellow, magenta, and then cyan. Fill the second unit inking fountain with black ink.
6. Adjust the ink keys for both units so that the ink film reaches our standard ink densities for the GTO.
7. First run the press with the maximum amount of oscillation (25mm) for the inking rollers on the first unit. Print 1,000 sheets after makeready is completed. Place a marker after each 100 sheets printed to allow for easier identification of every 100th sheet.
8. Wash up the plate, blanket, and inking system of the first printing unit.
9. Following the same procedure as before, by measuring out the locations on the inking fountain to place the splitters and place the ink in each section following the same sequence above.

10. Run the press with minimum (~4mm) oscillation for the inking rollers on the first printing unit. Print 1,000 sheets after makeready is completed.
11. Assess every 100th sheet from both press runs for the following criteria:
    a. Using the densitometer, measure the densities of the colours cyan and magenta used in the rainbow (the large grid), measuring cells F12, F20, F28, and F36. Make these same measurements in columns H and J as well. Next measure the densities of yellow and magenta for cells U12, U20, U28, and U36. Make these same measurements for columns W and Y.
    b. Using the densitometer, measure the densities of ink in the other image areas separated by a gap.
        i. Magenta: cells E1-12, E1-20, E1-28, and E1-36.
        ii. Yellow: cells A2-12, A2-20, A2-28, and A2-39.
        iii. Cyan: cells E2-12, E2-20, E2-28, and E2-36.
        iv. Magenta: cells A3-12, A3-20, A3-28, and A3-36.

*A chart was created to aid with recording the density readings.

12. Visually examine the press sheets to see what blending patterns or repeating effects occurred due to the contamination of the inks.

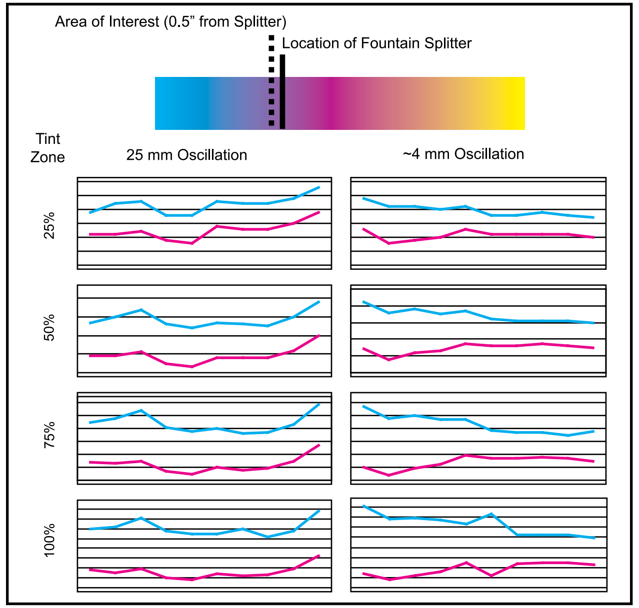
RESULTS

RAINBOW PRINT

Density readings were gathered in each tint zone (25%, 50%, 75%, 100%) at the location of the fountain splitter, and 0.5" towards each colour. This data was used to track contamination of the ink during the press run, by reading every 100th sheet.

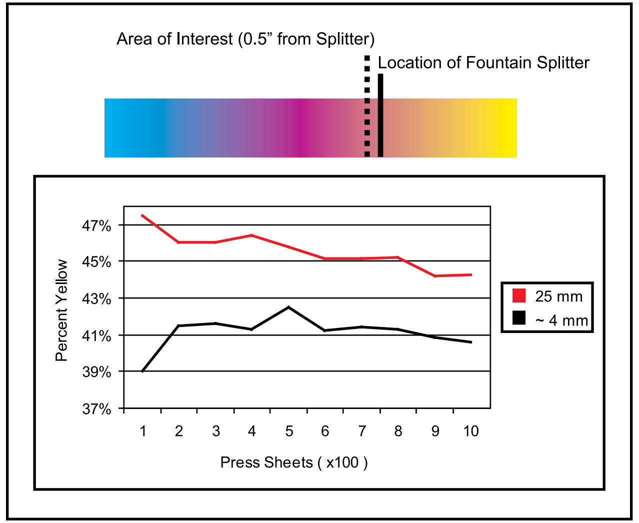
The following conclusions were made from the data:

1. At 25mm of oscillation, the colours showed that they had mixed at a higher amount visually, but the amount of contamination seemed to occur mostly during makeready, and then remained stable. In other words, the colours obviously mixed much more at the beginning, but seemed to stop mixing at a certain point. The contamination at approximately 4mm of oscillation seemed to occur more gradually, but did not tend to stabilize during the run, indicating that a longer press run would show more and more contamination over time. These graphs show cyan and magenta densities over the press runs. The amount of cyan and magenta in the first press run seem to increase and decrease at the same rate at the same time, indicating that little contamination of inks is occurring post-makeready. As the amounts of cyan and magenta come together in the second column, it shows the colours becoming contaminated.



2. We found no conclusive data to show that the amount of our tint zones (25%, 50%, 75%, 100%) had any effect on the amount of contamination. The trends of contamination over time were generally similar in each tint zone for each colour, with each amount of oscillation. This can also be seen in the graphs above.

3. In conjunction with our visual evaluation, we found conclusive data that showed some areas of the rainbow print at 25mm oscillation becoming less contaminated towards the end of the press run. The following graph shows a magenta area of the rainbow, where it is being contaminated by yellow. As more sheets are printed, the proportion of yellow compared to magenta and yellow is steadily decreasing, indicating that the magenta area is becoming less contaminated.



GAP-FOUNTAIN PRINT

Density readings were gathered at the edge of each strip for the contaminant colour. At both amounts of oscillation, contamination occurred immediately. Our data showed no real pattern, and could indicate no real conclusions without a more extensive test. The only results we could draw from this would be that a much larger gap would be needed to find acceptable gap-fountain printing without contamination, but such an amount could not be determined without further tests. Even at a 35mm gap (10mm wider than maximum oscillation), contamination was immediate. This involves the natural tendency of evenly viscous inks to flow laterally during impression from roller to roller (Leach & Pierce, 1993). A higher viscosity ink will have a lower lateral flow, but a wider gap would still most likely be necessary. Another method we discovered is to use a combination of fountain splitters and actually cut lines into the rubber rollers in the ink train (Larsen, 1962). This would not ensure that absolutely no mixing would occur, but could be used where maximum quality is not necessary. This is also only recommended for presses that would utilize split-fountain printing often, which would not be the case in many of today's shops. Also, since the rollers would be permanently cut, this would limit the areas of the press sheet as to where the fountain splitter could be located.

DISCUSSION

In order for ink to be spread smoothly across the length of a roller, lateral oscillation is needed. By shifting from left to right, the sharply defined channels of ink created by the fountain keys are blended together. Thus the tendency of the ink to form "rings" around the rollers as it travels through the ink train will be reduced (Porter, 1980). By blending the ink zones together through oscillation, halftone images that run across multiple ink zones do not show sharp colour shifts because ink densities do not undergo a sharp change. This, along with ink splitting between rollers and agitation in the ink fountain, all help work the ink into an ideal thixotropic state for printing. This oscillation is a vital part of any offset lithographic press, and is engaged for the majority of press runs.

However, when printing certain "difficult images" and especially in split-fountain work, roller oscillation should be reduced to improve printability (Porter, 1980). By reducing the oscillation of the ink train rollers during a split-fountain run, a more distinct split between two colours can be achieved. Because the rollers are travelling a lessened lateral distance, the length of the blend between two butting inks will also be lessened. This can plainly be seen when visually assessing the resultant press sheets of our experiment. The colours of the second run (minimum oscillation) have distinct areas of pure process colour with short blends between them, while the colours of the first run (maximum oscillation) were contaminated throughout the press sheet.

The consistency of these blends is of considerable importance for security printing applications, where product quality cannot be compromised. Our results show that oscillation of 4mm produced less consistent results than were seen in the full oscillation blends. In other words, contamination did not "run wild" with oscillation set to 25mm, as might be assumed. In fact, initial contamination during the makeready of the full oscillation test was actually lessened and stabilized as the press run proceeded. This finding was supported by both visual assessment of the yellow area, and densitometric evidence gathered. In the case of roughly 4mm oscillation, irregular peaks occurred in contamination, indicating that such a low oscillation setting may actually produce inconsistency over a long security document press run.

Either of these results may be advantageous depending on the application of the split-fountain technique. For the case of maximizing the number of colours-down per pass through the press, minimal roller oscillation would be preferred. This would allow for multiple distinct colours to be printed by one unit (ie. one spot colour + black) and minimize the transitional area between ink colours. For the case of rainbow and guilloche security patterns, oscillation may be engaged at a level above the minimum, in order to produce a longer "third colour" transition between two spots and increase blend consistency (Warner & Adams, 2005).

RECOMMENDATIONS

PRINTABILITY

For consistent rainbow prints during a long run, using higher oscillation would appear to be the better option, but will be offset by a larger amount of blending. However, less oscillation will lead to a more viscous ink and eventually more print quality problems. The thixotropic property of ink demands that it be broken down by the circumferential and lateral movement of the rollers. Printing at lower oscillation will allow for a higher-viscosity ink and uneven distribution on the rollers. These characteristics maximize the stress on the substrate, and can cause the surface to start picking or linting (Larsen, 1962). Mechanical ghosting can occur in solids with insufficient lateral distribution because the film is not even enough to replace a heavy solid of ink that has been removed from the form rollers by the plate (Scarlett & Eldred, 1984). The heavy amount of ink needed for the solid robs the form rollers of the necessary amount of ink needed to print the corresponding images. This often occurs where a narrow solid precedes or follows a wider solid (Crouse & Eldred, 1981). This is less of a problem on presses that use more form rollers. If this is not a problem, using a combination of lower oscillation and a lower viscosity ink may work, but can cause problems like streaks and tinting. The action of the ink train rollers will still lower the viscosity of the ink, and if the viscosity of the ink becomes too close to that of the fountain solution, the fountain solution begins to emulsify into the ink supply (Leach & Pierce, 1993). This occurs even when there is no chemical affinity between the solution and the ink. The optimum characteristics to minimize blending by using minimum oscillation, would be to print short runs at low speed or with substrates that have great ability to resist surface picking, but this will greatly increase cost.

In the case of some fountain splitters, a felt lining will be attached to the surface of the splitter which directly contacts the fountain roller as a precaution against scratching the roller's surface. As experienced in our press run, small particles of felt may break off of the fountain splitter felts due to friction with the ink fountain roller. These particles pose a contamination risk to the ink. The contamination caused by the fountain splitter felt eventually produced small hickies on the press sheets. This problem could have been avoided had solid metal fountain splitters been used, as there would be less likelihood of material breakdown on press.

RUNABILITIY

Adjusting the oscillation of an offset lithographic press is a somewhat uncommon task in the contemporary printing industry. These adjustments should be made by skilled and experienced press operators who are fully versed in the mechanical adjustments necessary to control the lateral distribution. If these settings are made improperly, severe damage could occur to the press or rollers, which would result in severe press run delays. Making the adjustment itself will also add time to makeready and wash-up, as the press will most likely not be used in its minimum oscillation configuration regularly. These factors will increase the costs needed to be covered by customers.

END USE

The end product of split fountain job can suit several very different purposes. In a less common use of fountain-splitting technique, the inking unit and imposition are modified to allow for two colours to be printed in a single pass through the printing unit. If used for this purpose, ink contamination is undesirable. For this process, we determined that even if oscillation is reduced to as little as 4mm contamination between inks will still occur across a fountain splitter of up to 35mm in width, as found in our experiment. In order to print two distinct colours from a single fountain, considerable distance must be allowed between the different colour areas on the plate (>35mm), a considerable gap should be created between the inks in the fountain itself (>35mm split), and oscillation should be set to the absolute minimum possible on the press.

The exact criteria to avoid contamination will vary depending on the characteristics of the inks used and the press itself, and was not determined by our experiment. If these criteria are met, then two pure colours could potentially be printed from a single unit. However, over a long press run the ink spreading (as seen with 4mm oscillation) and accidental cross-contamination when filling the ink fountain will produce a high allowance for colour contamination. This method is not advisable for high quality jobs, where exact corporate colour matching is important, due to the risk of accidental contamination.

Alternately, ink contamination is precisely the goal when printing security guilloches (rainbow). For rainbow printing, after makeready is completed we found that cross-contamination remained relatively constant when full oscillation was used. A consistent contamination level in the rainbow effect was produced in a press run of 1,000 sheets and proposes that a consistent effect can be maintained for a much longer run with considerable oscillation in the inking system. This means that consistent guilloches can be printed in security documents for lengthy runs with oscillation engaged on a Heidelberg GTO press. The inconsistency of contamination when the rollers were set to 4mm of oscillation indicates that instable blend quality would result over a longer press run. Thus, the somewhat counter-intuitive recommendation for producing security guilloches is not to set the oscillation to as low as 4mm. More extensive testing would be required to determine the optimal oscillation setting for consistent rainbow printing under our experiment conditions.

Additionally, lengthening the "gradient" between the two spot colours of a guilloche would increase the difficulty of reproduction by low quality means. First, scanning will be difficult due to the fine lines and shifting colours, which will result in the pattern being converted to dots. When printed, the pattern would be produced by halftone dots and not a solid single colour, thus making it easy to detect. A longer transition would simply make the pattern more evident to the naked-eye. A lengthy blend may also exceed the resolution abilities of lower quality non-impact devices. Such patterns could be produced consistently as a security measure, with full oscillation engaged.

A long transition between two spot colours may also be desirable for the production of limited-edition art prints or specialty posters, as it creates an appealing visual effect. This will give end-users a unique looking printed product, and allow the printer to provide an innovative artistic specialty service.

REFERENCES

Crouse, D.B. & Eldred, N.R. (1981). *Solving Offset Ink Problems*. Pittsburgh, PA: Graphic Arts Technical Foundation.

Larsen, L.M. (1962). *Industrial Printing Inks*. New York: Reinhold Publishing Corporation.

Leach, R.H., & Pierce, R.J. (Eds.). (1993). *The Printing Ink Manual*. London: Society of British Printing Ink Manufacturers Ltd.

Porter, A.S. (1980). *A Manual for Lithographic Press Operation*. London and Manchester: Litho Training Services Ltd.

Scarlett, T. & Eldred, N.R (1984). *What the Printer Should Know About Ink*. Pittsburgh, PA: Graphic Arts Technical Foundation.

Warner, Richard D. & Adams, Richard M. (2005). *Introduction to Security Printing*. Pittsburgh, PA: PIA/GATFPress.

LIGHT FASTNESS OF DYE-BASED, PIGMENT-BASED AND HYBRID INKJET INKS

Sandra Abballe, Julia Hennessey, Jieun (Eden) Kim, Aida Shirvani

SCOPE AND SUMMARY

The property tested for this report is lightfastness of pigment-based and dye-based inks when printed using industrial and home inkjet printers. The purpose of this test is to determine which of pigment-based or dye-based inkjet inks offer the best lightfastness.

Properties not tested for in this report include fading due to Ultraviolet (UV) light as well as exposure to ozone and gas. To test for lightfastness under UV conditions, a fluorescent lamp emitting UV radiation directed at a printed sample for a predetermined amount of time would have been needed. Investigating ozone and gas fading effects requires an ozone chamber to expose samples to the ozone pollutant (Ludlow, 2005). Following each test, exposed test strips are evaluated in comparison to unexposed originals.

The most important factors affecting the longevity of a printed piece are the colorant - dye or pigment - and the paper printed on in combination. The test was carried out using the ASTM 3424-01 procedure. The test samples were printed in CMYK and RGB on the various paper and ink combinations. The samples were exposed to the simulated equivalent to 40 days of actual exposure to sunlight in Washington, United States. We used a spectrometer to obtain ΔL^*, Δa^*, Δb^*, and ΔE_{ab} values in order to examine fading and gamut changes.

Based on our results, we determined the best lightfastness was achieved using a combination of the 8-colour pigment-based ink (UltraChrome K3™) and manufacturer recommended glossy paper. It was also found that the glossy papers consistently reproduced a larger colour gamut than the matte papers. Examination of the test results also came to show that the more technologically advanced inks used by industrial printers experienced less of a colour shift after exposure than the inks for the desktop printers. Of the desktop printers, the dye-based inks produced a broader colour gamut on glossy paper than the pigment-based ink.

INTRODUCTION

Lightfastness is an important consideration for printed items intended for long-term use, such as for archival purposes, indoor and outdoor billboards or signs, as well as photographs. It is a particularly relevant issue for any product that must withstand prolonged exposure to light. There continues to be a steady increase in the use of both personal and industrial inkjet printers since the early 1990's due to enhanced quality and low noise (Ahn, 2001). Ink jet's popularity is increasing especially as an alternative to traditional photography due to the increased use of digital cameras from which consumers wish to print their own photos. The problem with this trend is that photographs developed from film have a much higher fade resistance over time than documents printed on an inkjet printer.

In previous years, inkjets mostly utilized dye-based inks because they provide a wider colour gamut. However, due to the low lightfastness of dye-based inks pigment-based inks have grown in popularity (Fischer, 2007). With technological improvements both Epson and HP have developed advanced inks that retain a wide gamut and produce a higher lightfastness than their corresponding traditional inks. Epson's UltraChrome K3™ is a hybrid ink that uses the standard colour pigment with small additions of a light fast dye (Henry, 2004). HP developed the Vivera® dye based ink set that has improved lightfastness with a typical large gamut that dye inks can produce.

The objective of this test is to determine which combination of inkjet ink and paper result in the highest achievable lightfastness when exposed to the artificial sunlight of a Fade-o-meter. Expected educational gains from this test include a better understanding of the effect light exposure has on digital prints and a further exploration new inkjet ink technology.

DEFINITIONS AND EQUATIONS:

ASTM

American Society for Testing and Materials

ASTM D 3424-01

Standard Test Methods for Evaluating the Relative Lightfastness and Weatherability of Printed Matter1

ASTM D 2244-0

Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

LIGHTFASTNESS

The degree to which a paper or printed piece will resist a change in color when exposed to light (Lenz, 2007)

PERMANENCE

In paper terminology permanence refers to the ability of paper to retain, for a given period of time, desirable properties such as color, and folding endurance. Prolonged exposure to light, humidity, and adverse temperatures will affect the permanence of paper (Lenz, 2007)

CIE1976 Lab uniform color space

Color space based on nonlinear expansion of the tristimulus values on three axes for lightness (L*), red-green (a*), and yellow-blue (b*) (ASTM D2244-05).

CIELab color-difference equation:

ΔE_{ab}= Total colour difference between two colours

$$\Delta E_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

colour difference in L*a*b*

$$\Delta L^* = L^*_T - L^*_S$$

$$\Delta a^* = a^*_T - a^*_S$$

$$\Delta b^* = b^*_T - b^*_S$$

Where T=Trial and S=Standard

TESTING PRINCIPLE

This test is related to practical means in the printing industry because the inkjet inks and the different paper types and coatings we tested on are broadly used in both professional and home-based digital printing. For example the HP Indigo 5000 utilizes Vivera® dye-based inks for Variable Data Printing (VDP) and UltraChrome K3™ inks are used on large and small-format colour proofers and large format production printing. Lightfastness has become a major issue when generating inkjet-based prints because of the concern about their ability to endure over time. The degree of lightfastness varies depending on the properties of ink and paper. In industry, when prints are made using inkjet printers, either pigment-based or dye-based inks are used. Images that need to be preserved will be subjected to higher lightfastness requirements. Therefore choosing proper inks and paper is vital in order to minimize fading and prevent colour changes due to light exposure. In order to comply with industry, the lightfastness testing standard ASTM D 3424-01 was used to meet practical requirements for testing lightfastness.

An Atlas Fade-o-meter equipped with a carbon-arc light source to determine the resistance to fading was employed in this test. The carbon-arc emits an intense actinic light, simulating ordinary daylight that can produce results within days rather than months (Henry, 2004).

The Blue Wool Scale, adopted by the printing industry, was used to determine the exposure hours that are equivalent to an actual fading exposure period. The degree of lightfastness that was used to set the exposure period was #7. This is because according to the Blue Wool Scale it is the optimal standard period for fading. Step 7 in the Blue Wool Scale is an exposure of 80 hours of fading which is equivalent to 40 days of actual exposure to sunlight in Washington, United States.

Degrees of light fastness	Hours of exposure (using a carbon arc lamp, discharging at 135 volts, 16 amperes)	Comment
Blue Wool Scale #7	80	Excellent lightfastness A printed image will remain unchanged for more than 100 years of light exposure with appropriate mounting and display.

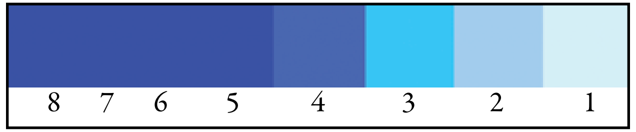


Figure 2–1: Blue Wool Scale

"This figure is based on the time to see visible changes (i.e. fade) when the particular wool is exposed to a carbon arc light source (that approximates to the same wavelengths emitted by the sun through a cycle of 50% light and 50% darkness" (Sun Chemical, 2007).

A Gregtag Macbeth Color-Eye 2145 Spectrophotometer was later used to measure the CIELab values of faded and unexposed printed samples.

There are other laboratory light sources that can be used as alternatives to carbon arc. Xenon filled discharged lamps are now commonly used as they produce a more continuous light spectrum (Jenkin, 2006). Although not all of them exactly duplicate the exposure effects to natural light, they are still effective indicators of resistance to fading (MacEvoy, 2006).

The carbon arc lamp with an appropriate filter system is closer to daylight than the carbon-arc. In turn, for this test carbon arc is better suited due to the fast rate of acceleration and is better with exposure to natural daylight. Since the Xenon lamp is bluer than the noontime tropical sunlight with clean air they also require Xenon short arc lamps. These lamps have the drawback of requiring very high voltage starting pulses at around 30,000 volts (Klipstein, 1996). Fluorescent light can also be used but it is similar to that of a daylight fluorescent lamp and fade can be 100 times slower compared to a carbon arc light (Sun Chemical, 2007).

MATERIALS TESTED:

INKS TESTED

- UltraChrome K3™ Ink (Epson Stylus Pro 4800)
- Pigment Based Ink (Epson Stylus C84)
- Vivera® dye based Ink (HP Designjet 130)
- Dye Based Ink (HP K60)

Substrates Tested

Testprint	Size (inches)	Basis Weight (lbs.)	Grammage (g/m²)
Epson Premium Glossy Photo Paper	8.5 x 11	68	260
Epson Matte Photo Paper	8.5 x 11	45	185
Staples Glossy Photo Paper	8.5 x 11	53	200
Staples Matte Photo Paper	8.5 x 11	61	230
HP Advanced Glossy Photo Paper	8.5 x 11	66	250
HP Advanced Matte Photo Paper	8.5 x 11	36	135

EQUIPMENT USED:

- Atlas Color Fade-o-meter (1950)
  Location: Dominion Colour Corporation
  515 Consumers Road, 7th Floor
  Toronto, Ontario, Canada M2J 4Z2

Figure 2–2: Atlas Color Fade-o-meter

Figure 2–3: Atlas Color Fade-o-meter (Chamber)

Printers

- Epson Stylus Pro 4800 (professional edition)
- Epson Stylus C84 (home inkjet)
- HP Designjet 130 (professional edition)
- HP K60 (home inkjet)

SPECTROPHOTOMETER

- Gretag Macbeth Color-Eye 2145
- ProPalette Software v5.2.1

SPECTRODENSITOMETER

- X-Rite 500 Series

SOFTWARE

- Microsoft Excel

PROCEDURE

1. Use Adobe InDesign to create 2" x 4" test strips.
2. Obtain two of: Epson Premium Glossy photo paper, Epson Matte photo papers, HP advanced glossy photo paper, HP advanced Matte photo paper and four of Staples® Glossy photo paper and Staples® Matte photo paper.
3. Print the test strips by placing two strips up on a page, trial to be exposed and one standard for later comparison.
4. Select four inkjet printers to print the test samples or forms - the four inkjet printers are: Epson Stylus Pro 4800, Epson Stylus C84, HP Designjet 130, and HP K60.
5. For each inkjet printer, output the test print in accordance with their manufacturer's paper, printing four copies on each inkjet: Glossy and Matte and the other two on Staples® Glossy and Matte.
6. Trim all samples to 2" x 4" once they have all been printed in order for the samples to fit into the Fade-o-meter, giving you 32 samples in total.
7. Label the test prints accordingly to the inkjet type and paper.
8. Take L*a*b* readings from the unexposed controls and save the data.
9. Set the humidity control and temperature controls for the Fade-o-meter.
10. Place the samples in the chamber of Fade-o-meter.
11. Expose samples for 80 hours at 135 volts, 16 amperes.
12. After exposure, take L*a*b* readings from the exposed samples using the spectrophotometer. Incorporate L*a*b* readings from unexposed controls in order to obtain ΔE_{ab}.
13. Organize the data in Excel and plot the gamuts for each type of paper.

RESULTS

PRINTER / PAPER	UNEXPOSED CONTROLS GAMUT SIZE	EXPOSED SAMPLE GAMUT SIZE	SIZE DIFFERENCE	REDUCTION IN GAMUT SIZE (%)
Epson Stylus C84 Manufacturer Glossy	377,698	366,600	11,098	2.94%
Epson Stylus C84 Manufacturer Matte	262,215	248,176	14,039	5.35%
Epson Stylus C84 Staples® Glossy	383,506	367,879	15,627	4.07%
Epson Stylus C84 Staples® Matte	252,366	239,567	12,799	5.07%
HP K60 Manufacturer Glossy	388,004	315,988	72,016	18.56%
HP K60 Manufacturer Matte	308,505	191,947	116,558	37.78%
HP K60 Staples® Glossy	369,611	270,233	99,378	26.89%
HP K60 Staples® Matte	319,195	252,508	66,687	20.89%
Epson Stylus Pro 4800 Manufacturer Glossy	641,044	597,322	43,722	6.82%
Epson Stylus Pro 4800 Manufacturer Matte	159,416	135,965	23,451	14.71%
Epson Stylus Pro 4800 Staples® Glossy	502,302	484,690	17,612	3.51%
Epson Stylus Pro 4800 Staples® Matte	311,666	279,820	31,846	10.22%
HP Designjet 130 Manufacturer Glossy	630,935	595,407	35,528	5.63%
HP Designjet 130 Manufacturer Matte	323,210	267,458	55,752	17.25%
HP Designjet 130 Staples® Glossy	494,249	410,531	83,718	16.94%
HP Designjet 130 Staples® Matte	296,201	254,526	41,675	14.07%

ΔE_{AB}

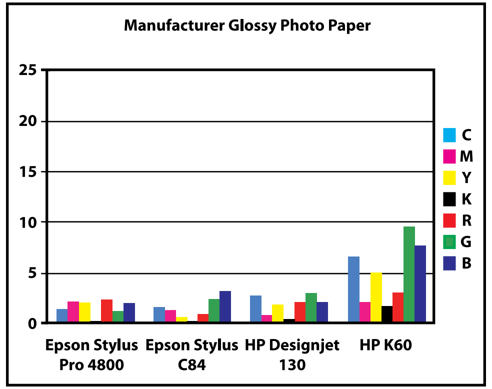


Figure 2–4: Manufacturer Glossy Photo Paper

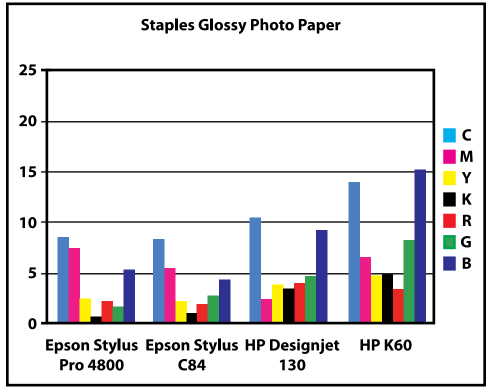


Figure 2–6: Staples® Glossy Photo Paper

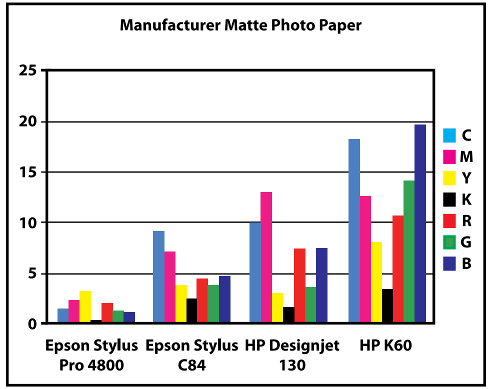


Figure 2–5: Manufacturer Matte Photo Paper

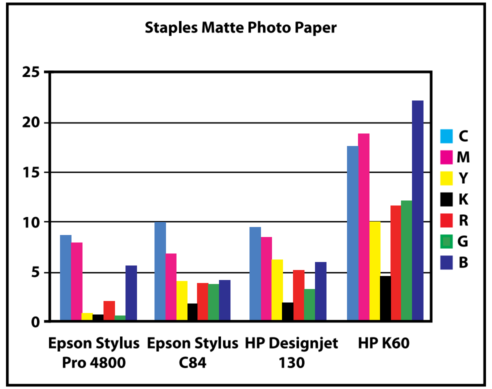


Figure 2–7: Staples® Matte Photo Paper

ΔL*

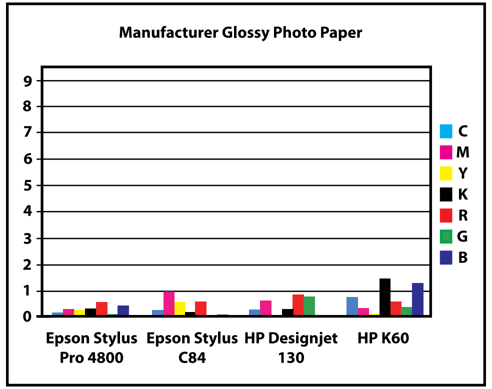


Figure 2–8: Manufacturer Glossy Photo Paper

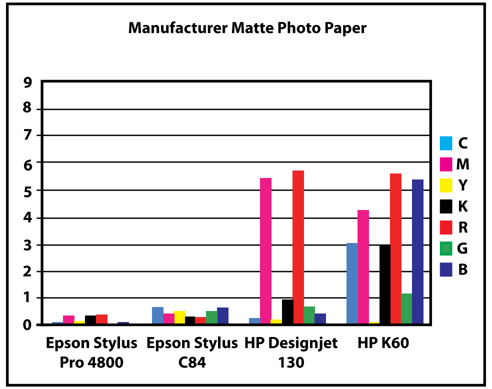


Figure 2–9: Manufacturer Matte Photo Paper

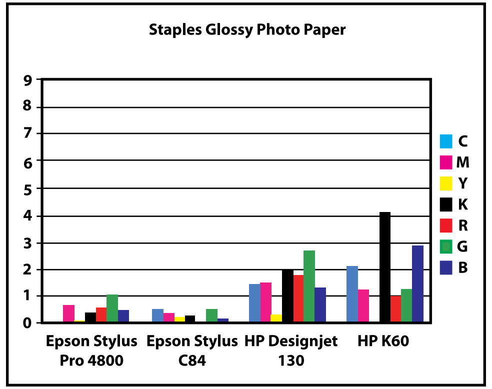


Figure 2–10: Staples® Glossy Photo Paper

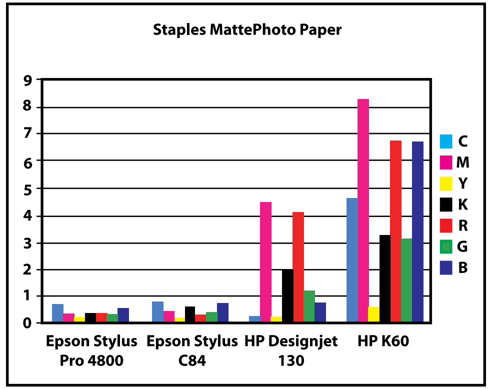


Figure 2–11: Staples® Matte Photo Paper

ΔA*

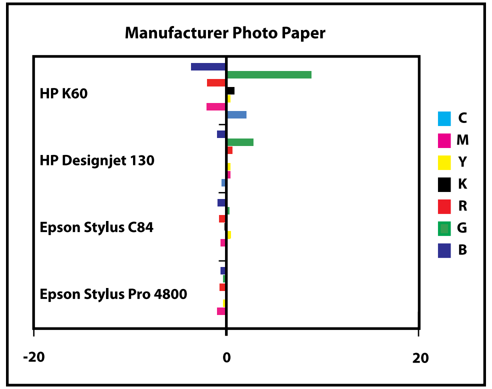


Figure 2–12: Manufacturer Glossy Photo Paper

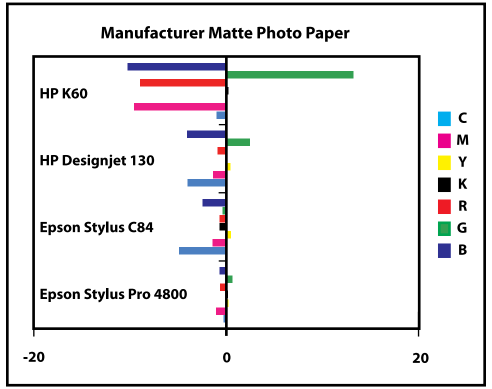


Figure 2–13: Manufacturer Matte Photo Paper

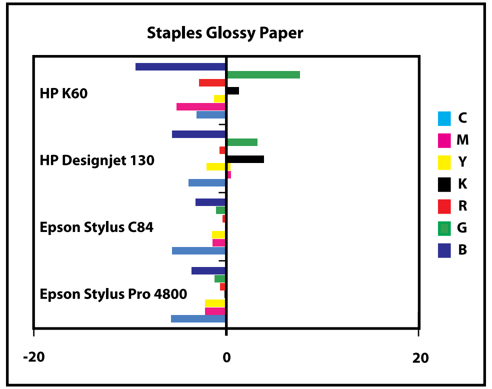


Figure 2–14: Staples® Glossy Photo Paper

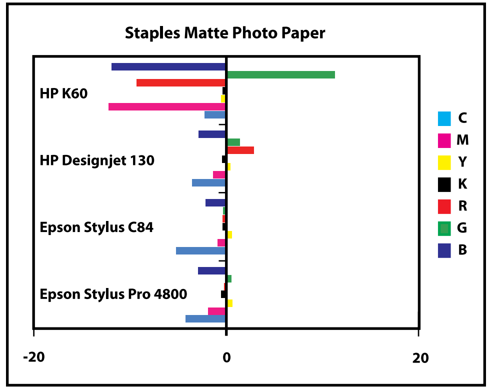


Figure 2–15: Staples® Matte Photo Paper

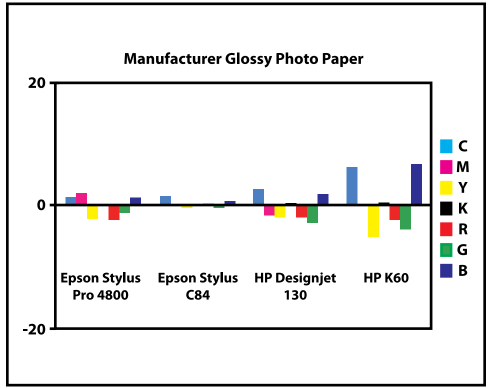


Figure 2–16: Manufacturer Glossy Photo Paper

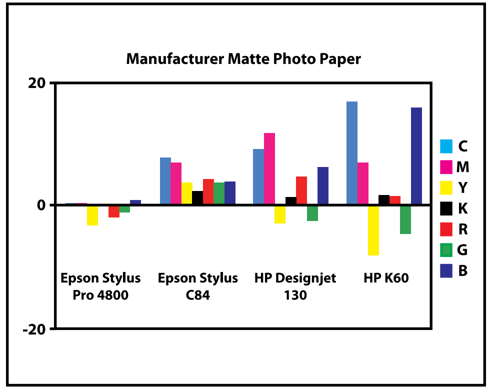


Figure 2–17: Manufacturer Matte Photo Paper

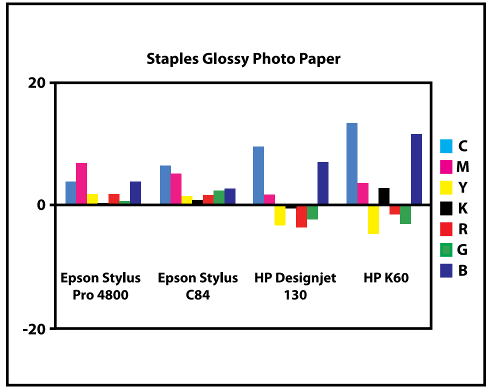


Figure 2–18: Staples® Glossy Photo Paper

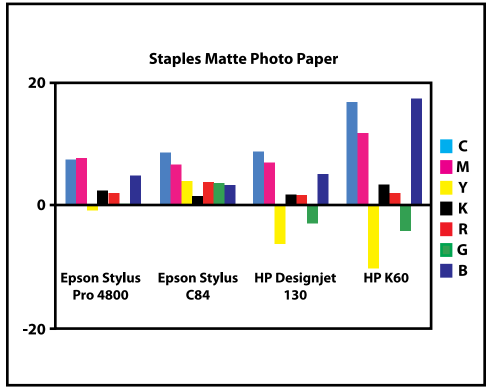


Figure 2–19: Staples® Matte Photo Paper

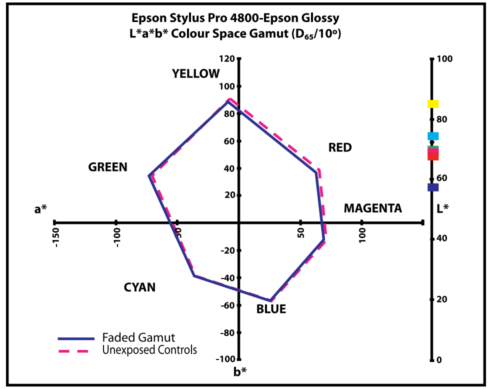


Figure 2–20: Epson Stylus Pro 4800-Epson Glossy

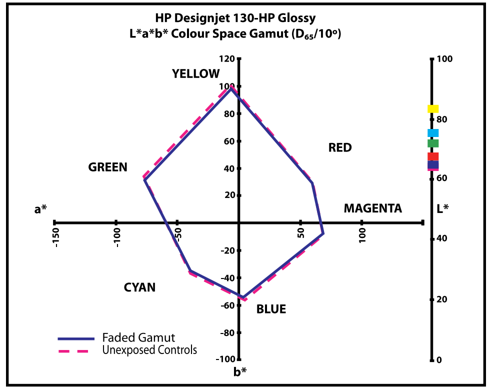


Figure 2–21: HP Designjet 130-Epson Glossy

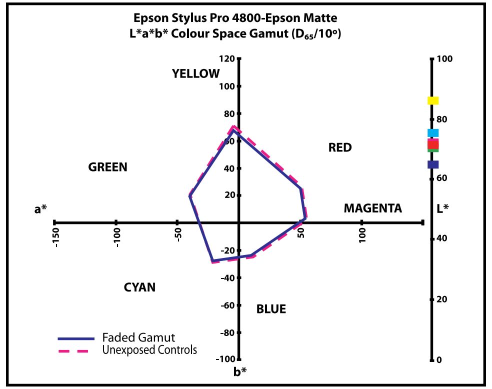


Figure 2–22: Epson Stylus Pro 4800-Epson Matte

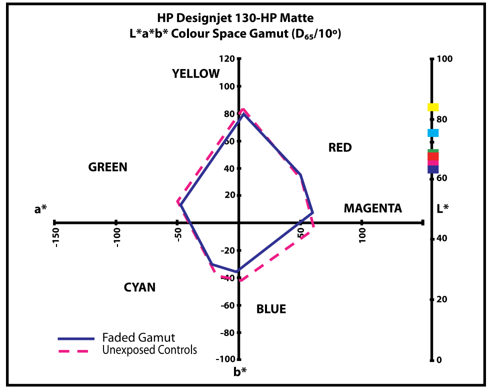


Figure 2–23: HP Designjet 130-HP Matte

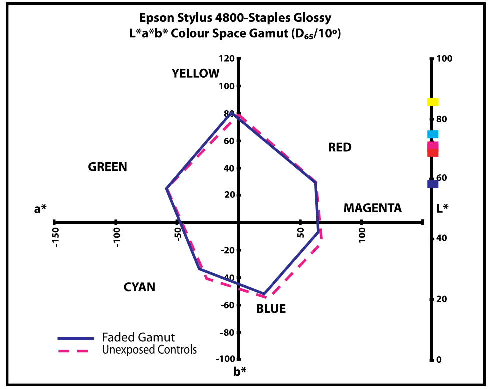


Figure 2–24: Epson Stylus Pro 4800-Staples® Glossy

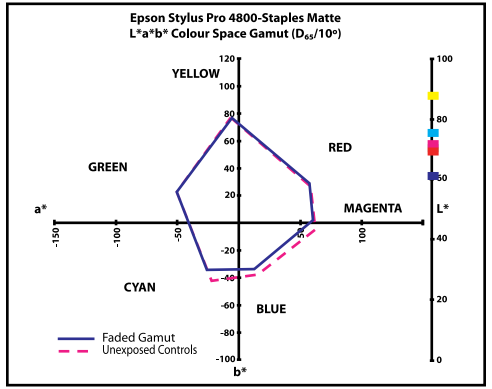


Figure 2–26: Epson Stylus Pro 4800-Staples® Matte

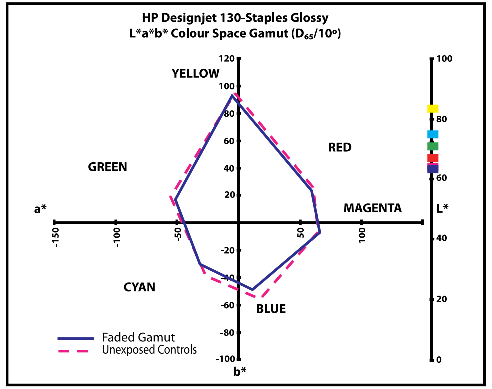


Figure 2–25: HP Designjet 130-Staples® Glossy

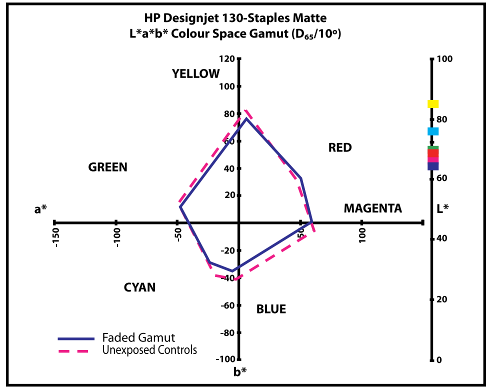


Figure 2–27: HP Designjet 130-Staples® Matte

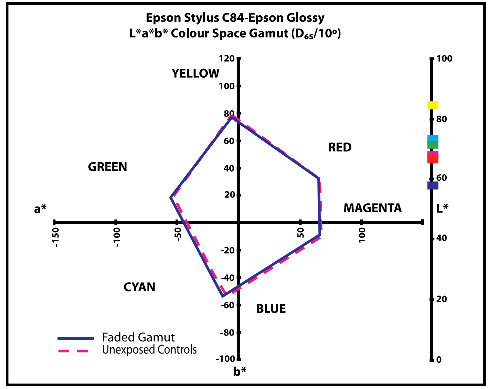


Figure 2–28: Epson Stylus C84 - Epson Glossy

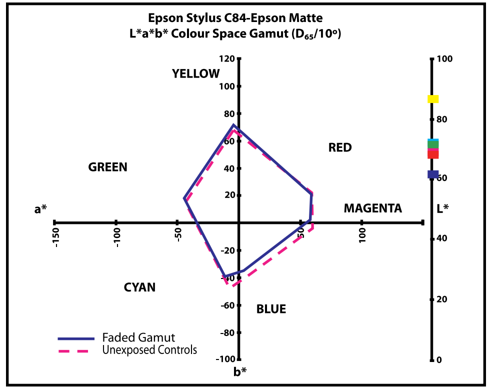


Figure 2–30: Epson Stylus C84 - Epson Matte

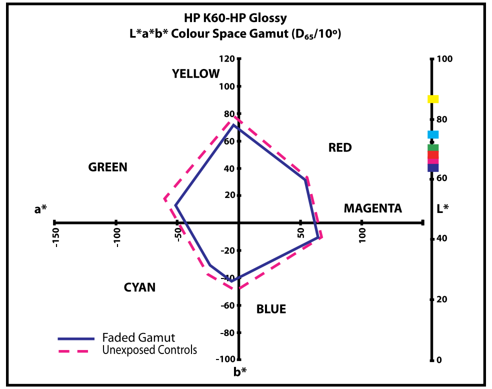


Figure 2–29: HP K60- HP Glossy

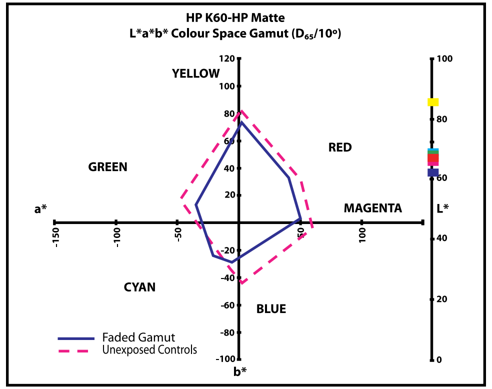


Figure 2–31: HP K60- HP Matte

gamut comparison (cont'...)

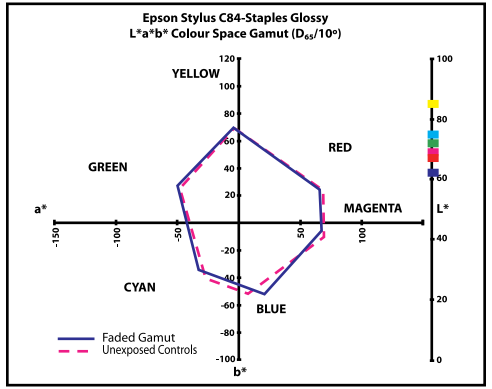


Figure 2–32: Epson Stylus C84- Staples® Glossy

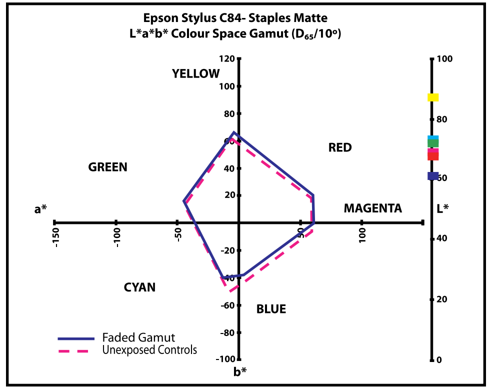


Figure 2–34: Epson Stylus C84- Staples® Matte

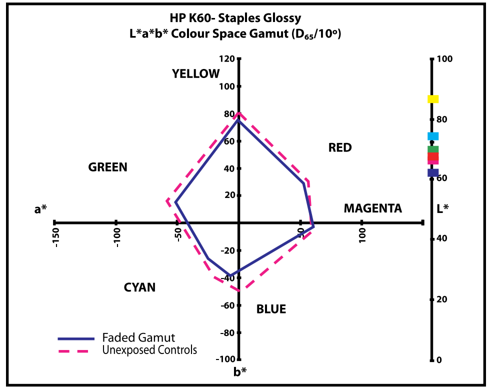


Figure 2–33: HP K60- Staples® Glossy

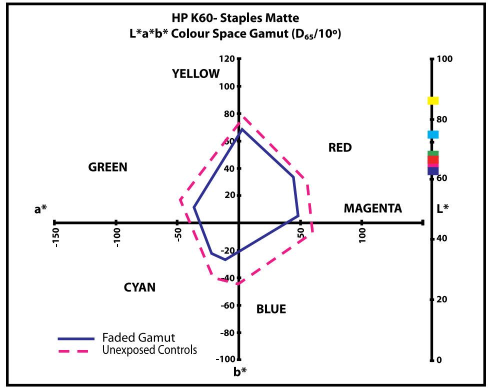


Figure 2–35: HP K60- Staples® Matte

DISCUSSION

The results are explained by analyzing ΔE_{ab} and the colour gamuts of samples due to the contrast correlation between dye-based and pigment-based inks. Dye-based inks produce a bigger gamut but tend to fade faster, whereas pigment-based inks have better lightfastness but produce a smaller gamut (Fischer, 2007). The results can also be explained in relation to the different papers used because "the choice of substrate, the substrate coating and stability of the substrate can have a profound impact on image lightfastness" (Sensient, 2005).

In our test the ΔE_{ab} range represents the change in colour after light exposure over a certain amount of time. When the ΔE_{ab} exceeds the tolerance of 5.0 the colour difference becomes clearly visible (Breede, 1999). From the results of our testing, we found that the ΔE_{ab} values of the unexposed control and the exposed samples from the Epson Stylus Pro 4800 (UltraChrome K3™) and Epson Stylus C84 (pigment-based) have fewer instances outside of 5.0 than the values from HP Designjet 130 (Vivera® dye-based) and HP K60 (dye-based). Our findings are parallel to research, which proves that pigment inks provide higher lightfastness when compared to dye-based inks (Fischer, 2007). The composition of the inks is the main cause for this difference. Since pigment-based inks are composed of larger molecules that are clustered together it inherently has a higher lightfastness (Sensient, 2005). Due to the fact that dye-based inks are composed of small molecules that are evenly spread out, the light will have a larger effect on the molecules (Boley, 1999).

In addition, when comparing the Epson Stylus C84 to the HP K60 it was found that the HP K60 printer produced the bigger gamut on all papers tested. That is because the smaller molecules of dye-based inks are transparent which produces more luminous and saturated colour (Fischer, 2007). On the other hand, the Epson Stylus C84 had a smaller gamut reduction due to fading, which is evidence of a higher lightfastness.

By comparing *Figures 2–4 & 2–5* to *2–6 & 2–7* we concluded that the ΔE_{ab} values were lower when the inks were printed on the manufacturer's recommended paper. This result is logical, as the ink was tested and improved by working with the manufacturer's paper. In addition, research shows that lightfastness can be improved when printed with paper that corresponds to the inks (Sensient, 2005).

It was found that the combination of the inkjet inks and the manufacturer's recommended paper produced a larger gamut than using the generic Staples® paper. Results indicate that the gamut produced by the HP Designjet

130 was smaller on the Staples® glossy paper than that printed on the manufacturer's glossy paper. The Staples® glossy paper produced a gamut with 494,249 colours, whereas the manufacturer's glossy paper produced a gamut with 630,935. A possible reason for this could be that the composition of the generic Staples® brand varies from the paper recommended by the printer manufacturer. Differences could lie in the ink holdout properties, smoothness and use of optical brighteners (Sensient, 2005).

Comparing *Figures 2–4 & 2–6* to *2–5 & 2–7* showed that the ΔE_{ab} values were lower when printed on glossy paper. This is particularly noticeable when examining the ΔE_{ab} of the manufacturer's paper. It has been found that ΔE_{ab} is typically higher in matte substrates. This is normally caused by matte paper having more colour shifts thus causing more out of gamut colours (Chovancova, 2005).

Our results confirmed the commonly found fact that glossy paper reproduces a larger colour gamut than matte paper (Chaney, 2004). This was particularly evident when comparing the glossy and matte Epson Stylus Pro 4800 colour gamuts printed on the manufacturer's recommended paper. Glossy paper was able to produce a gamut with 641,044 colours whereas the matte paper only produced a gamut with 159,416. The main reason for this drastic difference is that the glossy layer prevents the ink from being absorbed into the paper to the extent that it would be with a matte paper (Chaney, 2004).

The Epson Stylus Pro 4800 and HP Designjet 130 have produced a lower ΔE_{ab} and better gamut when compared to the standard desktop inks used in Epson Stylus C84 and HP K60. This is because the UltraChrome K3™ inks and Vivera® dye-based inks are based on two types of new technology. The UltraChrome K3™ ink incorporates "high-gloss Microcrystal EncapsulationTM Technology". Basically, a protective shell surrounds the pigment so that when it is exposed to light the colour remains vivid (*Figure 2–36*). The new generation dye ink, HP Vivera® dye-based ink uses the same concept in which "protective groups" shield the dye molecule from light (*Figure 2–37*).

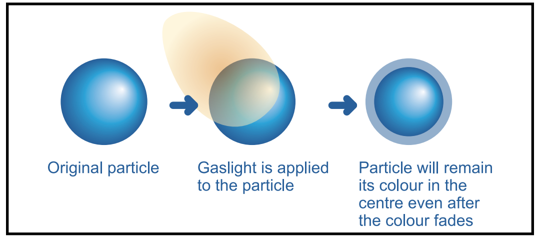


Figure 2–36: UltraChrome K3™ ink incorporates "high-gloss Microcrystal EncapsulationTM Technology"
(Epson, 2007)

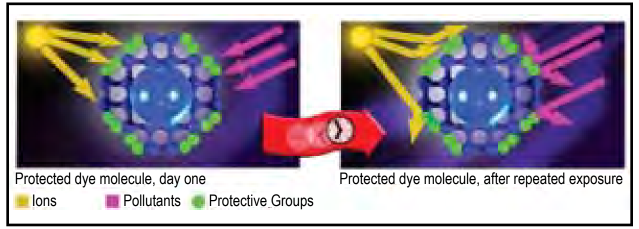


Figure 2–37: HP Vivera® "protective groups" shield the dye molecule from light
(Hewlett-Packard Company, 2004)

Our results found that Epson Stylus Pro 4800 and HP Designjet 130 inks produced a very similar colour gamut. The biggest gamut that Epson Stylus Pro 4800 inks can produce was found on manufacturer's glossy standard and provides 641,044 possible colour combinations. The biggest gamut that Vivera® inks can produce was found on manufacturer's glossy standard and provides 630,935 possible colour combinations. The results show that UltraChrome K3™ inks can achieve an almost identical gamut to that of Vivera® dye-based inks. It has been proven that the new technology the UltraChrome K3™ ink set uses can provide a gamut equivalent to that of dye-based inks (Boley, 1999). These two inks are also on par in terms of fade resistance. UltraChrome K3™ inks showed a reduced gamut of 5.63% and Vivera® dye-based inks showed a reduced gamut size of 6.83%. Research is consistent with our findings in that the difference between gamuts is minimal and one is not ranked over another (Reichmann, 2007). The fact that both of these ink systems utilize a light cyan and a light magenta has been proven to help increase lightfastness (Maher & Berman, 2005). The colour gamuts for both systems show minimal reduction between the unexposed control and the faded samples. However, the lower ΔE_{ab} values of UltraChrome K3™ shows it has better lightfastness than Vivera®.

The ink jet sector has yet to standardize a method for measuring print longevity. Companies such as Epson and HP have conducted independent research in conjunction with Wilhelm Imaging Research (WIR) to discover particular yearly values of permanence. Epson claims that images reproduced with their UltraChrome K3™ inks on Epson Premium Glossy photo paper will last up to 104 years without fading (Epson America, 2007). Similarly HP states that its Vivera® inks resist fading for 108 years (Hewlett-Packard Company, 2004). On the other hand, Staples® does not state any specific yearly value in which their product will resist fading. However, they do claim that their papers "resist fading" and it has been shown that Staples® has no scientific data to support this claim (Spring, 2005). WIR is in the process of creating certification for print longevity. Some companies are not interested in this certification since it is time consuming and costly. It will cost companies $15,000 to test one type of paper with one specific printer and ink.

The results confirmed our assumptions that printed samples from Epson Stylus Pro 4800 and HP Designjet 130 (on their manufacturer paper) produced the best lightfastness. We also expected the ΔL^* value to be higher than Δa^* and Δb^* since the test was conducted for lightfastness. Yet, our results show that Δa^* and Δb^* values were higher, which means that there was more colour shift than fading alone. Most colours moved toward yellow and green. This unexpected colour shift may be caused by the high-intensity accelerated light exposure from the Fade-o-meter (Wilhelm, 2003).

The weakness of this test is human error when importing the vast amounts of data used. After collecting the data we had to input approximately 1,285 entries manually into an Excel spreadsheet. When analyzing the data we identified our outliers and re-measured those data points to ensure accuracy. Nevertheless, there could still be slight entry errors in the data.

RECOMMENDATIONS

PRINTABILITY

Lightfastness is one of the most significant issues affecting quality in inkjet printing. Our result shows the inks that incorporate the benefit of both dye and pigment have the highest lightfastness and color permanence. Research for improving the properties of inkjet ink continues. Advancements in ink chemistry and improvements in paper have already increased the longevity of the colour inkjet image (Sensient, 2005). HP recently released their version of Vivera® pigmented inks which use the same technology as the UltraChrome K3™ inks. They are not designed to replace the Vivera® dye based inks, but simply to provide more flexibility to people who want to generate long lasting inkjet-based prints (Hewlett-Packard Company, 2004). Therefore, to achieve a high lightfastness while still maintaining a reasonable gamut size it is recommended to use either the Epson UltraChrome K3™ or the new HP Vivera® pigmented inks. The characteristics of paper can have a profound effect on lightfastness (Trevern, 2005). It is recommended to print on the manufacturer's paper as it will provide a higher degree of lightfastness. Inexpensive, generic substrates are designed for low cost applications, thus have a lower lightfastness (Sensient, 2005).

In theory, adding UV inhibitors and antioxidants in both the ink and the substrate coating should improve the lightfastness of a printed inkjet sheet. However, both additives have a brief lifespan, relative to their high cost (Sensient, 2005). It has also been suggested that some UV inhibitors cause a glossy sheet to appear yellow (Kiatkamjornwong et al, 2003).

RUNABILITY

The most common problem for runability with inkjet printers is the clogging of the print head nozzle. Since pigment inks have larger particles they tend to be more problematic in this area. Epson printers keep the nozzles clean by having a set cleaning cycle that sends fresh ink through the system and into waste tanks (Fischer, 2007). The cleaning cycle was found particularly useful when the printer was not operating at high demand (Fischer, 2007).

Another possible problem with ink for Thermal Ink Jet printers (HP K60 and HP Designjet 130) is kogation. This is the build up of dry ink on the thermistor of a print head (Nevins, 2001). It was once thought that this was caused by ink impurities. However, it was recently discovered that it is actually caused by "residual dye left from the continuous heating and cooling of the thermistor" (Nevins, 2001).

END USE

The lightfastness of a printed document can be a significant concern in many scenarios. Firstly, in the advertising industry colour density and contrast are highly important, as the quality of the advertisement's colour reproduction will alter consumer's buying decisions. For example, if an advertisement for a hair colour was displayed in a store where it is openly exposed to artificial light, the print could fade, changing the colour contrast and sharpness of the hair colour. Printed food advertisements or posters are other examples. It is important for the print to maintain its colour fidelity since this attracts the customer and makes the image appealing. Secondly, lightfastness is an important factor when printing wallpaper. Wallpaper is exposed to artificial and natural light for several hours at a time therefore, it must have a high lightfastness. Thirdly, lightfastness is critical for printed images found in art galleries and museums. Since there are spotlights positioned directly above the display, prints can fade quickly if not printed with the proper combination of inkjet inks and manufacturer recommended paper. Facilities of this nature should have controlled temperatures and humidity (Trevern, 2005). A common way to protect these prints is to store them in airtight glass displays or have them laminated. Both of these methods have been proven to filter out the shorter wavelengths of light thus improving lightfastness (Sensient, 2005). Lastly, advances in inkjet printers and digital cameras have allowed amateur photographers to print decent quality images at home. Typically, one would want their photographs to last years if not decades. In order for this to be possible, images must be properly stored. Images of this purpose are best kept under glass and away from direct sunlight. Albums should use acid-free sleeves instead of adhesives and be stored in a cool dry area (Trevern, 2005).

REFERENCES

Ahn, Byung-sun et al. (2001). Apparatus for injecting working liquid into micro-injecting device and method for injecting the working liquid. Retrieved from Google Patent Search. Web site: http://www.google.com/patents?lr=&id=cCMFAAAAEBAJ&vid=USPAT6199600&dq=inkjet+printer+popularity&q=inkjet+printer+popularity#search.

Lenz, Sabine. (2007). PaperSpecs. Retrieved March 8, 2007 from Paperspecs Resources. Web site: http://www.paperspecs.com/resources/glossary/l.htm.

Boley, Brian L. 1999. What is the difference between standard dye-based ink and pigmented ink? Retrieved February 12, 2007 from Oddparts. Website: http://www.oddparts.com/ink/faq19.htm.

Breede, Manfred H. (1999). *Handbook of Graphic Arts Equation*. USA: GATF

Chaney, Steve. 2004. The Great Paper Chase. Retrieved February 12, 2007 from Steve's Digicams. Website: http://www.steves-digicams.com/techcorner/september_2004.html.

Dawes, Trevern. 2005. How Long will an Inkjet Print Last. Retrieved March 2, 2007 from Wilhelm Research. Website: http://www.wilhelm-research.com/camera/Will_InkjetPrintsLast_2005.pdf.

Epson America. 2007. Premium Photo Paper Glossy. Retrieved February 23, 2007 from Epson America. Website: http://www.epson.com/cgi-bin/Store/ProductMediaSpec.jsp?BV_UseBVCookie=yes&infoType=Overview&oid=-8776&category=Paper+%26+Media.

Epson United Kingdom. 2007. Epson UltraChrome™ K3 & UltraChrome Hi-Gloss™ ink. Retrieved February 21, 2007 from Epson United Kingdom. Website: http://www.epson.co.uk/supplies/supplies/ink/types/ultrachrome.htm.

Field, Gary G. (1999). *Color and Its Reproduction*. (2nd edition). USA: GATF

Fischer, Monique. 2007. Creating Long-Lasting Inkjet Prints. Retrieved February 12, 2007 from Northeast Document Conservation Centre. Website: http://www.nedcc.org/resources/leaflets/5Photographs/04InkjetPrints.php.

Henry, Walter. 2004. Inkjet Color. Pigment Or Dye Inks. Retrieved February 27 from Pictureline News. Website: http://www.pictureline.com/newsletter/article.php?id=322.

Hewlett-Packard Company. 2004. New HP Vivera Inks Provide Unparalleled Combination of Image Quality and Fade Resistance. Retrieved February 12, 2007 from Hewlett-Packard Company. Website: http://www.hp.com/hpinfo/newsroom/press_kits/2004/digitalexplaunch/bg_vivera.pdf.

Hewlett-Packard Company. 2007. Vivera Inks. Retrieved February 22, 2007 from Hewlett-Packard Company. Website: http://h71036.www7.hp.com/hho/cache/331414-0-0-225-121.html.

Jenkin, Gordon E. 2006. The Colour Fastness of Ink-Jet Prints. Retrieved February 12, 2007 from Lyson News Centre. Website: http://www.lyson.com/040800.html.

Johnson, Harald. 2003. Mastering Digital Printing. Retrieved February 20 2007, from PEI Magazine. Website: http://www.peimag.com/pdf/pei03/pei0506_03/johnsonpei0506_03.pdf.

Kiatkamjornwong S, Rattanakasamsuk K, Noguchi H. (2003). Evaluation of some strategies to control fading of prints from dye-based ink. *Journal of imaging science and technology*, 47 (2) 149-154. Retrieved March 3, 2007 from Google Scholar.

Kipphan, Helmut. (2001). *Handbook of Print Media*. Germany: Springer.

Klipstein, Don. 1996. Various Notes on Carbon Arcs. Retrieved Februrary 2, 2007 from Don Klipstein's Web Site. Website: http://members.misty.com/don/carbarc.html.

MacEvoy, Bruce. 2006. Retrieved February 20, 2007, from Paintmaking. Website: http://www.paintmaking.com/testing.htm.

Maher, C. & Berman, L. 2003. The Archival Quality of Digital Print Media. Retrieved February 12, 2007 from Shutterbug. Website: http://www.wilhelm-research.com/pdf/Shutterbug_Nov_2003_HiRes.pdf.

Nevins, Jerry. 2001. Glossary of Terms: Inkjet printing and ink formulation. Retrieved February 25, 2007 from Ink Jet Glossary. Website: http://www.jnevins.com/inkjetglossary.htm.

Ludlow, Rob. 2005. An Alternate View of Fading on Inkjet Printers. Retrieved March 10, 2007 from Nifty Stuff. Website: http://www.nifty-stuff.com/docs/inkjet-fading.php.

Reichmann, Michael. 2007. HP Designjet Z3100 Review. Retrieved February 20, 2007 from The Luminance Landscape. Website: http://www.luminous-landscape.com/reviews/printers/HP-Z3100-review.shtml#.

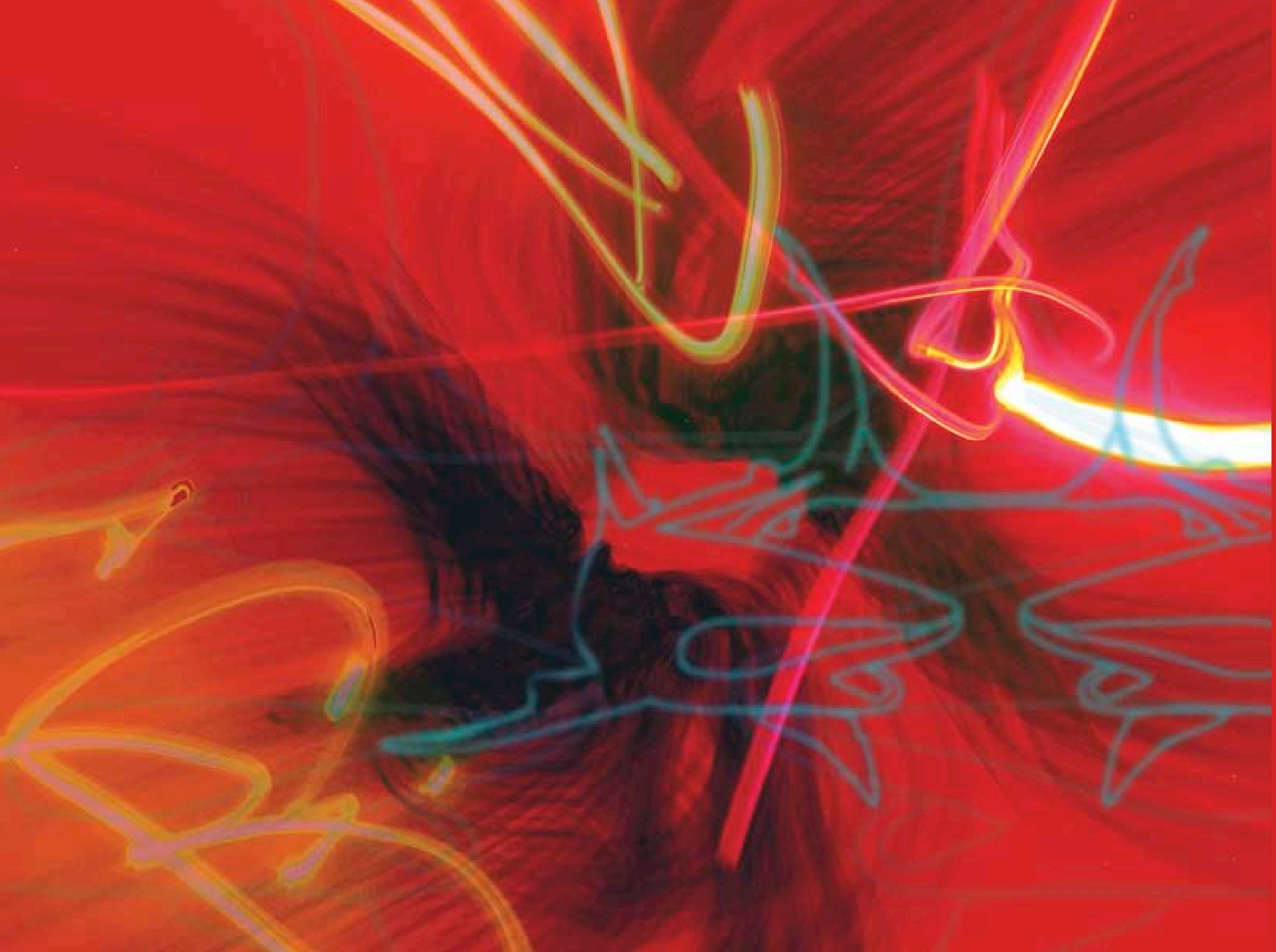
Siew, Calvin. (2004). HP's viva Vivera inks. Retrieved March 12, 2007 from Cnet Asia Reviews. Website: http://asia.cnet.com/reviews/hardware/printers/0,39001759,39193899,00.htm.

Specialty Graphic Imaging Assicociation. 2005. Necessity or Luxury? Fade-Resistant Inkjet Prints. Retrieved February 18, 2007 from Sensient Imaging Technologies. Website: http://www.sgia.org/pdf_server.cfm?pdf=/members/journals/2005/050309.pdf.

Spring, Tom. 2005. Lack of standards Sparks Inkjet Photo Fade Debate. Retrieved March 13, 2007 from PC World. Website: http://www.pcworld.com/news/article/0,aid,121752,00.asp.

Sunchemical. 2007. Lightfastness and Blue Wool. Retrieved February 12, 2007 from Sunchemical Help Desk. Website: http://www.sunchemicalhelpdesk.com/coldispense/Lightfast.htm.

Wilhelm, Henry. 2003. Yellowish Stain Formation in Inkjet Prints and Traditional Silver-Halide Colour Photographs. Retrieved February 12, 2007 from Wilhelm Imaging Research. Website: http://www.wilhelm-research.com/ist/WIR_ISTpaper_2003_09_HW.pdf.



Spectrophotometric evaluation of FM6's ability to reproduce Pantone colours

Diana Brown, Nicola Kidd, Scott Millward, Ahmed Sagarwala

SCOPE & SUMMARY

The property tested is the accuracy of which FM6 inks can reproduce Pantone™ colours. This test will also evaluate the benefits of using stochastic (frequency modulated) screening technology in order to facilitate matching the Pantone™ swatches. The purpose of this test is to determine if the actual performance of this seven-colour ink technology is in agreement with published information. The manufacturer states that this system can provide an effective solution for "85% of spot colours" (FM6, 2006). It is our objective to determine if FM6 can reproduce 85% of the Pantone™ colours within 5.0 Delta E (ΔE). The related properties that are not part of the test include an in-depth study of FM screening, densities, and overall gamut expansion.

The major quantitative results are as summarized: 85% of the colour swatches had no noticeable difference between the sample and standard because they had a ΔE of under 5.0. An obvious colour difference is found in 15% of the test samples that fall in between 5.0-10.0ΔE. Only one sample, 0.01%, measured over 10.0 ΔE. This effectively demonstrates that FM6 has potential cost and time savings by increasing the number of reproducible spot colours within one pass on a press with a minimum of six units. It is therefore recommended that a printer should use FM6 technology when running multiple Pantone™ colours as long as they fall within FM6's range of reproducible colours. The colours outside this range, should continue to be reproduced using premixed ink.

INTRODUCTION

FM6 is a technology developed by PrintTech in the Netherlands, that combines stochastic (or frequency modulated) screening and six of seven process inks to reproduce an array of Pantone™ colours in only one pass, hence the name FM6. It is a seven-colour system, the additional inks make it a "hi-fi" printing process, where the chroma range is expanded to allow for additional colour to be reproduced (Hinderliter, 2006). The inks are run in a fixed sequence of CMYK plus either orange and blue (to recreate 90% of Pantone™ colours) or orange and green (remaining 10%) (Dynagraph.net, 2006) This technology was created for the packaging industry, which is known for using many spot colours for branding purposes. The fixed sequence reduces makeready time associated when changing individual spot colours. It improves scheduling flexibility because jobs can be run in any order, eliminating the need to sequentially run similar coloured jobs. It saves money by eliminating the need to mix, purchase or store multiple Pantone™ inks.

FM6 is used in the Esko Graphics workflow and requires a prepress plug-in called Ink Wizard. This software separates the spot colour line work, such as logos and brand names, from the graphics, which remain CMYK (O'Brien, 2004). FM6 uses Creo Staccato, which is a "second generation" FM screening technology that varies dot size (10 microns and higher) as well as spacing (Fenton, 2005). FM screening also eliminates moiré created by the additional screen angles of the 5th and 6th colours (Fenton, 2005). It requires a CTP device in order to image the stochastic dots (Whitcher, 2004) and a printer can then run the job using their own standard set of CMYK inks along with the set pair of additional FM6 colours (FM6.com).

Our objective is to determine how accurately the FM6 system can reproduce Pantone™ colours. The L*a*b* values of 1,043 FM6 samples will be measured and compared to the standard Pantone™ swatches. The results will be quantified by calculating the ΔE between the standard and sample. The samples are measured using a spectrophotometer because it compares hue and lightness and provides the best evaluation of how colour is perceived by human vision (Edwards, 2002).

The educational gains of this project include our ability to validate the effectiveness of FM6 technology. We will be able to determine if it saves time or money and if it would be beneficial in a production environment. It will also allow us to gain a better understanding of ΔE equations and specrophotometric analysis by applying them to a new ink technology.

DEFINITIONS AND EQUATIONS

The following equation is the ΔE_{00} (Lindbloom, 2003)

$$\Delta E = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

WHERE

$$\overline{L}' = (L_1 + L_2)/2$$

$$C_1 = \sqrt{a_1{}^2 + b_1{}^2}$$

$$C_2 = \sqrt{a_2{}^2 + b_2{}^2}$$

$$\overline{C} = (C_1 + C_2)/2$$

$$G = \left(1 - \sqrt{\frac{\overline{C}^7}{\overline{C}^7 + 25^7}}\right)\bigg/2$$

$$C_1' = \sqrt{a_1' + b_1{}^2}$$

$$a_1' = a_1(1+G)$$

$$C_2' = \sqrt{a_2' + b_2{}^2}$$

$$a_2' = a_2(1+G)$$

$$\overline{C}' = (C_1' + C_2')/2$$

$$h_1' = \begin{cases} \tan^{-1}(b_1/a_1') & \tan^{-1}(b_1/a_1') \geq 0 \\ \tan^{-1}(b_1/a_1') + 360° & \tan^{-1}(b_1/a_1') < 0 \end{cases}$$

$$h_2' = \begin{cases} \tan^{-1}(b_2/a_2') & \tan^{-1}(b_2/a_2') \geq 0 \\ \tan^{-1}(b_2/a_2') + 360° & \tan^{-1}(b_2/a_2') < 0 \end{cases}$$

$$\overline{H}' = \begin{cases} (h_1' + h_2' + 360°)/2 & |h_1' - h_2'| > 180° \\ (h_1' + h_2')/2 & |h_1' - h_2'| \leq 180° \end{cases}$$

$$T = 1 - 0.17\cos(\overline{H}' - 30°) + 0.24\cos(2\overline{H}') + 0.32\cos(3\overline{H}' + 6°) - 0.20\cos(4\overline{H}' - 63°)$$

$$\Delta h' = \begin{cases} h_2' - h_1' & |h_2' - h_1'| \leq 180° \\ h_2' - h_1' + 360° & |h_2' - h_1'| > 180°; h_2' \leq h_1' \\ h_2' - h_1' - 360° & |h_2' - h_1'| > 180°; h_2' > h_1' \end{cases}$$

$$\Delta L' = L_2 - L_1$$

$$S_L = 1 + \frac{0.015(\overline{L}' - 50)^2}{\sqrt{20 + (\overline{L}' - 50)^2}}$$

$$\Delta C' = C_2' - C_1'$$

$$S_C = 1 + 0.045\overline{C}'$$

$$\Delta H' = 2\sqrt{C_1' C_2'}\sin(\Delta h'/2)$$

$$S_H = 1 + 0.015\overline{C}'T$$

$$\Delta\theta = 30\exp\left\{-\left(\frac{\overline{H}' - 275°}{25}\right)^2\right\}$$

$$K_L = 1$$

$$K_C = 1$$

$$R_C = \sqrt{\frac{\overline{C}'^7}{\overline{C}'^7 + 25^7}}$$

$$K_H = 1$$

$$R_T = -2R_C\sin(2\Delta\theta)$$

TEST PRINCIPLE

This test is a valid means of determining the property tested because of our reasoning behind the Delta E (ΔE) equation used, the lighting conditions used, the observer angle used and the standard Pantone™ L*a*b* values used. This test sheet was printed at the IPEX trade show in 2002, thus we are assuming that the test sheet we used was printed under the vendor's specifications (FM6, 2006). Our tolerance for evaluating colour difference (ΔE) is 5.0 because it is an industry standard and anything above this number is a noticeable colour difference (Breede, 1999).

The ΔE we used to calculate colour difference between the samples and standards was ΔE CIE2000 (ΔE_{00}). This equation is developed from ΔE CIE1994 (ΔE_{94}) but the main difference lies the lightness (L*) value. ΔE_{00} varies the L* value depending on where the colour falls in the lightness range (Upton, 2005). We will use this colour difference equation because it calculates the distance in L*a*b* colour space based on an "ellipitical" versus "spherical" area. This improves the accuracy as to which instrument measurement approximates visual color assessment (Sharma, 2004). The location on the colour wheel determines the shape and size of the ellipsoids. Colours that are in the green spectrum have wider ellipsoids because this is where humans have the highest

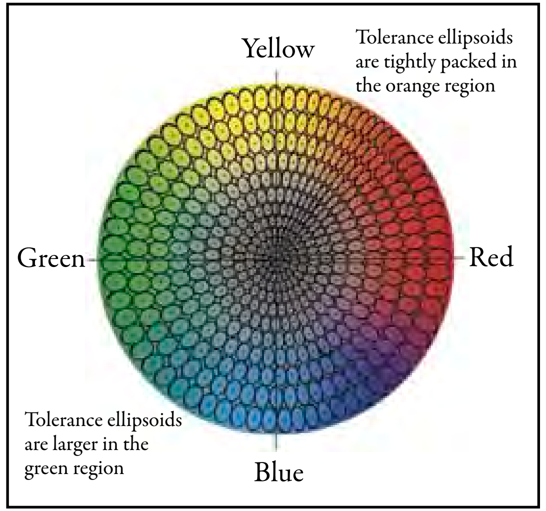


Figure 3–1: Tolerance ellipsoids in colour space (XRite, 2004)

sensitivity to colour difference (X-rite, 2006). Conversely, ellipsoids will be smaller in less saturated areas of the colour wheel because humans are less receptive to colour changes in the less saturated areas (Sharma, 2004).

We used standard D_{50} lighting, which is equivalent to 5000K or direct sunlight, because it is the norm for the printing industry. The ΔE calculations are dependent on the selected illuminant (Upton, 2005) because different light sources can vary widely in colour based on their "spectral energy distribution curves" (Sharma, 2004). Thus it is important that the illuminant remains constant.

We used the 2° observer angle to measure our samples, which standardizes the third element in our perception of colour, the human observer (Sharma, 2004). The measurements produced by this observer angle are preferred for the "reproduction of complex colour images" (Johnson, 1999). It replicates how the average person sees colour at a 2° field of view, which is about the size of your thumbnail placed 18" away from your eye (Field, 2004). It employs standard observer curves which directly relate to human vision of colour (expressed as x,y and z-bar) (X-Rite, 2006). These are aligned with the human eye's sensitivity of colour. This method is preferred over the 10° observer angle because it corresponds to using a portion of the retina, called the fovea, which is most sensitive to colour (Field, 2004).

The X-rite spectrodensitometer allows us to accurately quantify colour values within the L*a*b* colour space. The software within the instrument coverts spectral data read from the sample into colorimetric values (Field, 2004). The spectrodensitometer was attached to a Macintosh laptop via a USB adaptor. The Key Span plug-in and ToolCrib software read the L*a*b* values by attaching

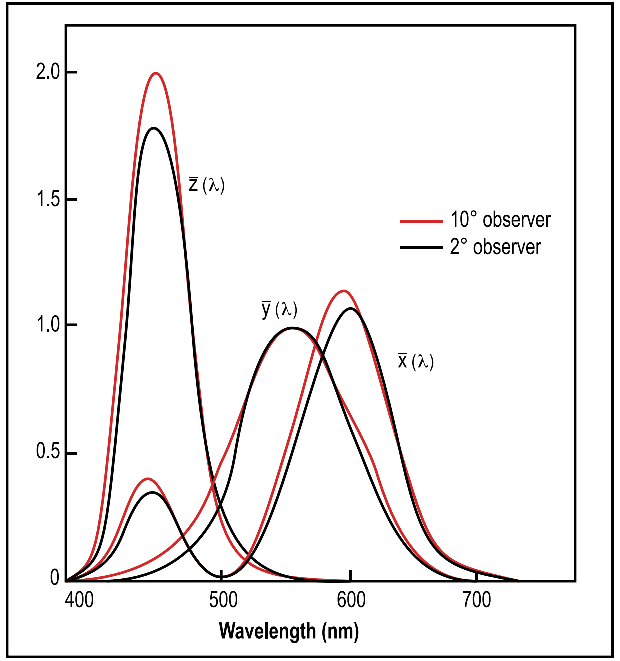


Figure 3–2: The CIE colour matching functions for the 1931 2° observer and the 1964 10° observer. (Field, 2004)

the spectrodensitometer directly to the computer. These values were automatically input into an excel spreadsheet. The standard L*a*b* values for each Pantone™ colour were placed into the database prior to measuring the samples.

The ΔE_{00} formula was then applied within the excel spreadsheet to calculate the colour differences of each FM6 swatch and the corresponding Pantone™ L*a*b* standard. The FM6 colour swatches with the least and greatest colour differences were then examined visually.

The test is carried out in the method described above in order to accurately quantify colour differences based on numerical data. For purposes of calculating the colour difference, it is impossible to do so by visual comparison. By using a means in which we can draw precise conclusions, we can better assess the plausibility that FM6 inks perform as the manufacturer claims. The Pantone™ L*a*b* values used for this test are licenced by Pantone™ to Adobe used to create a standard library for Photoshop.

An alternative test related to our current focus could be to experiment with various colour difference equations (ΔE_{ab}, ΔE_{94}, ΔE_{CMC} and ΔE_{00}) to assess their effect on the colour difference of FM6 inks. Additionally, a test of printing FM6 inks at varying densities on the Prüfbau printability tester or the Universal TestPrinter by TestPrint would allow the user to understand the optimal densities required to achieve accurate colour matching to Pantone™ values.

This test replicates conditions of end use because spectrophotometers are able to "see" colours the same way the human eye sees colour (Edwards, 2002). By measuring the L*a*b* values, the spectrophotometer compares the colour swatch to a reference patch, which determines the hue values. Cai von Rumohr, Heidelberg's 2002 product manager for CPC quality control products, stated that, "Printers do not sell the density value of the printed sheet, but they do sell how it looks. Spectrophotometry is the "only way to evaluate and measure how colour really looks" (Edwards, 2002). Our method of spectrophotometic measurement, along with the ΔE_{00} calculation, replicates the end use principles.

MATERIALS TESTED

- FM6 test form, printed at IPEX 2002

EQUIPMENT USED

- Pantone™ Color Bridge Color Matching Guide (2007)
- Adobe Photoshop CS2 for Pantone™ Coated L*a*b* values
- Microsoft Office Excel 2003 spreadsheet
- X-Rite, Inc. 500 Series Spectrodensitometer
- Key Span USB adapter for Spectrodensitometer
- X-Rite, Inc. ToolCrib Version 5.0 Software
- Carl Zeiss Electronic Microscope, 6.3x magnifier

PROCEDURE

1. Obtain previously printed FM6 samples (1,043 swatches) that replicate known Pantone™ colours.
2. Input Photoshop's Pantone™ L*a*b* values into an excel spreadsheet.
3. Measure all swatches on the printed sample using a calibrated handheld spectrodensitometer & Key Span serial USB adaptor to import L*a*b* values into an excel spreadsheet.
4. Compare the sample and standard values using ΔE_{00} colour difference formula.
5. Analyze data.

RESULTS & DISCUSSION

Figure 3–4 reveals the accuracy of which FM6 reproduces Pantone™ colours by showing the top 100 swatches with the lowest ΔE_{00}. There was no common colour grouping that showed consistent low ΔE. Overall, the samples that made the top 100 best matches varied greatly in hue. *Figure 3–3* reveals, that 85% of the FM6 samples match the Pantone™ swatches because they are under 5.0 ΔE_{00}. This means that, 85% of the FM6 swatches do not have a noticeable colour difference. Thus FM6 is able to accurately reproduce 887 of the 1,043 Pantone™ colours tested. Only 15% of the measured FM6 samples varied by 5.0-10.0 ΔE_{00} and they therefore show visible differences in colour compared to the Pantone™ swatch. One sample,

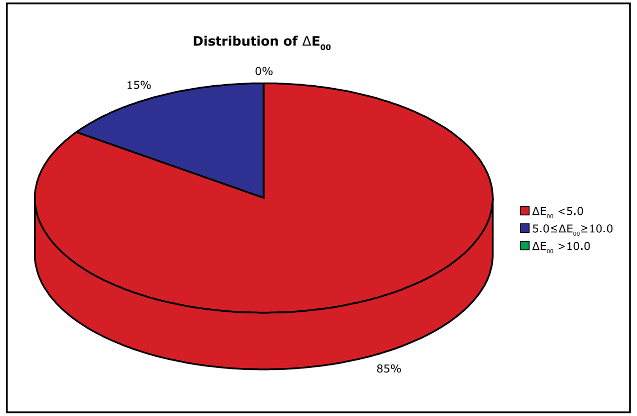


Figure 3–3: ΔE_{00} Distribution for FM6.

Pantone™ 2375, measured over 10.0 ΔE_{00}, indicating an obvious deviation in colour. Therefore, this "hot pink" Pantone™ colour cannot be reproduced by FM6. Upon visual comparison we can confirm the unmistakable dissimilarity between this sample and standard.

The 15% of samples that varied by 5.0-10.0 ΔE_{00} were mostly in the light oranges, rich reds, pinks and purples. *Figure 3–5* illustrates the colour variation between the FM6 and Pantone™ swatches for the worst 100 colours (highest ΔE_{00}). To determine where the colour difference originated, the worst 100 matches were broken down into their respective a* (green-red) and b* (yellow-blue)

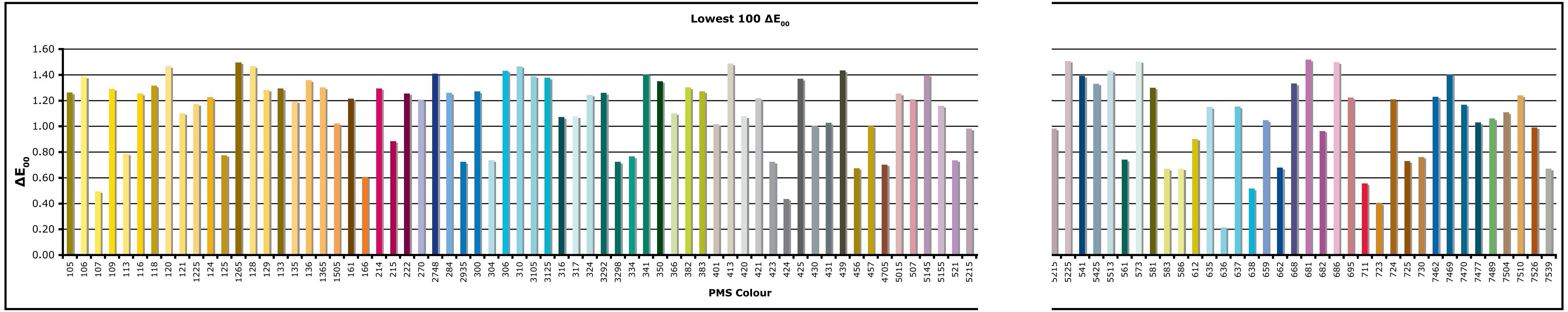


Figure 3–4: Lowest 100ΔE_{00}

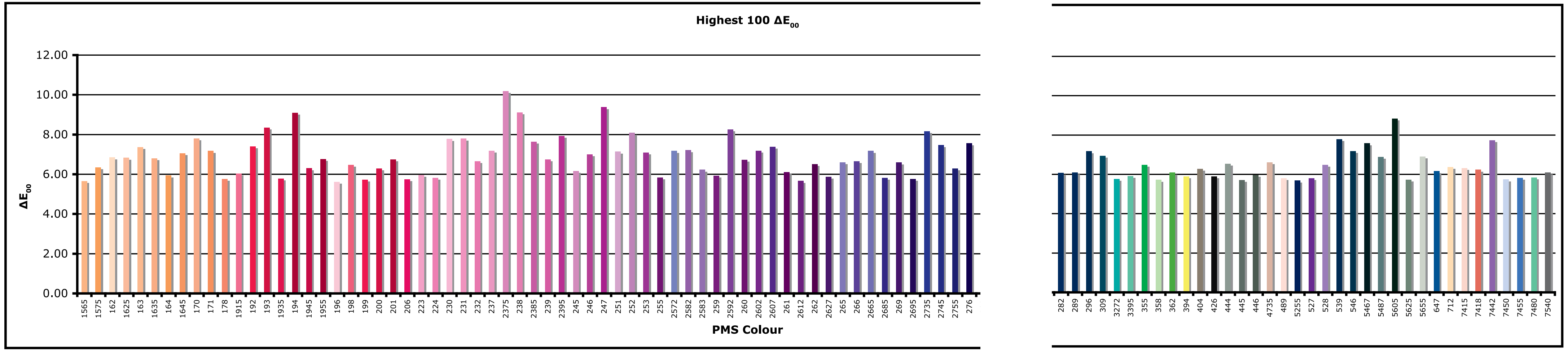


Figure 3–5: Highest 100ΔE_{00}

values. Since we are using CIE 2000, ΔL^* is excluded in this analysis because it has little effect on the overall ΔE result. *Figures 3–6 & 3–7* (please see CD) compare the standard a* and b* Pantone™ values against the measured FM6 samples.

THE FOLLOWING IS OBSERVED: GRAPH A* (GREEN-RED)

- A trend toward green (-a*) is observed in the FM6 pink and purple samples. Their hues are closer to the -a* section of the scale and therefore seem more green in hue.
- Within the green hues, FM6 samples 355 and 362 are too green, and therefore higher -a* value in comparison to the Pantone™ swatches. Although, still within the green hues the FM6 samples numbered 3272, 3395, and 358 have a low -a* (green) versus the equivalent Pantone™ values, thus these FM6 samples dot not have enough green.

GRAPH B* (BLUE-YELLOW)

- Throughout the oranges, reds and pinks the FM6 sample are too yellow (samples 1565-3272). From sample 1565 to 206 the +b* are too positive, thus too yellow. This same trend occurs within 223 to 3272 as the samples are still too yellow because they don't have as much blue as the standard Pantone™ colours.
- As a general statement there is an overall trend towards +b*, thus the FM6 swatches have more yellow hues in comparison to Pantone™ swatches.

- Overall, there is no solid trend as to why FM6 cannot reproduce the remaining 15% with a higher degree of accuracy. If we had the original L*a*b* values of the CMYK + Orange, Blue and Green FM6 process inks we could compare them to the sample L*a*b* values and the highest ΔEs.

Additionally, FM6 differs from other hi-fi printing technologies because it incorporates frequency modulated screening technology as part of the system. Using FM screening, the number of reproducible colours increases by 15.4% over conventional amplitude modulated screening (Rosenburgh, 1999). FM screening creates a smoother solids and colours because of the lack of screen angles that can create a grainy effect or undesirable visual patterns. Staccato dots (a type of FM screening employed by FM6) are all highlight dots, which grow in size throughout the "midtone range forming worm-like patterns" (Whitcher, 2004) (see *Figure 3–9*). The second generation FM screening is more advantageous than the first generation because second generation dots vary in placement as well as dot size, which allows for more "smooth transition within the mid-tone dot structure" (Whitcher, 2004).

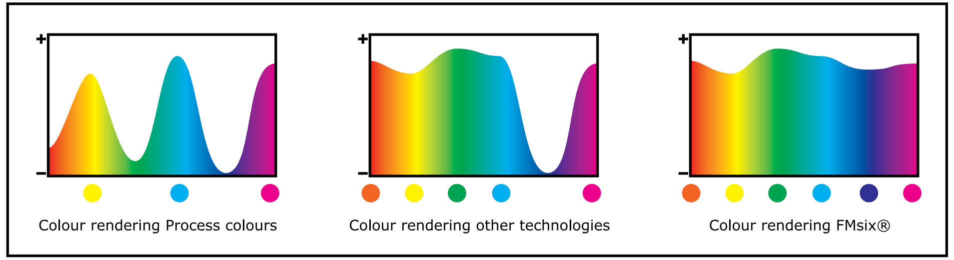


Figure 3–8: Process Spectrogram
(FM6, 2006)

According to FM6, their technology is supposed to accurately reproduce 85% of the Pantone™ book (FM6, 2006). Our test results confirm their claim, because 85% of the swatches, which are a representative sample of the Pantone™ book, measure lower then 5.0 ΔE_{00}. Although this is true, FM6 raves that their blue ink will "get you a much higher colour stability" within the blue and violet range because "it does not change its hue being wet, dry or when you look at it again some days after printing". FM6 says that it "fills the gap" in comparison to other hi-fi printing methods, by including inks that extend the gamut into in the blue-violet range (FM6, 2006). Please refer to *Figure 3–8*. As shown in this diagram, the published information was not in agreement with our results. We saw deficiencies within the blue and violet areas as they consistently appear on *Figure 3–5* for the highest colour difference. Therefore, we can conclude that FM6 technology is able to address some of the blue-violet reproduction deficiencies, although they are not perfect. We cannot assess to what degree they are accurately reproduced because according to our results, they are still deficient.

Our original hypothesis was that this technology would not be able to replicate as many colours as claimed using only a six-colour process. Our hypothesis was proven wrong once the results were examined. FM6 was able to reproduce many more Pantone™ colours than initially conceived. Our group also predicted that the metallic Pantone™ colours would not reproduce accurately using a six-colour process. This is simply because there are no metallic particles within the inks. Our prediction was correct, which was in congruence with published information, because the ΔE_{00} values were over 20.0 (M.Y. Cartons, 2002). We also predicted that pastels would be hard to replicate, because they are notorious for dot gain or dot loss which cause hue shifting. This variation occurs because there is not a lot of pigment within the ink film. Our results were inconclusive, whereby some of the sample pastels were under 5.0 ΔE, but others were in the 5.0-10.0 range.

One weakness of the test includes our standard Pantone™ solid coated L*a*b* values, which are derived from Photoshop CS2's "Colour Library" menu. Unfortunately, these values are rounded to the nearest whole number which will produce less exact results. Another weakness is that we do not know the original L*a*b* values of CMYK or FM6's Orange, Green or Blue, thus we can only estimate target density values. This might explain why some samples show hue shifts in either the ±a* or ±b* direction. It is also important to note that the ΔE_{00} equation is optimal for this application, however not all ΔE equations are created equally. If we had used an alternate version of the equation, we would have yielded somewhat different results.

In terms of human weakness or inaccuracies, there were a few mistakes within the standard FM6 L*a*b* values, simply because they were manually input into our database. We minimized this error while inputting the values by continually checking over our numbers and reduced it further by seeking out outliers after all ΔE_{00} had been calculated. We revisited the standard L*a*b* values of the outliers to ensure they were input correctly. This technique of revisiting outliers proved to be helpful in creating the most accurate results possible.

RECOMMENDATIONS

PRINTABILITY

The FM6 technology is recommended for businesses that paperboard packaging because of the benefits associated with spot colour reproduction. There are many advantages when using FM screening on press. It is consistent, stable and predictable on press; therefore it is difficult for a press operator to completely change the overall colour. An operator can change the ink keys up to 20% without seeing any colour changes (Fenton, 2005). This ensures colour consistency, thus maintaining brand colour fidelity. Tonal and colour stability are increased because the small dot size reduces problems created by the variation in dot gain and wet trap (Whitcher, 2004). The darkening effect, commonly associated with heavy ink film is effectively minimized due to the small 10-micron dot size.

In comparison to AM screening, the overall ink film thickness of FM screening is lower because there is less ink buildup in the center of the dots (Rosenburgh, 1999). Ink costs are therefore decreased because FM screening permits less ink to be printed to produce the same result (Fenton, 2005). FM screening is made up of all highlight dots which chain together in the mid-tone range forming worm-like patterns, which create smoother flat tint areas

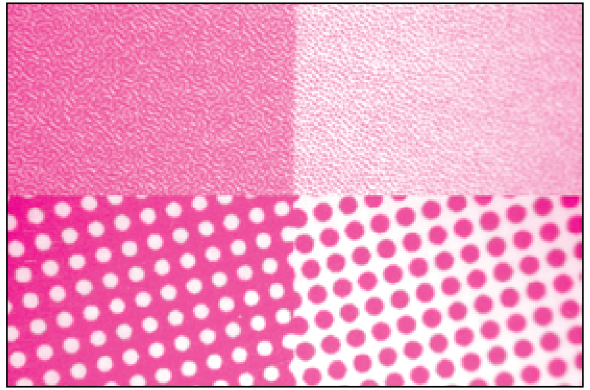


Figure 3–9: 20x magnification of FM and AM 80% shadow and 40% highlight tints

and smooth transitions between tints (Whitcher, 2004). These features reduce the patchy look that can occur when printing large areas of spot colours and it can also facilitate the flawless transition of spot colour blends.

RUNABILITY

FM6 technology's main benefit is the decreased makeready time on press. FM6 allows printers to save time between runs, as well as time getting the job up to optimal quality levels. This is achieved because all of the spot colours are reproduced using the same six colours, therefore there is no need to wash up the press between runs. In conventional printing, sequential jobs with varying spot colours would have additional makeready time included to wash up the inking units between runs. This wastes valuable time and money that could go straight to the company's bottom line. You also lose the ability to pass on potential cost-savings to the customer. With FM6, a plate change is all that is necessary between runs when running jobs with dissimilar spot colours (On Demand Journal, 2006).

FM6 also saves time when getting the job up to standard before a good copy is pulled. Registration and ink density/colour fidelity must be achieved before good copies can be printed. The use of stochastic screening decreases makeready to register colours in a job, because achieving accurate registration on press is less challenging with this screening method (Hinderliter, 2006). Additionally, multiple passes are not needed for jobs requiring more colours than number of units on one's press. A designer could use over 1,000 spot colours in a single document, which would be printed in one pass of a six-colour press by using FM6 technology. This saves the printer from having to make 168 passes through this same, six-colour press! The cost saving possibilities in this case make FM6 an obvious ink technology to consider.

END USE

Since CMYK printing has become a commodity, printers feel they need to differentiate themselves to remain competitive in the marketplace. One way to achieve this is to invest in new technologies that give them a competitive advantage by increasing efficiency and reducing costs. The FM6 system would be a good consideration for printers in the packaging sector because approximately 90% of packages are printed using spot colours (Edwards, 2002). The FM6 process is not meant to increase overall colour gamut; rather it focuses on spot colour reproduction. It is traditionally difficult to reproduce violets, greens and oranges using only a four-colour process (only 60% of Pantone™ colours are reproducible with CMYK), which is why the extended gamut colours are introduced (Hershey, 2005). Internationally known companies such as Walmart, Home Depot and Yellow Pages print their marketing material using the same Creo Staccato screening that FM6 employs (Fenton, 2005). These companies spend lots of money shaping their image, thus they use this stochastic screening method to maintain the precision of their brand. The consistency of stochastic screening allows for reliable colour reproduction, therefore brand colour fidelity is now faithfully achievable using this FM6 process (Hershey, 2005).

REFERENCES

Breede, M. (1999). *Handbook of Graphic Arts Equations*. GATFPress: Pittsburgh, PA

Dynagraphy.net (2006). *Efficient Six-Colour Printing High-Quality Folding Box Production*. Press Release. Retrieved on February 2, 2007 from http://dynagraph.net/home/PressReleases/2006/PRNo59%202006.pdf

Edwards, K & Fininen, K (2002). *Evaluation and Comparison of Common Method, Used to Measure Special Colors*. Technical Association of the Graphic Arts Journal. Rochester, NY.

Fenton, H. (2005). Screening Options: Just the Facts. *Graphic Arts Monthly*, [77(8)], 22.

Field, G.G. (2004). *Color and its reproduction: fundamentals for the digital imaging and printing industry (3rd Edition)*. GATFPress: Pittsburgh, PA.

FM6. (2006). *FM6: a world of colours in one pass, technical information*. Retrieved on March 8, 2007 from the World Wide Web at http://www.FMsix.com

Hershey, J (2005). Expanding the Possibilities of Color. *PackagePrinting*. [52(10)], 14.

Hinderliter, H (2006). Head to Head Screens. *Graphic Arts Monthly*, [18(11)], 22.

Hinderliter, H (2006). Hi-Fi Color. *Graphic Arts Monthly*. [20(8)] 23

Johnson, T & Green, P (1999). *Issues of Colour Measurement and Assessment*. Technical Association of the Graphic Arts Journal. Rochester, NY.

Lindbloom, B (2007). *Useful Color Equations*. Retrieved on February 18, 2007 from the World Wide Web at http://www.brucelindbloom.com

M.Y. Cartons (2002). *M.Y. Cartons Debuts Revolutionary New Print Process At IPEX*. Retrieved on February 2, 2007 from the World Wide Web at http://members.whattheythink.com/allsearch/article.cfm?id=6034

O'Brien, K. (2004). Drupa Developments. *Graphic Arts Monthly*, [223(1)], 49.

On Demand Journal (2004). *Esko-Graphics and M.Y. PrintTech announce cooperation*. Retrieved on February 1, 2007 from the World Wide Web at http://www.ondemandjournal.com/sitesearch/article.cfm?id=18308

Pantone™ (2007). *PANTONE™ COLOR BRIDGE® coated*. Retrieved on February 2, 2007 from the World Wide Web at http://www.pantone.com/pages/products/product.aspx?pid=293&ca=1

Rosenburgh, A and Andreas, P (1999). *Color gamut improvement when using FM screening*. Technical Association of the Graphic Arts Journal. Rochester, NY.

Sharma, A. (2004). *Understanding color management*. Thomson Delmar Learning: Clifton Park, NY.

Upton, S (2005). *Delta E: the color difference*. Retrieved on February 20, 2007 from the World Wide Web at http://www.colorwiki.com

Whitchner, J (2004). Stoked on Stochastic. *Graphic Arts Monthly*, [76(1)], 18.

X-Rite. (2004). *A guide to understanding color communication*. Retrieved on March 7, 2007 from the World Wide Web at http://www.optronik.de/L10-001_Understand_Color_en.pdf

X-rite. (2006). *Observer angle*. Retrieved on March 7, 2007 from the World Wide Web at http://www.xrite.com/product_overview.aspx?Industry=1&Segment=5&ID=758&Action=Support&SupportID=3544

QUALITY AUDIT

Shiraz Israel, Matthew Kasumovic, Michael Kimpton, Mark Petch

SCOPE AND SUMMARY

SCOPE

The properties to be tested in this quality audit are solid ink densities, dot gain, and physical print defects. According to George Schultz, Production Manager at St. Joseph Communications Thorn, these are the attributes that are most important to the press-run, so we decided to focus on them. There are other properties that may be included in a quality audit such as hue error, grayness, and trapping but due to the scope of the project, we have limited it to three attributes.

The purpose of this test is to gain an appreciation of the quality auditing process and how it applies to the printing industry. We will then use this understanding to evaluate the process to the best of our ability by interpreting the feedback given to us.

SUMMARY

- Use of check sheets showed that the largest defect is hickeys making up a total of 85% of the defects.
- The standard deviations of CMYK are extremely tight, indicating a narrow dispersion of data.
- The variation of the data so slight that even a small variation can be seen as an assignable cause. According to tolerances this process is out of control, but a problem would not be seen in the final product because it is well within tolerances.
- Yellow ink had the highest dot gain at 6% (SWOP Standard 18%).
- Each colour shows a negative sloping trend as the press run progressed.
- According to statistical analysis, the process is out of control. In a real world situation the variations seen in the process would not cause any noticeable affect on quality.

INTRODUCTION

The nature of this project is to mimic as closely as possible a quality audit that would be performed in industry. Quality audits are very important in maintaining the quality that customers demand in industry. They ensure that each process within the company is performing at its best, and that a quality product is being produced. The significance of this test is that it emphasizes the need for quality in printing. Quality audits are a way to improve efficiency and reduce cost factors such as waste, makeready times, reprints, and turnaround time. In turn, costs would be reduced and the company would save money. Our audit will be broken down into three sections, preliminary data retrieval, data evaluation, and verdict and conclusions. The objectives of this test are to use statistical, as well as management tools to create a quality audit that will effectively evaluate a real industry process, and then use that data to determine whether the process is at its best. The educational gains from this test will be centered on gaining a further understanding of the production process and seeing areas in which quality errors can occur. Also, this will give us a good idea of how management handles quality errors, which is valuable for our management education.

TEST PRINCIPLES

Quality control is all about putting theory into practice, and this involves using the many tools that are available to monitor and evaluate quality. First, data will be gathered using a process flow diagram and a check sheet, and then evaluated using Pareto diagram, histogram, and control charts.

PRELIMINARY DATA RETRIEVAL: DATA GATHERING

Examination of Documents

- Looking at press sheets, examining density, dot area, and defects

Process Flow Diagram

- Helps visualize where and how the product moves through production. This helps identify where potential bottlenecks can occur.

Check Sheets

- Identifies the frequency of occurrence for different types of defects. It helps to categorize and prioritize each defect for further analysis.

PROCESS EVALUATION: DATA EVALUATION

Pareto Analysis

- Shows the frequency and importance of causes to allow you to eliminate the "vital few".

Histogram

- Looks at the average of errors over a period of time helping to see their distribution.

Control Charts

- Will identify whether or not a process is out of control due to an assignable cause.

VERDICT AND CONCLUSIONS

Forecasting

- Uses the data to predict how the process will behave in the future.

Verdict

- Whether the process has met quality standards or needs improvement.

The tools of quality control are only one half of the equation. Managers must know what to do with the feedback that is generated from these tools. Data must be properly evaluated to effectively monitor sufficient quality and to identify poor quality. Without the data, managers would be without valuable data, and resort to guessing. Overall, the tools of statistical process control are very important, but must be accompanied by those who can apply and effectively use the feedback derived from them.

MATERIALS TESTED

- 50 press sheets from St. Joseph Communications

EQUIPMENT USED

- X-Rite Scanning Densitometer ATS 40-00-01 and ATD Software
- Statistical Quality Control (SQC) for Excel
- X-Rite Spectro-densitometer

PROCEDURE

1. Obtain 50 press sheets from St. Joseph Communications.
2. Use X-Rite Scanning densitometer to scan solid ink densities into ATD software.
3. Use X-Rite Spectro-densitometer to measure screen tints and record.
4. Visually scan press sheets for defects and record frequency of occurrence for each defect on check sheet.
5. Create a Pareto diagram from the check sheet and determine the "vital few" from the "trivial many".
6. Create a histogram to evaluate process control and distribution.
7. Create a control chart to determine whether there is an assignable cause.
8. Use the data to evaluate the process and forecast future trends.

PROCESS FLOW

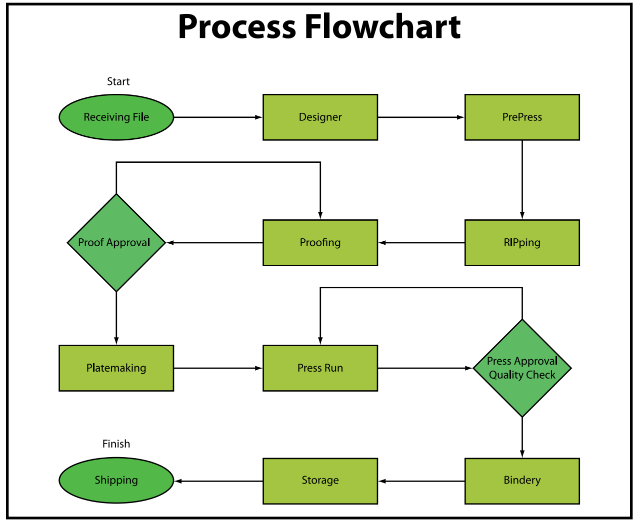


Figure 4–1: Typical process flow

RESULTS

CHECK SHEET

FAULT	OCCURANCES	PERCENTAGE
Hickeys	1,333	78.23%
Artifacts	254	14.91%
Large Hickeys	117	6.87%

Figure 4–2: Check Sheet results from analysis of the press sheets.

Page by page faults can be found in *Appendix on CD*.

PARETO ANALYSIS

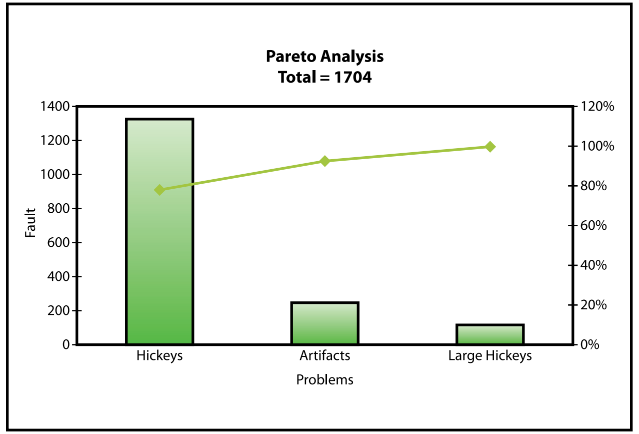


Figure 4–3: Pareto Analysis

SUMMARY OF STATISTICAL ANALYSIS

RESULTS						
COLOUR	MEAN	MEDIAN	MODE	STD DEVIATION	CP	CPK
Black Solid	1.575	1.570	1.570	0.013	2.078	2.061
Black 50%	0.581	0.578	0.587	0.012	1.743	1.714
Cyan Solid	1.273	1.270	1.273	0.011	1.750	1.722
Cyan 50%	0.526	0.522	0.522	0.011	3.022	2.995
Magenta Solid	1.003	1.000	1.010	0.008	6.649	6.649
Magenta 50%	0.476	0.476	0.484	0.008	4.454	4.381
Yellow Solid	0.884	0.880	0.890	0.009	6.649	6.596
Yellow 50%	0.453	0.451	0.441	0.015	2.927	2.919

Figure 4–4: Results of Statistical Analysis

All data and charts can be found in *Appendix on CD*.

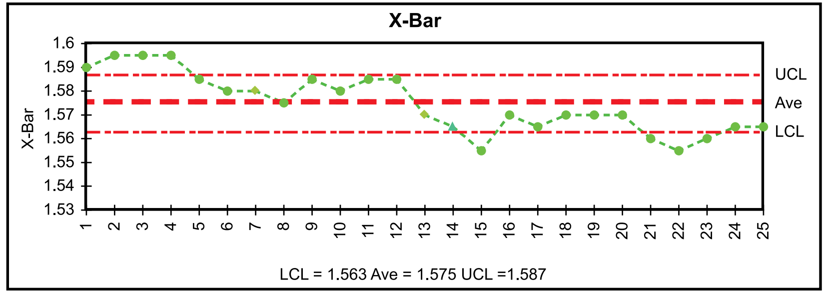


Figure 4–5: Black X-Bar

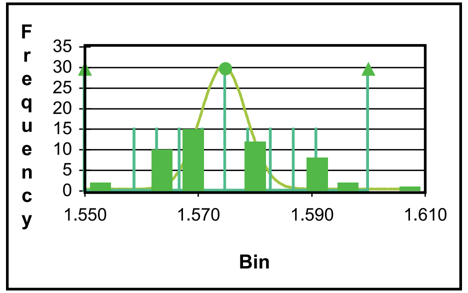


Figure 4–6: Black Histogram

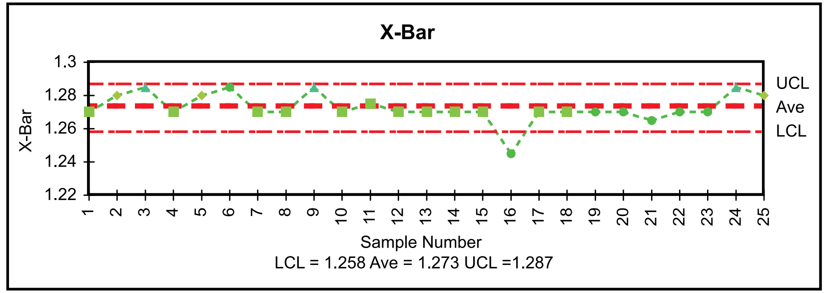


Figure 4–7: Cyan X-Bar

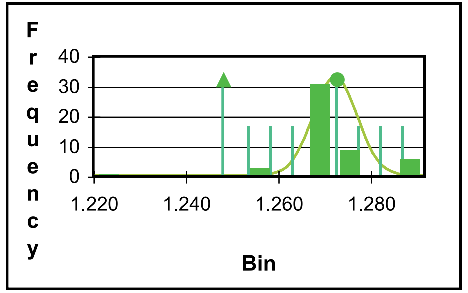


Figure 4–8: Cyan Histogram

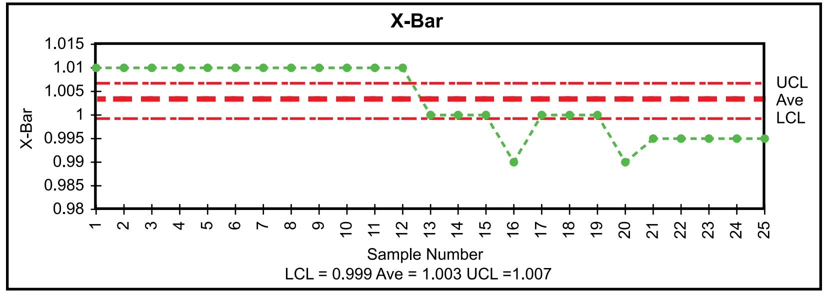


Figure 4–9: Magenta X-Bar

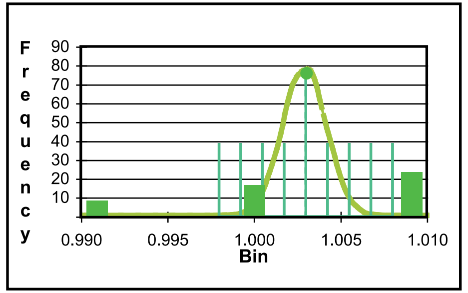


Figure 4–10: Magenta Histogram

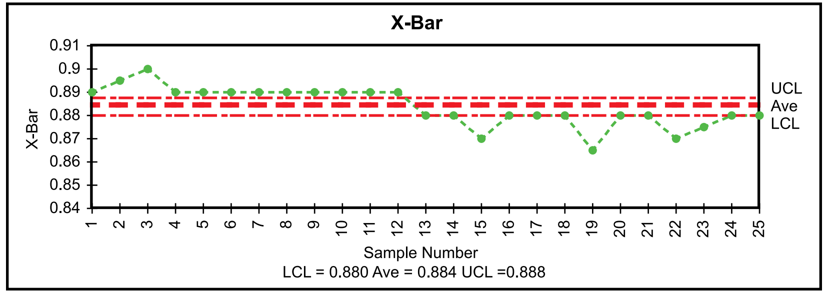


Figure 4–11: Yellow X-Bar

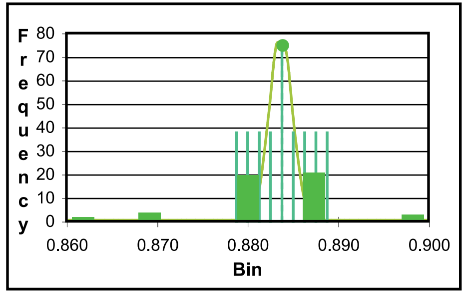


Figure 4–12: Yellow Histogram

DISCUSSION

DATA EVALUATION

Using the data generated from a quality audit is crucial because it allows managers to make informed decisions. In this quality audit we will be extracting data from Pareto diagrams, histograms and control charts, while using a process flow diagram to help pinpoint where a problem lies, and to get a solid understanding of how the process performed. Firstly, understanding which errors need to be fixed the most is important. By looking at the Pareto diagram, it is evident that hickeys are a large problem in this job due to their high frequency, and the high cumulative percentage. Knowing this, it would make sense to tackle this problem first.

The process flow diagram identifies that the problem is in the press stage of production. From a managerial standpoint, the most likely cause is that ink skin or foreign particles are present in the magenta unit. These particles could be on the plate or blanket, or even in the ink. To fix this problem, the plate or blanket must be changed, or the press must be washed and a new ink that is free of skin should be used.

DEFECTS
Hickeys
Large Hickeys
Artifacts

Figure 4–18: Defects

The next important attribute to be discussed is the solid ink density. By inspecting the results chart, one will see that the standard deviations of all colours are very tight. This indicates a very narrow dispersion of data, which in the case of press densities is desirable. Specifically, magenta had the lowest standard deviation at 0.008, while the black had the largest standard deviation of 0.013. This is confirmed by looking at the solid ink density histograms of each colour. The magenta normal curve is more leptokurtic then the black normal curve, which indicates that the black has a higher dispersion. Even though cyan has a larger standard deviation, the differences are very minute and do not pose a problem. It is very common for densities to vary by up to 0.10. For example, the standards used by Ryerson University's Graphic Communications Management program are C: 1.30, M: 1.30, Y: 1.00, and K: 1.60 with a tolerance of plus or minus 0.10.

This is important to understand because if those values are compared to the values derived from this audit, they are somewhat troubling. The average density of magenta for example is 1.005, which is very low. This may be due to the high gloss and weight of the paper along with the varnish. Perhaps since the ink holdout is so high on the paper, lower densities can achieve the same look as the standard densities. The next step to understanding whether or not the solid ink densities are performing at an acceptable level are the control charts.

By looking at the cyan control chart, it appears to have an assignable cause at sheet #16. Although this would appear out of control, it depends on the tolerances set by the specific company. Because the standard deviation is so small, it makes it easy for small variations to appear as assignable cause. Based on the process tolerances, this process is out of control, but would not cause a problem because the assignable cause is within 0.1, or even 0.05 of the mean. Realistically, small variations like this would be ignored. Therefore, action would not need to be taken on the cyan. The magenta control chart is very interesting because not only is it out of control, it is displaying a cyclical pattern. It stays consistent for a period of time, then suddenly drops, and stays consistent again. This could be explained by understanding the job. The samples taken could have been printed near the beginning of the job when the magenta ink had not been worked into the press and warmed up.

As the press run went on, the magenta ink density slowly dropped due to agitation and a decrease in tack. Perhaps the magenta ink had been sitting in the fountain longer then the other inks. It would be wise to look at press sheets further down the press run to see if the densities had evened out. If not, the integrity of the ink should then be questioned and new ink used. This cyclical pattern continues for the yellow and black colours. Yellow is showing the same values for a majority of the readings. This indicates the process is out of control because there is no random variation in the data. Similarly, the black is also out of control because it is steadily decreasing.

According to Besterfield, recurring cycles are due to seasonal effects of incoming material, temperature and humidity, any daily or weekly chemical, or mechanical event, or the rotation of operators (Besterfield, 2004). Therefore, these cycles could have been caused by makeready like the magenta ink, or perhaps heavy ink coverage caused ink densities to decrease near the tail edge of the sheet which would explain the pattern of decrease. For all colours, this cyclical pattern may also be explained by the construction of the control chart. The increments between the densities are very small, so the minor differences may have been eliminated and displayed as the same amount.

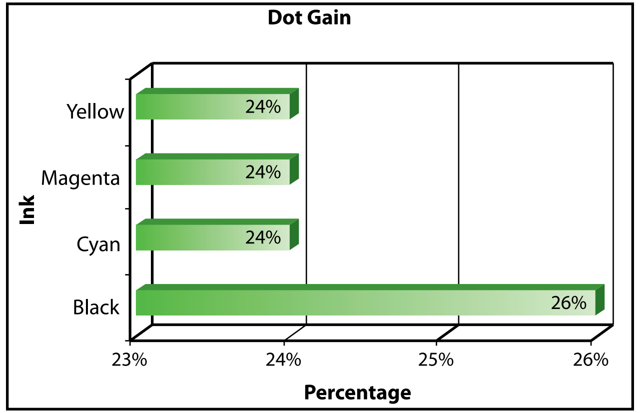


Figure 4–13: Dot gain

The third important attribute to be discussed is dot gain. Unexpectedly, the yellow ink had the highest dot gain which is unusual since black usually has the higher dot gain in sheetfed printing than cyan, magenta, and yellow due to the higher densities required. The type of substrate used has a significant effect on dot gain. In this particular job coated stock was used. Coated stock is usually effective at minimizing dot gain, which is why the values were around what we expected. The general dot gain values from press sheet to press sheet are consistent through cyan, magenta, yellow, and black.

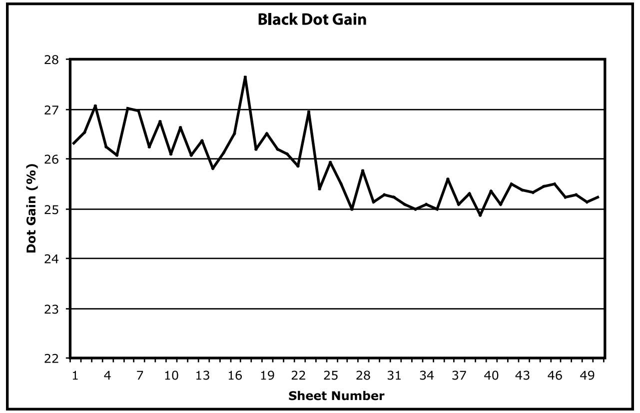


Figure 4–14: Black dot gain trends

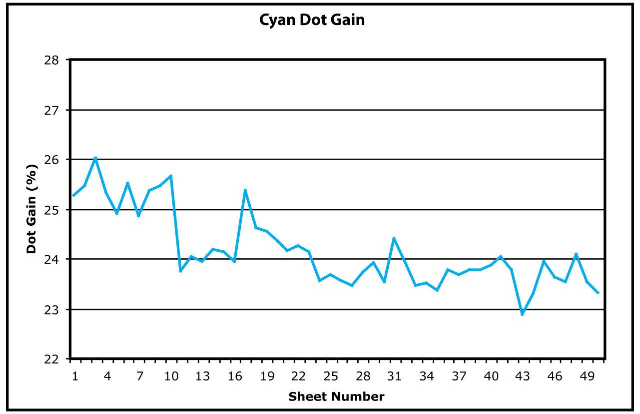


Figure 4–15: Cyan dot gain trends

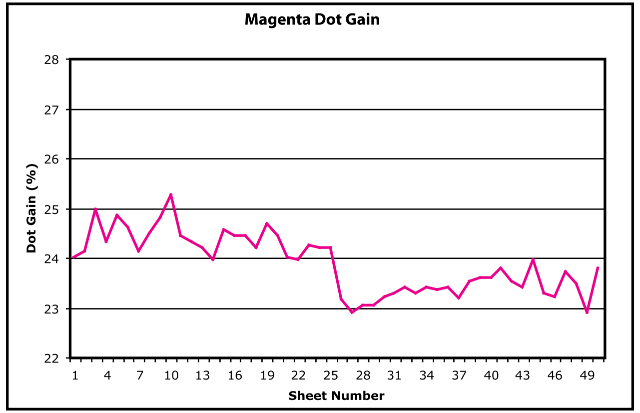


Figure 4–16: Magenta dot gain trends

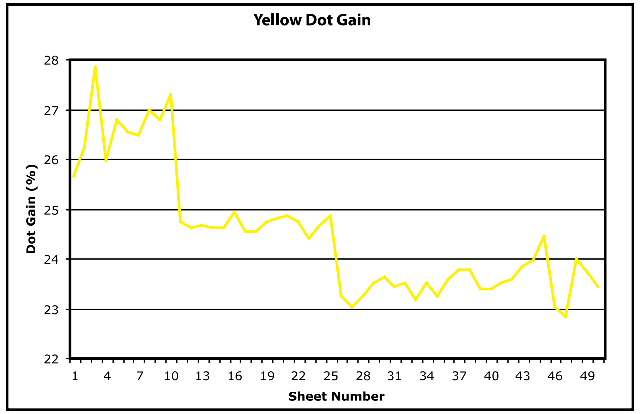


Figure 4–17: Yellow dot gain trends

The trend in the data for each colour shows a negative slope. This means that the dot gain slightly decreased from press sheet to press sheet. This trend could be explained by several factors that have an impact on dot gain values. The most significant one being ink tack. Ink tack is the force required to split an ink film and usually varies throughout a press run. The dot gain that varied the most was cyan. This most likely happened because a large portion of the image was blue and contained a fair amount of cyan. The more ink coverage laid down, the higher the probability for dot gain. This is why yellow had the most consistent dot gain level because there was a small amount of yellow used to make the print. Since the image is dark and the total ink coverage was high, it would definitely result in a higher dot gain, which would result in plugged or lost dots. The highest value of dot gain occurred at press sheet #18. This was quite high compared to the other values around it but only occurred in black and cyan. On inspection of these graphs this appears to be an assignable cause. Something like this could be caused by poor ink/water balance and perhaps the ink keys were not set correctly.

Dot gain can be determined by multiple factors including ink tack, cylinder packing, and the substrate. The higher the ink tack the less dot gain should occur because it is more difficult for the tacky ink to spread. Cylinder packing must be applied correctly or else too much squeeze between either of the blanket or plate cylinder could cause serious dot gain problems. Substrates play a large role in it as well. Most uncoated substrates like newsprint would have a greater dot gain due to the increased absorptivity of the stock. On the other hand, coated substrates would result in a better dot because of their ability to hold out the ink. Measuring dot gain in a quality control audit is essential because it helps produce high quality work. If an image consists of dark shadows the significance of dot gain becomes more evident. Often, shadows become plugged due to dot gain, but since there is more room for gain in the midtones, this is where dot gain is seen most.

PROCESS EVALUATION

During this stage of the audit, all data that has been evaluated must now be used to identify whether the process is capable. In terms of solid ink densities, although the processes appeared out of control, realistically they would be okay. This is because the tolerances on the control charts were so tight and did not reflect the actual tolerances used in industry. For instance, black showed assignable cause on the 15^{th} sheet, but the density was only 0.02 off of the mean. Comparing this to a commonly used tolerance of 0.10, this really would not be an assignable cause. This is why it is important to understand the printing process as well as statistical quality analysis, or else unnecessary actions could be taken that would waste time and money. This is also true for cyan, magenta, and yellow. None fell above or below 0.10 of the mean showing that the densities are suitable for sheetfed printing. This is also confirmed visually. On inspection, colour balance appeared correct and produced detailed highlights and shadows. Also, skin tones, where variation is typically most noticeable, appear balanced and realistic. Although the statistics say otherwise, the densities are suitable and it would take a trained eye to know there is a difference. This can also be seen in the Cp indexes. In black, the Cp index is 2.078, which is very capable. Similarly, cyan, yellow and magenta also show capable indexes of 1.750, 6.649, and 6.649 respectively. Looking at all colours, these Cp indexes show a very capable process. “Based on the experience of a number of practitioners, they have a suggested a ‘safe’ lower limit Cp of 1.50. A value above this level will practically guarantee that all units produced by a controlled process will be within specifications”(Evans, Lindsay, 1999). This only confirms that the solid ink densities are suitable for the processes.

In order to evaluate dot gain, the values acquired for this job will be compared to SWOP standards. As mentioned, black had the highest dot gain of 26%. Comparing this value to the standard of 22% for black, there is a variance of 4%. Although the tolerance for SWOP is + or - 3%, 4% is too little to have a real effect (SWOP, 2006). Looking at cyan, magenta, and yellow, all had dot gain of 24%. Since SWOP standards tolerate + or – 3%, cyan, and magenta are acceptable, but yellow fell out of standards with gain of 6%. Perhaps too much yellow was running through the press causing the dot gain.

In actual practice, the use of quality audits is different from company to company. It is important to understand quality in different print industries because it is common for managers to move around in the industry, and they must know how to satisfy the customer depending on the application. This is why the way in which companies implement quality control varies. For instance, Andrea Grey, Quality Manager at the Globe and Mail runs a quality audit with several steps:

QUALITY AUDIT PROCESS (GREY, 2007)

1. Measure solid ink density
2. Measure grey bar
3. Check registration
4. Check for print defects
5. Average each value and compare between each print site
6. Generate a quality report, show averages and how close they are to the targets

If quality is not up to par, Andrea is responsible for letting the printer know that improvements need to be made. The improvements that need to be made are based on the data derived from the quality audit. It is common for companies to have a database that stores data such as densities, grey bar values, L*a*b* values, or any data relative to their needs. At the Globe and Mail, the database is used to create monthly and annual quality reports that evaluate the printers' quality. It is unusual that there would be large shifts in quality at different sites because they all strive for quality. There may be a month where a shift in quality is noticed, but that is usually due to a press malfunction and time was needed to repair the press (Grey, 2007). For a manager in this industry, consistency is very important. This makes it important for managers to be able to create standards that represent ideal quality and audits give managers the tools needed to do this.

Newsprint quality control differs from sheetfed mainly in the need for consistency. In commercial printing, each job can be unique and therefore strict quality guidelines would not be appropriate. According to Gary Schultz from St. Joseph Communications, for shops with a high volume of jobs a long list of quality procedures may be too time consuming and unnecessary. At St. Joseph's, quality is primarily judged visually. This requires highly skilled press operators who have an excellent understanding of each press. This is why managers must have detailed knowledge of each press and should be able to address quality issues, especially when crucial jobs come up for repeat customers and very important clients. By doing so, managers can give the customer the peace of mind needed to know their job will be completed to their quality standards. Also, in sheetfed quality control, procedures are often different than in newsprint quality control.

According to Andrea Gray, Quality Control Manager at the Globe and Mail, newsprint quality procedures do not differ and all jobs must adhere to the same quality standards. Conversely, at St. Joseph's, quality standards can differ from job to job (a high-end job compared to a flyer, for example). This is why quality management procedures may not be necessary. "Strong social and commercial pressure and even trends to adopt TQM practices that are not always considered technically necessary, often lead to a legitimization rhetoric in organizations" (Cole, 1998, De Cock, 1998). Companies may implement quality control practices just for the image, which may not be a good idea, especially if it is not doing anything to improve processes within the company. At St. Joseph's, they do not use quality assurance procedures. To them, quality is achieved when the client is satisfied (Schultz, 2007). This puts a large responsibility on quality managers to figure out if quality assurance is right for the company.

VERDICT AND CONCLUSIONS

When taking all data into account, it is wise to use quality control analysis to predict the capability of a printing process. It is clear that an action plan must be put in place because as can be seen by the results, as the press run progressed the solid ink densities gradually decreased. Consistent monitoring of this during the whole press run would help alleviate this concern. Quality guidelines must be put into place and must be followed stringently through each press run. If this is done it will become second nature to the press operator.

Management plays a key role in implementing and following any standards put in place. A strategic plan is put in place to deal with the shortcomings of a company's processes and must be worked out in order for them to stay competitive in the printing industry. The concern of improving quality would need to top of mind for the management of St. Joseph's because, "Quality improvement objectives like increasing customer satisfaction, reducing defects, and reducing process cycle times now generally receive as much attention as financial and marketing success" (Evans, Lindsay, 1999).

Based on the data and by using managerial instinct, the solid ink densities for this process performed quite well despite the processes being out of control. They all fell between realistic industry standards. What was slightly troubling was how low the average densities for each colour were. This may be some sort of standard that St. Joseph's uses or a condition of the paper, press and substrate. It also could have been a malfunction of the equipment.

If the dot gain values were to be looked at independently and compared to industry specifications, this job would be considered out of control. Although the dot gain values are slightly higher than recommended, the variables present on this particular job need to be taken into account. Again the process should be looked at to see whether this is acceptable or not and steps need to be taken to rectify the situation if necessary.

The number of hickeys and artifacts found on this job should be of great concern for the management of St. Joseph's. This is an expensive job for a large client, so great care should have been taken so ensure that the job was printed with minimal defects. The solid ink densities and dot gain values are not something thing that a client would be able to notice without special equipment and previous knowledge. The amount of hickeys both large and small contributed to 85% of the problems associated with a sample size of fifty sheets. This is the greatest opportunity for quality improvement and is something that is relatively easy to fix, it could be as simple as washing up the unit. The press time lost doing this would be minimal compared to the impact of losing this client. In the printing industry, as competition and consumer expectations increase, there is a need to provide impeccable quality while cutting costs at every opportunity (Evans, Lindsay, 1999). Investing in a Total Quality Management program would help provide them with the competitive advantage they need in the current state of the industry.

RECOMMENDATIONS

Quality audits are composed of both statistical and managerial methods that can apply to any aspect of printing as long as it is measurable. Quality is not limited to a certain printing condition or situation which is why it is difficult to pinpoint a quality audit specifically to printability, runability, and enduse. As an alternative, it is wise to discuss ways that a quality audit can be applied to printability, runability, and enduse.

Using process evaluation, managers can pinpoint certain areas within a process that show an assignable cause and attack the problem head-on. It is a very valuable way for managers to keep abreast of their processes. For example, it would be the responsibility of production managers to establish standards that represent ideal printing densities that should be established so that there is a target for press, and so that actual densities can be compared and monitored based on those standards. With that in control, printability problems such as colour shifts, setoff, and plugged highlights or shadows can be avoided. If any problems in density were detected, it could easily be seen in the control chart. Similarly, runability problems such as wrinkling can be monitored closely using observation and examination.

Quality must be ascertained and maintained at every stage of the printing process as each stage affects the next, from prepress all the way to bindery. If quality standards are not met throughout the printing process, companies will not be able to provide the level of quality their customers are looking for. Additionally, without a sufficient level of quality the end use applications of a product will not be met. For example, with outdoor signage, misregister of the product would make it difficult to read causing the ad to be less effective. Analyzing the press sheets received from St. Joseph's we found an unacceptable number of hickeys and artifacts. Had this job been shipped and put into its end use application, it would have reflected poorly upon Esso, which in turn, would have reflected poorly upon St. Joseph's, possibly losing them business.

REFERENCES

Besterfield, Dale. H. (2004). *Quality Control: 7th Edition*. Upper Saddle River, NJ: Pearson Prentice Hall.

Boiral, Olivier. (2003). ISO 9000: Outside the Iron Cage. Organization Science, 14, 720-737.

Evans, James R. & Lindsay, William M. (1999). *The Management and Control of Quality*. Cincinnati, OH: South-Western College Publishing.

Gray, Andrea, Phone Interview. March 15, 2006.

Schultz, Gary, Phone Interview. March 15, 2006.

Specifications Web Offset Publications, Retrieved March 24, 2007, from SWOP Specification Web site: http://swop.org/specification/

MODERN COLOUR DIFFERENCE EQUATIONS AND THEIR RELATIONSHIP TO PRINTED INK DENSITIES

Zeinab Panahi

INTRODUCTION

Measuring and monitoring are the basis of standardization. Objective measurements of important printing properties such as the inking values of solids are crucial (Bestmann, 2006). Densitometers are a common tool in print shops to control the quality of the printed materials during the press run; but the density values tell the press operators nothing about the appearance of the printed colours. Many modern and larger printing facilities are equipped with spectrophotometers in order to control the colour variations. Researches have been done in attempt to translate the colour and density variations into each other. The article "How Many ΔEs Are There in a ΔD?" shows that "densitometry and colorimetry are equivalent in terms of maintaining consistent colour on press" (Seymore, 2007). Also, "the colorimetric tolerances in ISO 12647-2 can be converted to a reasonable density tolerance" and "within a press run, running to a density tolerance will assure colorimetric tolerance". In addition, he converted the colour variation tolerances into density tolerances and concluded that "the conversion between densitometric and colorimetric tolerances for coated stocks is pretty much the same for all stocks" (Seymour, 2007).

PARAMETERS	COLOUR			
	BLACK	CYAN[1]	MAGENTA[1]	YELLOW[1]
Deviation tolerance	5.0	5.0	5.0	5.0
Variation tolerance[1]	4.0	4.0	4.0	5.0
[1]The contribution of the hue difference shall not exceed 2.5.				

Figure 5–1: CIELab ΔE_{ab} tolerances for the solids of the process colours (ISO 12647-2:2004)

In this paper, the deviation tolerances (*Figure 5-1*) are used to determine whether the reproduced colours conform to the ISO standards and to establish a target density for each colour that results in the lowest ΔE (if there is any). The question here is whether a press operator can use densitometry measurements and still meet the specified colour standards. Each paper has different surface structure, gloss, absorptivity and brightness. How do these characteristics affect the reproduced colour?

Since 1976, various colour differencing equations such as ΔE_{ab}, ΔE_{94}, ΔE_{CMC} and ΔE_{00} have been established by colour scientists. The purpose has been to adjust the equations to more closely match with the human perception of colour differences (Habekost, 2007a, 2007b). In a research by Habekost , it was established that the more recent equations (ΔE_{00} and ΔE_{CMC}) correlate well with the perceived differences by human eyes. Also, the latest tests on this topic revealed that ΔE_{00} correlates better with the human perception of colour differences (Habekost, personal communications, 2007). However, none of these formulas have a uniform colour space. DIN99 has been developed to address this issue. Also, this formula generally yields smaller values with better correspond to the visual impression (DIN 6176). But, which one of these equations does correlate better with density variations? Are the deviation tolerances the same for all the ΔE formulas?

TEST PARAMETERS

The custom mode of the Universal Testprinter (UTP) was set to the print length of 200 mm and speed of 1 m/s for print arm #1. A pre-measured amount of ink (using the Prüfbau ink pipette) was applied to the rubber roller of the UTP inking unit and was distributed for 30 seconds. Then the printing disk was dropped on the rollers and inked up for another 30 seconds. The disk was then weighed on the digital balance, which was connected to a computer with a data logging software. The printing disk was placed on print arm #1 of the Testprinter and a print was made on the paper strip taped onto the printing sector (printed area is measured 0.21m x 0.048m). The printing disk was then weighed again. This procedure was repeated for the next 16 samples of the same paper without adding ink to the inking system, thus each printed sample had lower density (and ink film thickness) than the previous one.

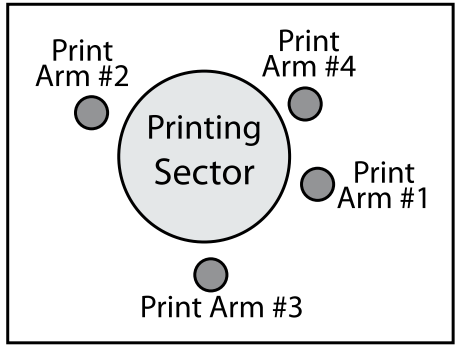


Figure 5–2: Diagram of the Universal Testprinter (courtesy of N. Kidd, Ryerson University)

The same procedure was followed for each process ink on each of four coated papers (16 sets of samples). At least 24 hours was allowed for the samples to dry before measuring them.

In the X-Rite Color Master QAII software, the spectral reflectance values of 0°/45° geometry for each colour specified in ISO 2846-1:1997(E) were entered as the standard. Illuminant D_{50} and 2° observer were used as the standard settings. A spectrodensitometer connected to the computer was used to make three measurements on each sample. All the density measurements throughout the test were status T and made on white backing (three sheets of unprinted paper).

The setting test was done on the Prüfbau printability tester using 100 mm^3 of the setting test ink and pressure of 600 N. The PSE test (Paper Surface Efficiency) was carried out using the K&N testing ink and averaged for both sides of the paper. The same spectrodensitometer was used throughout the test.

EQUIPMENT/MATERIALS

- Universal Testprinter printability tester and inking unit
- X-Rite spectrodensitometer, 500 series, X-Rite Inc.
- Prüfbau ink pipette
- Denver Instrument analytical balance with Pinnacle USB version 1.2 software
- X-Rite Color Master QAII software
- Prüfbau printability tester
- Novo-Gloss, Statistical Glossmeter, Rhopoint Instrument Ltd.
- Drawdown blade
- Setting Test Ink, 520068, Michael Huber Munchen GmbH
- K&N testing ink, NO. D79, K&N Laboratories Inc.

HOSTMANN-STEINBERG, HUBER GROUP		
YELLOW	1 QK 1765	Rapida Optima HiT Process Yellow
MAGENTA	2 QK 1765/5	Rapida Optima HiT Process Magenta
CYAN	3 QK 1765	Rapida Optima HiT Process Cyan
BLACK	8 QK 1765	Rapida Optima HiT Process Black

Figure 5–3: Ink set used in this experiment

	BASIS WEIGHT (LB.)	GRAMMAGE (G/M²)	BRIGHTNESS	L*	A*	B*	GLOSS
PHOENIX APCO II/II (STANDARD PAPER)	100	160	84.72	96.15	0.09	4.13	72.20
SUPREME GLOSS COATED	80	120	90.55	94.71	0.88	-2.60	72.5
EXACT GLOSS COATED	70	100	90.24	94.11	1.70	-3.23	66.8
EUROART GLOSS	100	150	90.77	94.28	1.28	-3.49	75.2

Figure 5–4: Paper samples tested in this experiment

RESULTS AND DISCUSSION

WHICH DELTA E SHOULD BE USED: ΔE_{AB}, ΔE_{94}, ΔE_{CMC}, ΔE_{00} OR DIN99?

The question here is, which one of the ΔE equations corresponds better to the density variations? To find out the answer, all five ΔE values of each colour on each paper were plotted as a function of density in a scatter diagram and the R^2 values of the 2nd order polynomial trendlines were determined. The second set of diagrams was made by plotting the density values against the ΔE's of below and above target density in two separate diagrams (target density here is defined as the density yielded in the lowest ΔE). Out of 160 R^2 values for the second set of diagrams (five ΔE's, four papers, four colours and below/above the target density), only three of them were lower than their relative values in the first set. Therefore, the later R^2 values have been used for the purpose of this section to determine which ΔE corresponds better to the density changes. *Figure 5–5* displays the ΔE equation that corresponded better to density variations for each process colour on all the papers (highest R^2s).

As the results show, only yellow and black samples have a dominant ΔE and cannot determine a single ΔE equation that defines the best relationship between density and colour changes for all the colours.

YELLOW	MAGENTA		CYAN		BLACK
ΔE_{ab}	Above target density	Below target density	Above target density	Below target density	DIN99
	ΔE_{00}	DIN99	ΔE_{cmc}	DIN99 and ΔE_{00}	

Figure 5–5: The ΔE equation with the highest R^2 values for each colour

Also, comparing the R^2 values in the first set of diagrams where all density values were plotted against ΔE's on the same diagram, only ΔE_{00} was dominant for yellow and no single ΔE was found for the rest of the colours.

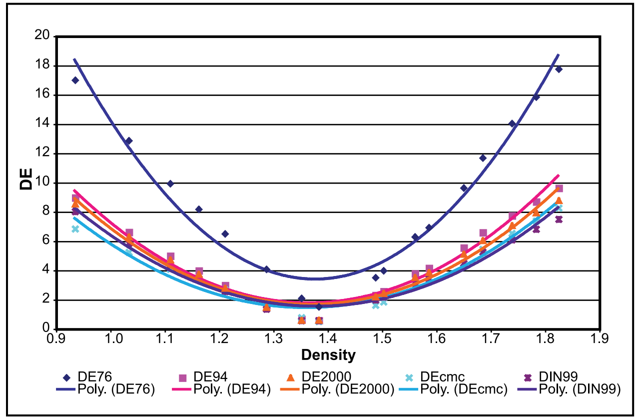


Figure 5–6: ΔE values versus density for magenta printed on Exact Gloss Coated

How do L*a*b* values correspond to density changes?

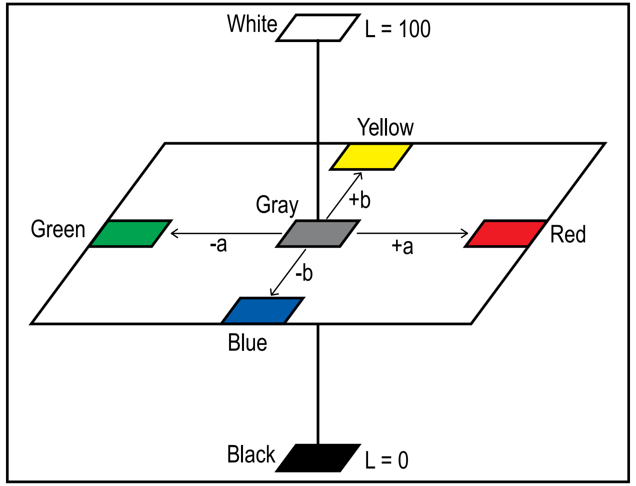


*Figure 5–7: The CIE L*a*b* colour scale*
(Based on Field, 1999)

Density versus L*

For all four colours, as density increases, L* values decreases (colour becomes darker). The L* values are very close for all the papers printed with the same colour at any given density and in case of black samples, all four trendlines are on top of each other. The only exception is the Phoenix samples printed with yellow where they have higher L* values than other three papers. The unprinted Phoenix paper has higher lightness value than the other stocks. The L* value of the plain paper has a great influence on the L* value of the printed yellow than on the other process colours. Also, ΔL*'s are minimal from one sample to the next as density changes in yellow samples. Therefore the lightness of yellow remains almost the same as density increases.

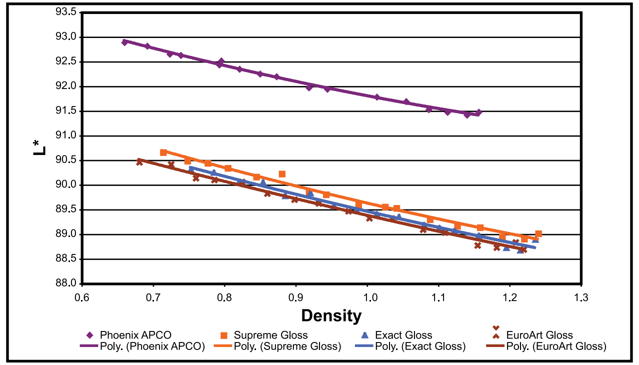


Figure 5–8: Density versus L for yellow printed on coated stocks*

Density versus a*

For yellow samples, Δa*'s are minimal for ΔD's below target density and they rise more quickly above the target density, whereas for magenta, Δa's are minimal for ΔD's above the target and the trendlines have a sharper upward slope below target density. Therefore, increasing the density of the printed yellow above target density causes the printed colour becomes slightly reddish as oppose to achieving a more saturated yellow.

Also, the trendlines for yellow and magenta tend to be linear compared to parabolic trendlines of cyan and black. For cyan, a* is the lowest for the target density while for black, a* is the greatest at the target.

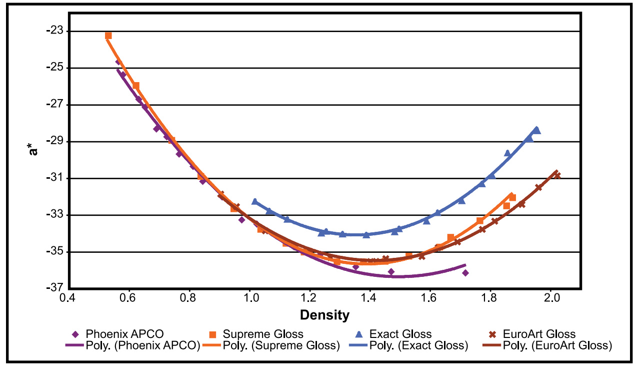


Figure 5–9: Density versus a for cyan printed on coated stocks*

Density versus b*

The Phoenix APCO samples have higher b* values than the other papers in all printed colours. The reason could be the fact that Phoenix is the only paper sample in this test which has a positive b* value (yellowish paper). For yellow and magenta, b* values increase as density increases (colour becomes more yellowish) while for cyan they decrease as density increases (colour becomes more bluish). For black all the trendlines with the exception of Phoenix paper are downward parabolic with the maximum point somewhere below the target density.

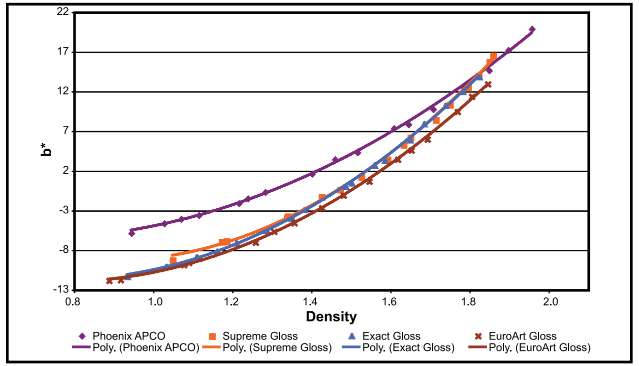


Figure 5–10: Density versus b for magenta printed on coated stocks*

Comparison of the relationship between L*, a* and b* values and density of the four process colours

Figure 5–11 displays the slope of the L*a*b* values versus density (averaged for all papers). Note that for cyan and black, the slope is calculated for densities above and below the target in order to be comparable with the other non-parabolic trendlines.

	YELLOW	MAGENTA	CYAN	BLACK
DENSITY VS. L*	-3.28	-13.06	-18.91	-27.19
DENSITY VS. A*	5.13	13.73	8.38 (above target) -10.65 (below target)	-1.40 (above target) 0.67 (below target)
DENSITY VS. B*	67.16	27.94	-18.67	-5.51 (above target) 1.27 (below target)

Figure 5–11: The slope of L, a* and b* versus density*

As the results show, black has the highest ΔL* and the lowest Δa* and Δb* slopes (the colour of black remains almost the same at various densities) (refer to *Figures 5–13 & 5-14*). Also, yellow has the lowest ΔL* and the highest Δb* slopes. The Δa* slope is the greatest for magenta. Overall, comparing the a* and b* values of all colours as density varies, Δb* has the highest slope across all the colours. This means that as density changes, colours are more shifted between the yellow and blue corners of the colour space than between the red and green corners.

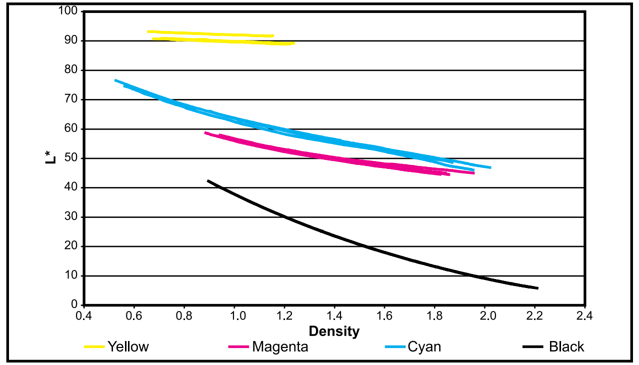


Figure 5–12: Density versus L for all the printed samples in this experiment*

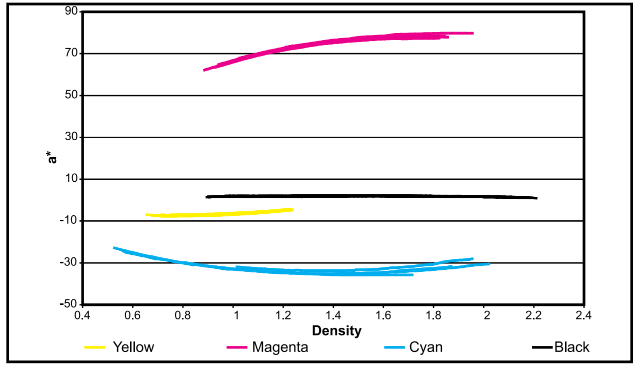


Figure 5–13: Density versus a for all the printed samples in this experiment*

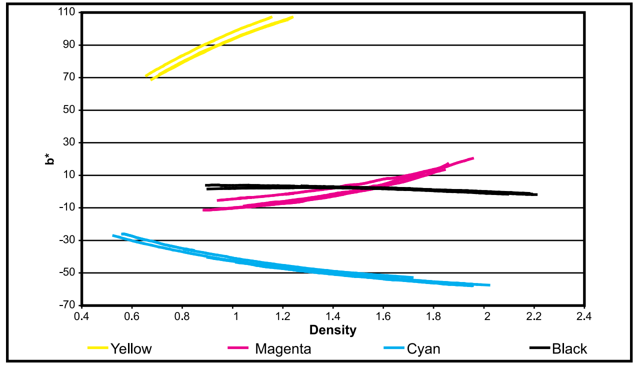


Figure 5–14: Density versus b for all the printed samples in this experiment*

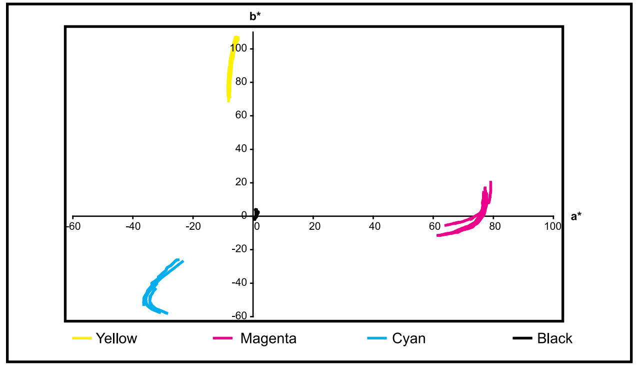


*Figure 5–15: Plot of a*b* values for all the printed samples in this experiment*

THE RELATIONSHIP BETWEEN DENSITY AND ΔE_{AB}

The ΔE_{ab} values of all samples were plotted as a function of density in a scatter diagram. In order to visually compare the effect of paper on ΔE as density changes, all ΔE values of papers printed with the same colour were plotted on the same diagram. The equation of each polynomial trendline was used to calculate the density values at which ΔE's are within the deviation tolerance (ΔE of 5.0) specified by ISO 12647-2 (refer to *Figure 5–1* for deviation tolerances).

For example:

Yellow on Phoenix APCO:

$$Y = 212.63X^2 - 415.87X + 207.97$$

$$Y = \Delta E_{ab}$$

$$X = \text{Density}$$

$$Y = 5 \rightarrow X_1 = 1.02 \quad \text{and} \quad X_2 = 0.94$$

$$\text{Mean (target density)} = \frac{X_1 - X_2}{2} = 0.98$$

$$\text{Tolerance} = \frac{X_1 - X_2}{2} = 0.04$$

Therefore for any density value between 0.94 and 1.02 conforms to the ISO standards as an acceptable colour because the ΔE_{ab} is equal or less than 5.0 .

Figure 5–16 & 5–17 show the density range for each paper and colour which yielded to ΔE_{ab} equal or less than 5.0.

	YELLOW			MAGENTA		
PAPER	DENSITY RANGE	TARGET DENSITY	TOLERANCE	DENSITY RANGE	TARGET DENSITY	TOLERANCE
PHOENIX APCO	0.94 – 1.02	0.98	±0.04	1.22 – 1.40	1.31	±0.09
SUPREME GLOSS	0.98 – 1.11	1.04	±0.06	1.21 – 1.55	1.38	±0.17
EXACT GLOSS	0.97 – 1.12	1.04	±0.08	1.23 – 1.52	1.38	±0.15
EUROART GLOSS	1.00 – 1.10	1.05	±0.05	1.22 – 1.56	1.39	±0.17
AVERAGE		1.03	±0.06		1.36	±0.14

Figure 5–16: Density range yielded to $\Delta E_{ab} \leq 5.0$ for yellow and magenta samples

	CYAN			BLACK		
PAPER	DENSITY RANGE	TARGET DENSITY	TOLERANCE	DENSITY RANGE	TARGET DENSITY	TOLERANCE
PHOENIX APCO	1.22 – 1.47	1.35	±0.13	1.50 – 1.84	1.67	±0.17
SUPREME GLOSS	–	1.29*	–	1.49 – 1.85	1.67	±0.18
EXACT GLOSS	–	1.24*	–	1.44 – 1.84	1.64	±0.20
EUROART GLOSS	–	1.27*	–	1.49 – 1.84	1.67	±0.18
AVERAGE		1.29	±0.13**		1.66	±0.18

* For no X value, the trendline equation equals 5.0. The mentioned target density had the lowest ΔE_{ab} among all the samples.
** The tolerance based on Phoenix samples only

Figure 5–17: Density range yielded to $\Delta E_{ab} \leq 5.0$ for cyan and black samples

	YELLOW	MAGENTA	CYAN	BLACK
ACHIEVED TARGET DENSITIES IN THIS EXPERIMENT	1.03 ±0.06	1.36 ±0.14	1.29 ±0.13	1.66 ±0.18
TARGETS BY COLOR MASTER SOFTWARE*	1.00	1.35	1.35	1.60
GRACOL TARGETS	1.05	1.50	1.40	1.70

* These target densities are calculated by the Color Master software based on the typical spectral reflectance values, 0°/45° geometry, ISO 2846-1:1997(E)

Figure 5–18: Target density comparison

Based on the results, black has the widest and yellow has the smallest density tolerance range. The cyan samples of the standard paper (Phoenix) were the only samples that conformed to the ISO cyan colour. This paper does not have any optical brightener. The other three stocks are bluish white papers with optical brighteners. In order for cyan to be seen by human eyes, light is reflected from the blue and green areas and absorbed in the red area of the spectrum. Optical brighteners increase the light reflectance in the blue range of the colour spectrum. This artificial boost in the blue area where cyan has its highest reflectance values pushes the L*a*b* values out of ISO conformity.

The achieved target densities are close values in each set of samples printed with the same colour. These target densities are also close to the target densities calculated by the Color Master software based on the ISO reflectance values. However they are different from the GRACoL targets in case of magenta and cyan. This can be due to the fact that magenta and cyan have the highest hue error and grayness among the process colours (Breede, 1999). Therefore, it can be concluded that within the group of coated stocks, a target density can be established (based on colorimetric values) for a solid colour as long as the same ink is used. As a result, meeting the standard target densities (i.e. GRACoL) will not guarantee a colour match (lowest colour difference).

	YELLOW	MAGENTA	CYAN	BLACK
$\Delta E_{ab}/\Delta D$	59.57	36.08	24.89	25.54
$\Delta D/\Delta E_{ab}$	0.02	0.03	0.04	0.04
Density Variation Tolerances	±0.05 $((\Delta D / \Delta E_{ab}) \times 2.5)$	±0.06 $((\Delta D / \Delta E_{ab}) \times 2)$	±0.08 $((\Delta D / \Delta E_{ab}) \times 2)$	±0.08 $((\Delta D / \Delta E_{ab}) \times 2)$

Figure 5–19: Conversion of colour variation tolerances into density variation tolerances

"The colour differences between a production copy and the OK print shall not exceed, and should not exceed one half of the pertinent variation tolerances specified" (ISO 12647-2, 2004). Therefore, during the production, if the density variation tolerances in *Figure 5–19* are met, the reproduced colours fall within the ISO colour variation tolerances (refer to *Figure 5–1* for ISO variation tolerances).

DEVIATION TOLERANCES FOR ΔE_{00}

In the same procedure as before the ΔE_{00} values were plotted against density and the related equation of each trendline was obtained. The density range that conforms to the ISO standard colour was used to determine the ΔE_{00} tolerance for each solid colour. For example:

Yellow on Phoenix APCO:

$$Y = 37.33X^2 - 75.642X + 39.572$$

$$Y = \Delta E_{00}$$

$$X = \text{Density}$$

$$X_1 = 1.02 \text{ and } X_2 = 0.94 \rightarrow Y_1 = 1.26 \text{ and } Y_2 = 1.46$$

$$\text{Average} = \frac{Y_1 + Y_2}{2} = 1.36$$

Therefore, if the colour difference of yellow printed on Phoenix paper calculated using ΔE_{00} equation is equal or less than 1.36, the colour conforms to the ISO standard yellow.

	YELLOW	MAGENTA	CYAN	BLACK
PHOENIX APCO	1.36	2.75	2.83	3.57
SUPREME GLOSS	1.63	2.55	3.03	3.72
EXACT GLOSS	1.57	2.45	3.41	3.74
EUROART GLOSS	1.66	2.55	3.23	3.69
AVERAGE	1.56	2.57	3.13	3.68
SUGGESTED ΔE_{00} DEVIATION TOLERANCE	1.60	2.60	3.20	3.70

Figure 5–20: ΔE_{00} deviation tolerances for solids of process colours

Figure 5–20 shows the deviation tolerances for ΔE_{00} within which the colour conforms to the ISO standard colours. These deviation tolerances for ΔE_{00} equation are lower than those specified in ISO 12647-2:2004 for ΔE_{ab}. Therefore, if different ΔE formula is selected for colour control purposes, new deviation tolerances need to be established. *Figure 5–20* also displays the suggested ΔE_{00} tolerances.

DEVIATION TOLERANCES FOR DIN99

Using the previous ΔE_{00} calculation, the deviation tolerances were calculated for DIN99. *Figure 5–21* displays the deviation tolerances for DIN99 within which the colour conforms to the ISO standard colours.

	YELLOW	MAGENTA	CYAN	BLACK
PHOENIX APCO	1.28	2.52	2.66	6.27
SUPREME GLOSS	1.59	2.31	2.88	6.14
EXACT GLOSS	1.58	2.22	3.32	6.27
EUROART GLOSS	1.65	2.31	3.12	6.22
AVERAGE	1.52	2.34	3.00	6.22
SUGGESTED DIN99 DEVIATION TOLERANCES	1.60	2.40	3.00	6.30

Figure 5–21: DIN99 deviation tolerances for solids of process colours

THE RELATIONSHIP BETWEEN DENSITY, ΔE_{AB}, ΔE_{00} AND DIN99

The plot of ΔE values versus density for each paper printed with each one of the process colours shows that ΔE_{00} and DIN99 have a very close values in yellow samples and as the colour gets darker (comparing the lightness of the four process colours in order of yellow, cyan, magenta and black) the difference between ΔE_{00} and DIN99 values becomes larger (*Figure 5–12* shows the difference between the lightness of four process colours). Also, ΔE_{ab} has the highest colour difference values and the highest slope ($\Delta E/\Delta D$) among all the ΔE equations for yellow, magenta and cyan samples. However, for black samples, DIN99 has the greatest colour difference values as well as the highest slope ($\Delta E/\Delta D$).

As demonstrated in *Figure 5–19*, colour variation tolerances defined in ISO 12647-2:2004 can be translated into a set of density variation tolerances. *Figure 5–22*, displays suggested density variation tolerances for ΔE_{00} and DIN99 equations. The colour variation tolerances for ΔE_{00} and DIN99 were assumed to be the same as their deviation tolerances. Therefore, if the density variation tolerances are met during production run, the reproduced colours will fall within the colour variation tolerances as the acceptable colour.

		YELLOW	MAGENTA	CYAN	BLACK
$\Delta E/D$	$\Delta E_{AB}/D$	59.57	36.08	24.89	25.54
	$\Delta E_{00}/D$	10.29	18.16	16.20	17.15
	DIN99/D	9.76	16.27	15.72	32.57
$\Delta D/E$	$\Delta D/E_{AB}$	0.02	0.03	0.04	0.04
	$\Delta D/E_{00}$	0.10	0.06	0.06	0.06
	ΔD/DIN99	0.10	0.06	0.06	0.03
Density variation tolerances: ($\Delta D/\Delta E$) x (1/2 colour variation tolerance)					
ΔE_{AB}		±0.05	±0.06	±0.08	±0.08
ΔE_{00}		±0.08	±0.08	±0.10	±0.11
DIN99		±0.08	±0.07	±0.09	±0.10

Figure 5–22: Conversion of colour variation tolerances idensity and ΔE_{ab}, ΔE_{00} and DIN99 and the suggested density variation tolerances for ΔE_{ab}, ΔE_{00} and DIN99

INK COVERAGE

The ink coverage and the ink film thickness of each printed sample were calculated using formulas specified in ISO 2834:1999(E).

Ink coverage:

$$C = \frac{m_1 - m_2}{A}$$

C = Ink coverage (in grams per square meter)

m_1 = The mass of the ink forme before printing (in grams)

m_2 = The mass of the forme after printing (in grams)

A = The printed area (in square meter)

Ink film thickness:

$$d = \frac{C}{\rho}$$

d = The ink layer thickness (in microns)

C = The ink coverage (in grams per square meter)

ρ = The mass density of the ink (refer to *Figure 5–23*)

HOSTMANN-STEINBERG, HUBER GROUP			MASS DENSITY (G/CM³)
YELLOW	1 QK 1765	Rapida Optima HiT Process Yellow	1.0487
MAGENTA	2 QK 1765/5	Rapida Optima HiT Process Magenta	1.0958
CYAN	3 QK 1765	Rapida Optima HiT Process Cyan	1.0483
BLACK	8 QK 1765	Rapida Optima HiT Process Black	1.1143

Figure 5–23: The mass density of the inks used in this experiment

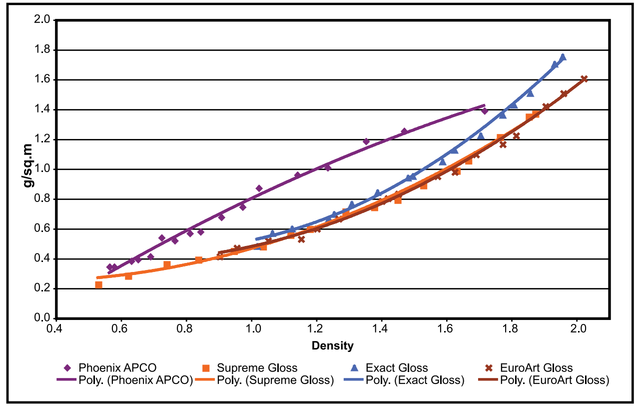


Figure 5–24: Ink coverage as a function of density for cyan printed on coated stocks

As *Figure 5–24* shows, the Phoenix paper has the highest ink coverage at the target density (1.29). This means that more ink is required to achieve the target density on Phoenix paper than on the other stocks. The results were the same for all four colours. The first assumption as the reason of the difference between Phoenix and the other stocks was the higher absorptivity of the Phoenix paper. In order to verify the assumption, the PSE (paper surface efficiency) test was done on the papers.

Paper Surface Efficiency:

$$PSE = \frac{(100 - A) + G}{2}$$

A = Absorptivity of paper (in %)

G = Gloss of paper (in %)

	PHOENIX APCO	SUPREME GLOSS	EXACT GLOSS	EUROART GLOSS
ABSORPTIVITY	17.16	19.8	19.8	17.16
GLOSS	72.20	72.5	66.8	75.2
PSE	77.52	76.35	73.5	79.02

Figure 5–25: PSE results for the tested coated papers

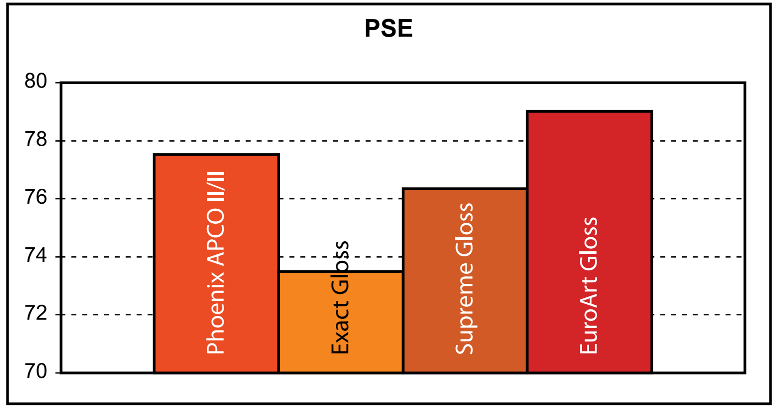


Figure 5–26: PSE results for the tested coated papers

For further determination of the paper/ink relationship, the ink setting test was carried out on the Prüfbau printability tester. The setting test ink from Michael Huber Munchen (Germany) was used for this test. The density of the solid ink film and the first transferred stain onto the unprinted paper were measured *Figure 5–27*). The higher the density of the transferred stain, the lower the amount of ink is that has been set into the paper.

	DENSITY OF THE PRINTED INK FILM	DENSITY OF THE 1ST TRANSFERRED STAIN ONTO THE UNPRINTED PAPER
PHOENIX APCO	0.90	0.35
SUPREME GLOSS	1.05	0.39
EXACT GLOSS	1.02	0.24
EUROART GLOSS	1.05	0.44

Figure 5–27: Setting test results

Based on the results, Phoenix is a fast-setting paper which had the lowest initial density and the second lowest ink transfer to the unprinted sheet in the setting test. Whereas, EuroArt Gloss had the best ink holdout. The absorptivity values from the PSE test did not match the setting test results. In order to find out which test is more reliable, the microscopic images of the paper surfaces were taken by AFM (Atomic Force Microscope). *Figures 5–30* to *5–33*, are the three-dimensional models of the AFM images.

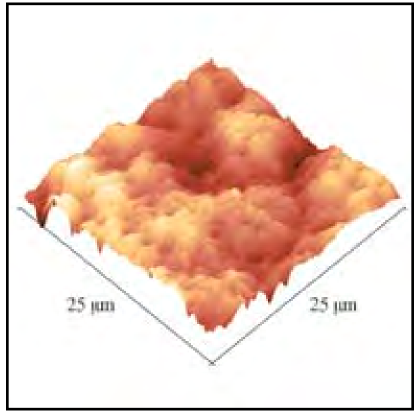


Figure 5–30: The AFM picture of the surface of Phoenix APCO II/II

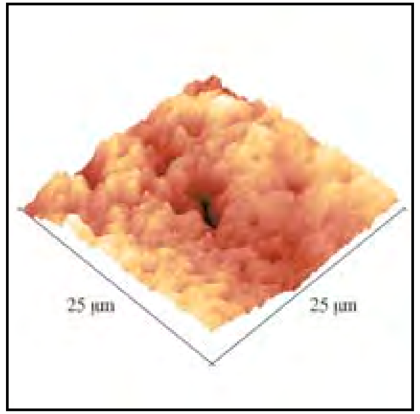


Figure 5–31: The AFM picture of the surface of Exact Gloss Coated

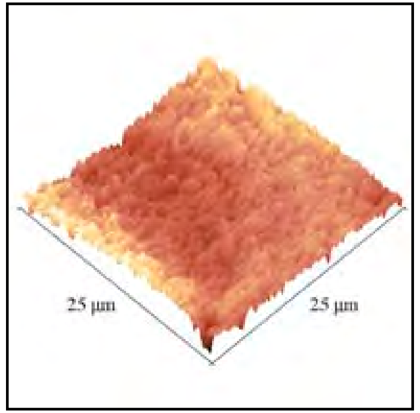


Figure 5–33: The AFM picture of the surface of Supreme Gloss Coated

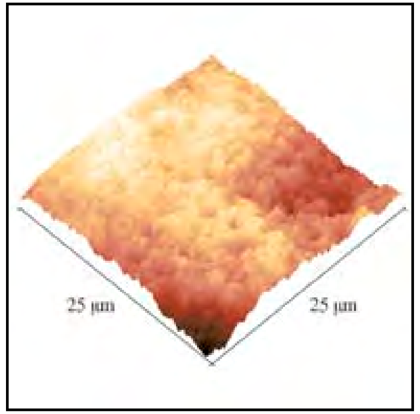


Figure 5–32: The AFM picture of the surface of EuroArt Gloss

The AFM images clearly show the evenness of each paper surface. It is clear by images that the Phoenix paper has the most irregular surface among all the papers tested in this experiment. Therefore it needs more ink to fill up the voids of the surface and reach the target density while other papers with more even surface have better ink holdout and need less ink coverage. Therefore the setting test results are a better prediction of the surface behaviour than the PSE tests. Yet none of these tests consider the colour of the paper and therefore not reliable in terms of predicting the colour of the printed ink film.

CONCLUSION

Seymour (2007) established that densitometry and colorimetry are equivalent in terms of maintaining consistent colour on press and provided ΔD tolerances for each ΔE (ΔE_{ab}) variation tolerances specified in ISO 12647-2:2004. I would add that a target density can be established for each colour within the group of coated stocks as long as the same ink is used due to the inherent hue error and grayness of inks.

Establishing the GRACoL densities can be a starting point to adjust the ink zones and get close to the optimum colour, but colorimetry is necessary to obtain the OK sheet. During a press run, a densitometer can be used to control the density variations while meeting the colour variation tolerances. Depending on the brightness level of paper, cyan is the only colour for which a press operator may not be able to achieve a ΔE_{ab} less than 5.0.

As density increases/decreases, the largest change in colour of printed ink happen with b* values than with a* (colour is more shifted between the yellow and blue corner of the colour space than between red and green). Black has the lowest a* and b* changes and highest L* changes as density varies while yellow has the lowest L* and the highest b* changes. The greatest a* change rate belongs to magenta.

None of the five ΔE equations has a better correlation with density than the other ones. If one choose to use the ΔE_{00} equation for the purpose of colour control (because of its better correlation with the human eyes' perception of colour differences), or DIN99 because of its uniform colour space, the following deviation tolerances are suggested (*Figure 5–28*).

	YELLOW	MAGENTA	CYAN	BLACK
$\Delta E2_{00}$	1.60	2.60	3.20	3.70
DIN99	1.60	2.40	3.00	6.30

Figure 5–28: Suggested colour deviation tolerances for ΔE_{00} and DIN99 equations

The ISO 12647-2:2004 colour variation tolerances as well as the suggested colour deviation tolerances in *Figure 5–28* (which are assumed to be the same as variation tolerances in this paper) can be translated into a set of density variation tolerances for each colour difference formula (*Figure 5–29*). If these density variations are met during production run, the reproduced colour will conform to the ISO standard colours.

DENSITY VARIATION TOLERANCES ($\Delta D/\Delta E$) x (1/2 colour variation tolerance)				
ΔE_{AB}	±0.05	±0.06	±0.08	±0.08
ΔE_{00}	±0.08	±0.08	±0.10	±0.11
DIN99	±0.08	±0.07	±0.09	±0.10

Figure 5–29: Suggested density variation tolerances for ΔE_{ab}, ΔE_{00} and DIN99 equations

Depending on the evenness of the paper surface, different amount of ink – and therefore different ink coverage (g/m^2) and ink film thicknesses – is required to achieve the target density. The more even the surface of the paper, the lower the amount of ink needed to achieve the optimum colour.

The setting test results are a better prediction of the effect of the paper surface structure on the ink coverage than the PSE test. However, none of these tests predict the colour of the paper and its effect on the reproduced colours.

FUTURE RESEARCH

The test samples have been printed on the Universal Testprinter which cannot simulate some of the actual processes happening during a press run. For example, ink-water balance is an important factor affecting the appearance of colour. In a future research, the laboratory results will be verified in a local printing facility. In addition, this test was done only on coated stocks. The same test will be carried out on uncoated stocks and the results will be compared.

ACKNOWLEDGEMENT

I would like to thank my supervisor, Dr. Martin Habekost, for his help, support and guidance. I also, would like to acknowledge Ryerson University's Office of Research Services for the funding of the research assistant position. The AFM images of the paper surface were taken by the atomic microscope of the School of Nutrition, Ryerson University. In addition, I would like to thank Nicola Kidd for the permission of using her drawing of the Universal Testprinter.

REFEEERENCES

Bestmann, G. (2006). *Prinect colors solutions - User guide, Standardization in offset printing*. Heidelberger Druckmaschinen AG, Germany.

Breede, M. (1999). *Handbook of graphic arts equations*. Pittsburgh: GATFPress.

Chung, R. (2007). *Implementing process color printing by colorimetry, Test Targets 7.0*. R.I.T School of Print Media Publication, pg 7-16.

Cui, G., Luo, M. R., Rigg, B., Roesler, G., Witt, K. (2002). Uniform colour spaces based on the DIN99 colour-difference formula. *Colour Research and Application*, 27(4), 282-290.

DIN 6176, Beuth Verlag, Germany.

Field, G. (1999). *Colour and its reproduction*. (2nd Edition). Pittsburgh: GATF Press.

Habekost, M. (2007a). Delta E, DE94, DE2000 or DEcmc? Which one should be used in everyday operation? *Canadian Printer*, 115 (4), 38 – 41.

Habekost, M. (2007b), The evaluation of colour difference equations. *TAGA 59th Annual Technical Conference Proceedings*, pg 201 - 212

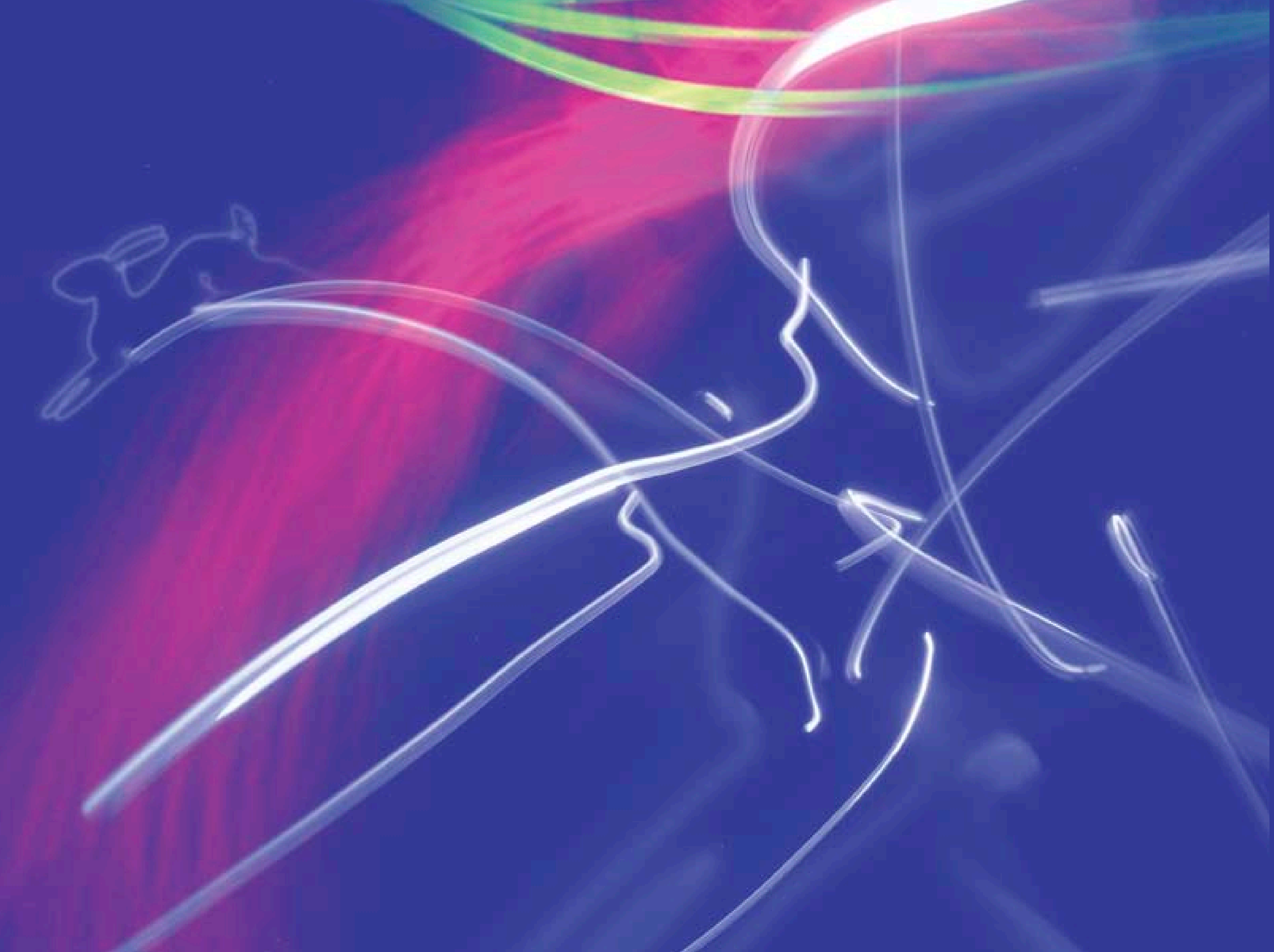
ISO 2834:1999(E), Graphic Technology – Test print preparation for offset and letterpress inks.

ISO 2846-1:1997(E), Graphic Technology – Colour and transparency of ink sets for four colour printing – Part 1: Sheet-fed and heat-set web offset lithographic printing.

ISO 12647-2:2004(E), Graphic Technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes.

Nurmi, O. (2002). *Colour quality control in Karkimedia Newspapers*, Advances in printing and media technology. Volume XXXIII. 29th IARIGAI Conference, Furingen, Switzerland.

Seymour, J. (2007). How many ΔEs are there in a ΔD? *TAGA 59th Annual Technical Conference Proceedings*. pg 311-349.



How many camera ICC profiles do we really need?

Saleh Amr Abdel Motaal

INTRODUCTION

The demand for color accuracy in printing has led to a great deal of exploration and innovation in all aspects of the printing industry. In today's workflow, scanners have been replaced with digital single lens reflex (SLR) cameras. Meanwhile, the expertise of scanner operators has been incorporated into application-based eyedropper alterations and ICC color profiles. Such workflows are becoming more accessible, cheaper, and effective for most printing applications (Padova & Mason, 2006).

This paper explores the application of color management in digital photography by exploring different approaches to outline their effectiveness and to identify the variables that may limit or promote color accuracy.

COLOR MANAGEMENT PRACTICES IN DIGITAL PHOTOGRAPHY

Color management in digital photography is a matter of much debate (Rodney, 2005). For some, camera ICC profiles are specific to the scene, which are only valid for images that are captured under the same lighting conditions and scene setup parameters. Others believe in the validity of a camera-specific profile, generated under good studio conditions, can be used for a large number of shoots in various situations (Rodney, 2005). Furthermore, it is believed that, in cases of uncontrolled scene conditions, ICC profiles are invalid and impractical, and the dependence on image correction alone will yield better results (Grey, 2006). One study, which assessed the effectiveness of a camera ICC profile, showed they might yield large colorimetric prediction errors when compared to the results of other applications, like displays and printers (Rao et al., 2005).

Although many texts have been published with information relating to different practices, it becomes important to explore these different methods and assess their viability in order to maximize the benefits of color management in digital photography. However, do we need to use ICC profiles? Do we need image corrections? Or, do we need both? To answer these questions, we must look at the ability of each method for acquiring and reproducing the color of the subject as accurately as possible.

Regardless of the color correction method, the aspect of retaining the highest level of detail possible in a digital photo may also be affected by other factors, such as the format at which the images are stored (Kennedy, 2006), and the use of image correction functions that irreversibly alter the pixel data of the image. This research will only focus on the color corrections aspect and will follow practices that retain high color detail while not manipulating other aspects of the image.

When comparing the different approaches for color management, the ability for an approach to provide accurate color reproduction must be weighed against the practicality, repeatability, and the ease of applying this approach under different conditions. In other words, profiling every scene might not always yield similar results due to the many variables that need to be consistently adjusted. Also, expecting a camera-specific profile to work under any condition could be limited as the spectral properties of the scene may result in metameric effects that are inconsistent under different light sources. However, not employing profiles will most likely result in images with inaccurate color due to the unique characteristic of each imaging device (Sharma, 2004), including digital cameras.

VARIABLES THAT AFFECT THE COLOR OF IMAGES

Light sources are characterized by many properties, including color temperature and intensity (Field, 2004). In digital photography, the intensity of the light source may be leveled to promote adequate exposure by adjusting the shutter speed, which will optimize the tonal range and preserve as much detail from the scene in the highlight and shadow areas of the image under different light intensities (Grey, 2006). As for the color temperature, the information captured by the image sensor will incorporate a tint based on the light source's temperature. Captured images need to undergo a white balancing process in order to eliminate this tint and reproduce the true color of the subject. With the large number of artificial light sources, commonly ranging between 2400 K and 6500 K, achieving neutral images require the fine-tuning of the balancing process, which often falls beyond the capabilities of camera presets.

Many digital SLR cameras employ a feature that measures the scene's white-point by recording the color of a neutral calibration tile. The camera then assesses the captured color data and calculates the adjustments needed to make the captured sample neutral. The ratio is then applied to the data of successive shots yielding images that are neutral, eliminating the tinting effects. In the case of using the RAW format to store images, the white-point of the measured scene is simply tagged to the files but not applied to the data in the camera. When the images are rendered in RAW converting software, the stored white-point information may be applied to the image in a synonymous manner. Furthermore, the option of manually controlling the white-point using a slider or an eyedropper allows the selection of a white-point based on numerical indicators rather than a visual confirmation on the camera's display.

ICC profiling for digital cameras employs similar techniques as those used for scanners, but only to a certain degree. It involves the use of color targets, like the GretagMacbeth Digital ColorChecker SG. Profiling software, like ProfileMaker and EyeOne Match, will compare the color of the captured target to a reference target description file (TDF). Based on the variations between the captured and the reference data, the software will produce a profile that predicts the color of captured data through algorithms (Lukac & Plataniotis, 2007). Camera profiles differ from scanner profiles in the sense that a scanner may have one or two scene setups, such as controlled light sources. However, cameras will encounter endless scene setups that might affect the response of the image sensor. Hence, we are not only profiling the digital camera's characteristics, "we are [also] profiling the scene and the light" (Rodney, 2005), which justifies the common practice of generating scene-specific profiles.

The quality of an ICC profile is dependent on the range of colors available in the used target. To promote accurate color, some texts suggest that the color targets used should be measured using a spectrophotometer and the actual color be appended to the target description file used when creating the profiles (Rodney, 2005).

As such, it is believed without doubt that, while color corrections might be useful, ICC profiles are necessary for achieving color accuracy in digital photography. But, the question is, how can their accuracy be maximized?

This paper will look into the effectiveness of ICC profiles in digital photography while exploring the feasibility of employing a single camera-specific profile. It will briefly investigate the effects of color corrections and the need for ICC profiles, then, assess the effects of a measured TDF reference on the quality of profiles. Finally, this paper will compare the color accuracy of images captured under different lights, using scene-specific profiles against their counterparts, with a camera-specific profile. All assessments will be based on the ΔE_{00} (CIE2000) color difference equation. This allows for the comparison of the different methods in an objective manner to better understand the abilities and limitations of color management in digital photography.

RESEARCH DESIGN OVERVIEW

In this research, a Digital Color Check SG will be photographed under varying light sources in a controlled environment. These images will then be rendered using Adobe Camera Raw to generate samples of different color correction levels. Next, profiles will be produced using ProfileMaker and applied to the images to generate samples under the different color management practices. The resulting samples will be compared against the colorimetric data of the actual color target, using ColorThink Pro, to outline the achieved accuracy of the various methods and any underlying factors behind color variation.

DEFINITIONS AND EQUATIONS

RAW IMAGE (FILE FORMAT)

A proprietary file format used to record the color representation of images captured by the sensors of digital cameras.

RENDERED, JPEG OR TIFF IMAGE (FILE FORMAT)

A widely used image format that holds a representation of color images. Rendered, in terms of digital photography, implies the conversion of the color data from the RAW format to the image state that is intended for visual appreciation.

COLOR RENDERING INDEX

A measure of the degree to which a light source, especially a fluorescent light, under specified conditions, influences how the perceived colors of objects illuminated by the source conform to those of the same objects illuminated by a standard continuous source. The standard source is usually some aspect of daylight (Field, 2004).

DELTA E (CIE2000) OR ΔE_{00}

Referring to color difference as calculated using ColorThink 3.0 Pro.

EQUIPMENT, SOFTWARE, AND SPECIMENS USED

EQUIPMENT

- Pentax K100D Super with Pentax smc P-D FA 50mm Macro Lens
- X-Rite 500 Series Reflection Spectrophotometer
- X-Rite i1 Pro with Ambient light filter
- Studio-grade light stand
- LuxLife #37100-B Grandbulb (Rated: 100 W — 6400 K)
- GE Soft White Floodlight 120 (Rated: 120 W — Temperature not indicated)
- Just NormLicht Color Proof Station with Color-Control daylight 5000 light (36 W — 5000 K)

SOFTWARE

- GretagMacbeth Eye-One Share — Version 1.4
- Chromix ColorThink 3.0 Pro
- MathWorks MatLab — Version 7.5 (R2007_b)
- GretagMacbeth ProfileMaker — Version 5.0.8
- Adobe Photoshop CS3 with Adobe Camera RAW Plug-in

TEST SPECIMENS

- Digital ColorChecker SG (140 Patches — Semi-Gloss)
- Mini ColorChecker Gray Balance Card

PROCEDURE

REFERENCE DATA GENERATION

1. Using the X-Rite 500 spectrophotometer, measure each patch of the Digital ColorChecker SG target, producing a spreadsheet with averages of three L*a*b* readings under a D_{50} illuminant and a 2° observer.
2. Copy the 'Application TDF' located in the references folder of ProfileMaker, then sort the measured data accordingly.
3. Use ColorThink to convert the measured information from LAB to XYZ and place it in the file.

SCENE SETUP

1. Place the color target in the centre of the viewing booth.
2. Place the camera on a tripod, perpendicular to the target.

Figure 6–1: Sample Scene Setup

3. Position the light stands at a 45° angle and ensure good light dispersion.
4. Using Eye-One Share and the EyeOne in ambient mode, document the spectral distribution curves of each of the test lights, including the booth's. Then, compare your lights to those of the available theoretical illuminants to find the closest match as indicated in *Figure 6–2*.

ILLUMINANT NAME	RATED TEMPERATURE (°K)	MEASURED TEMPERATURE (°K)	CAMERA TEMPERATURE (°K)	EYEDROPPER TEMPERATURE (°K)	MEASURED CRI	THEORETICAL COUNTERPART
JustLicht	5000	4682	4800	4700	97	D50
LuxLife	6500	5971	5600	5500	84	F10
Floodlight	N/A	N/A	3150	3150	0	A

Figure 6–2: Comparison of the Documented Illuminant Colour Temperatures

IMAGE CAPTURE

1. Place the gray card in the centre of the shot. Use the camera's white-point metering feature in spot mode to measure the white-point.
2. Ensure the camera is set to the manual mode and configured to store unadjusted RAW files.
3. Adjust the focus and clamp the lens to prevent variations.
4. For each light source, manually adjust the shutter speed to achieve an exposure indication of +0.0. Then, capture the image at the established shutter and on a faster and slower step. This will produce three samples for later steps.

IMAGE RENDITION

1. The samples will be processed in Camera Raw, starting from a completely linear setting to generate 16-bit TIFF images tagged with the 'ProPhoto RGB' profile.
2. For each sample, use the eyedropper tool to achieve a neutral reading in patch 'H5'.
3. For each sample set (of different exposures), assess the histogram of each and shortlist the one that demonstrates no clipping of detail.
4. For the shortlisted samples, save a copy of each, designated as a 'linear' sample.

5. Change the 'Exposure' from the linear setting to the 'Default' setting, for each sample, then adjust the exposure slider to achieve an RGB reading of around 236, 236, 236 in patch 'E5'.
6. Save a second copy of each, designated as the 'corrected' sample.
7. Open all the images and discard the attached profile.

ICC PROFILE GENERATION

1. Use ProfileMaker to generate ICC profiles from each image, using the measured TDF reference, ensuring that all the advanced features are switched off.
2. Generate a profile using the corrected D_{50} image and the application's TDF reference.

PRODUCTION OF SAMPLES

1. Open the images in Photoshop and assign profiles based on *Figure 6–3*

TEST	SAMPLE DESIGNATION	PROFILE / REFERENCE
LINEAR VS. CORRECTED VS. PROFILES	Linear Untagged (D_{50})	Untagged
	Corrected Untagged (D_{50})	Untagged
	Linear Profile (D_{50})	D_{50}L / Measured TDF
	Corrected Profile (D_{50})	D50C / Measured TDF
APPLICATION VS. MEASURED TDF	Application TDF Profile (D_{50})	D50C / ProfileMaker TDF
	Measured TDF Profile (D_{50})	D_{50}C / Measured TDF
SCENE- VS. CAMERA-SPECIFIC ICC	'D_{50}' (Optimal)	D_{50}C / Measured TDF
	'A' Scene-Specific	AC / Measured TDF
	'A' Camera-Specific	D_{50}C / Measured TDF
	'F10' Scene-Specific	F10C / Measured TDF
	'F10' Camera-Specific	D_{50}C / Measured TDF

Figure 6–3: Summary of Samples for the Tests

2. Save the files as 16-bit TIFF.

DATA COLLECTION AND ANALYSIS

1. Tally the L*a*b* values of each patch for each generated sample in an Excel document.
2. Use ColorThink Pro to calculate the ΔE_{00} differences between each sample and the actual target readings.

For this test, a customized workflow utilizing MatLab was used to tally the values as shown in *Figure 6–4*.

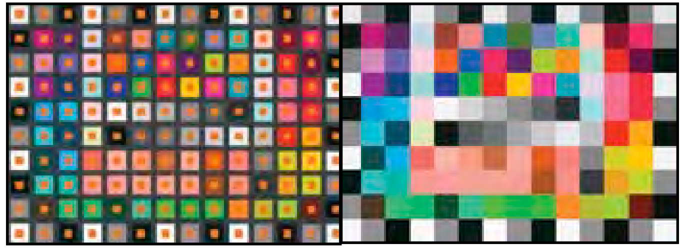


*Figure 6–4: The tallydcsgex() function's Sampled Pixels (left) and Results (right) for L*a*b* data in MatLab*

RESULTS AND DISCUSSION

LINEAR VERSUS CORRECTED IMAGES AND THE USE OF ICC PROFILES

	LINEAR UNTAGGED	CORRECTED UNTAGGED	LINEAR & PROFILED	CORRECTED & PROFILED
ALL PATCHES	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}
Average	12.94	5.88	3.16	2.55
Maximum	21.29	11.03	6.61	5.22
Minimum	2.75	1.58	0.62	0.48
Std. Dev.	4.85	2.71	1.41	1.04
BEST 126 PATCHES				
Average	12.16	5.41	2.83	2.34
Maximum	18.41	9.66	5.67	3.86
Minimum	2.75	1.58	0.62	0.48
Std. Dev.	4.46	2.44	1.06	0.87

	Linear Untagged		Corrected Untagged		Linear & Profiled		Corrected & Profiled	
Worst 14 Patches								
Average		19.98		10.10		6.10		4.40
Maximum		21.29		11.03		6.61		5.22
Minimum		18.59		9.68		5.77		3.86
Std. Dev.		0.93		0.35		0.27		0.42
Worst Patches 127-140								
Rank 127	E3	18.59	I7	9.68	E6	5.77	G8	3.86
Rank 128	F2	18.77	H8	9.71	F10	5.78	N1	3.89
Rank 129	B3	18.91	C9	9.74	I10	5.86	A8	3.90
Rank 130	K3	19.11	H9	9.82	A5	5.92	K2	4.14
Rank 131	J3	19.29	H10	10.01	A8	5.92	F10	4.14
Rank 132	D2	19.64	A9	10.04	N9	5.97	I10	4.18
Rank 133	I3	19.70	E10	10.04	L1	5.99	M1	4.30
Rank 134	N1	20.43	F9	10.07	C10	5.99	D1	4.52
Rank 135	K2	20.69	B10	10.19	F1	6.19	G1	4.53
Rank 136	D1	20.72	B8	10.21	L10	6.20	A1	4.56
Rank 137	G1	20.78	G8	10.26	I1	6.38	F9	4.60
Rank 138	J2	20.85	D8	10.29	D5	6.43	J1	4.74
Rank 139	A1	20.94	D9	10.33	M3	6.45	C8	5.05
Rank 140	J1	21.29	C8	11.03	C1	6.61	B8	5.22

Figure 6–5: ΔE_{00} Results for the Untagged and Profiled 'Linear' and 'Corrected' Sample Variations

From *Figure 6–5*, it is clear that the untagged samples resulted in the worst color accuracy, averaging with ΔE_{00} values of 12.94 and 5.88, for the 'Linear Untagged' and the 'Corrected Untagged' samples, respectively. Their ICC profiled counterparts resulted in much better averages, of 3.16 and 2.55, for the 'Linear & Profiled' and the 'Corrected & Profiled' samples, respectively. The use of profiles was able to predict 126 patches (90% of the patches) within a ΔE_{00} maximum of 5.67 and 3.86 for the respective set, as opposed to the 18.41 and 9.66. The 'Corrected & Profiled' sample has demonstrated the best overall color accuracy with the lowest ΔE_{00} values across the board. The affected colors were different in each sample, resulting in an almost completely unique set of worst patches from each sample.

It comes with no surprise that profiled images will yield better accuracy if the process is carried out correctly. The lack of color management, for both 'Untagged' samples, and the limited amount of correction applied to the 'Correct Untagged' sample were intended to demonstrate their limited ability, but these approaches are insufficient for any practical application. The idea here is to identify a good starting point for color management. Which, based on the results, is definitely correcting the images to a certain degree during the rendition process,

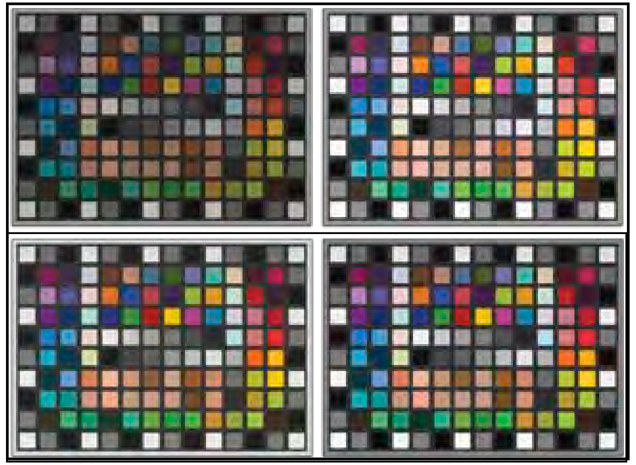


Figure 6–6: Final state for 'Linear Untagged' (top-left), 'Corrected Untagged' (top-right), 'Linear Profiled' (bottom-left), and 'Corrected Profiled' (bottom-right) samples

prior to the generation and application of ICC profiles. This is synonymous to a monitor calibration or a press characterization, whereby the optimal tonal range can be achieved prior to generating the ICC profiles

Ultimately, these samples do prove that initial color corrections will adjust the accuracy of color as the best color accuracy was achieved in the 'Corrected & Profiled' sample. Digital image data stored in the RAW format are usually "flat" in appearance (Lisi & Sharma, 2007), as it represents the basic data as captured by the sensors (Rodney, 2005). The RAW format is not intended for visual appreciation, but rather to maintain the data effectively, prior to the rendering process, where it can be adjusted for perceptual appeal. While rendering 8-bit images, like JPEG files, the extended, high-bit based (Grey, 2006) RAW data is usually downsampled, resulting in loss of tonal range and detail *Figure 6–7*. Correcting the images to spread the data across a wider tonal range prior to the downsampling process will allow the preservation of the fine detail at lowered bit depths.

FORMAT	BIT DEPTH	TONAL RANGE
JPEG	8-bit	256 Tone Values / Channel
TIFF	8-bit	256 Tone Values / Channel
RAW	12-bit	4096 Tone Values / Channel
TIFF	16-bit	65,536 Tone Values / Channel

Figure 6–7: Image Formats, Bit Depth, and Tonal Range
(Kennedy, 2006) (Padova & Mason, 2006)

As such, it is recommended for color management applications to have the images remain in a 16-bit linear state, or correct the images adequately prior to their conversion into 8-bit files. However, a surprising fact about this data is that the ICC profiles were applied to the 'Untagged' images while they were in a 16-bit state. Both the profiles and the images were generated at 16-bit throughout the process and downsampled to 8-bit prior to their analysis in MatLab. This fact, together with the noticeable difference between the 'Linear Profiled' and 'Correct Profiled', indicate that other factors will affect the validity of an ICC for predicting accurate color. The reason for this degradation in profile validity is beyond the scope of this research but the data suggests that profiles will work better if generated from samples of somewhat more accurate color, contrast, and, more importantly, have a wide tonal range.

APPLICATION VERSUS MEASURED TDF PROFILING

Figure 6–8: ΔE_{00} Results for D50 Samples with Application TDF and Measured TDF Profiles (on right)

	D50 APPLICATION TDF		D50 MEASURED TDF	
ALL PATCHES		ΔE_{00}		ΔE_{00}
Average		2.47		2.45
Maximum		4.94		5.16
Minimum		0.61		0.37
Std. Dev.		1.01		1.06
BEST 126 PATCHES				
Average		2.25		2.22
Std. Dev.		0.80		0.83
WORST 14 PATCHES				
Average		4.44		4.57
Std. Dev.		0.33		0.33
WORST PATCHES 127-140				
Rank 127	M3	3.93	H1	4.14
Rank 128	N1	3.96	B1	4.16
Rank 129	F10	4.13	C8	4.24
Rank 130	F9	4.15	N1	4.25
Rank 131	K1	4.23	B8	4.31
Rank 132	I10	4.27	L7	4.39
Rank 133	K2	4.39	K1	4.42
Rank 134	B8	4.59	B7	4.67
Rank 135	D1	4.61	K2	4.71
Rank 136	A1	4.68	G1	4.78
Rank 137	G1	4.70	D1	4.81
Rank 138	C8	4.70	A1	4.89
Rank 139	M1	4.81	M1	4.98
Rank 140	J1	4.94	J1	5.16

From *Figure 6–8*, we can see that both methods yield results that are very similar. The overall ΔE_{00} average was 2.47 and 2.45, for the 'Application TDF' and the 'Measured TDF' samples, respectively. Similarly, the maximum ΔE_{00} variation was at 4.94 and 5.16. However, the worst patches are not identical, indicative of a potential difference in the order of color accuracy.

Slight variations between the samples are highly inconclusive of any preference. Such differences will have no impact on color in most applications. Under these conditions, the practice of correcting the TDF seems unnecessary, it may result in inconsistency and increase the chances of error.

Figure 6–9: Application TDF vs. Measured TDF Profiled Sample (on left)

SCENE-SPECIFIC VERSUS CAMERA-SPECIFIC PROFILING

	D_{50}/D_{50}	F10/F10	$F10/D_{50}$	A/A	A/D_{50}
Illuminant	D_{50}	F10	F10	A	A
Profile	D_{50}	F10	D_{50}	A	D_{50}
Profile Class	Scene Specific	Scene Specific	Scene Specific	Scene Specific	Scene Specific
Profile TDF	Measured	Measured	Measured	Measured	Measured
ΔE00 Ref	Measured	Measured	Measured	Measured	Measured
Import Method	Corrected	Corrected	Corrected	Corrected	Corrected
ALL PATCHES	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}	ΔE_{00}
Average	2.45	2.01	2.79	2.14	3.15
Maximum	5.16	7.01	8.58	9.44	12.61
Minimum	0.38	0.10	0.32	0.18	0.55
Std. Dev.	1.06	1.32	1.64	1.38	1.98
BEST 126 PATCHES					
Average	2.22	1.68	2.41	1.81	2.66
Maximum	4.09	3.57	5.15	3.50	5.26
Minimum	0.38	0.10	0.32	0.18	0.55
Std. Dev.	0.83	0.83	1.21	0.82	1.19
WORST 14 PATCHES					
Average	4.57	4.99	6.20	5.14	7.56
Maximum	5.16	7.01	8.58	9.44	12.61
Minimum	4.14	3.61	5.27	3.54	5.32
Std. Dev.	0.33	1.10	0.98	1.72	2.19

	D_{50}/D_{50}		F10/F10		$F10/D_{50}$		A/A		A/D_{50}	
WORST PATCHES 127-140										
Rank 127	H1	4.14	A5	3.61	H9	5.27	I10	3.54	L3	5.32
Rank 128	B1	4.16	G7	3.62	A3	5.32	J10	3.54	D9	5.57
Rank 129	C8	4.24	C6	4.04	D9	5.35	G10	3.57	G4	5.58
Rank 130	N1	4.25	J8	4.20	K9	5.38	B6	3.70	I9	5.60
Rank 131	B8	4.31	E8	4.28	M7	5.53	N10	3.72	B4	6.41
Rank 132	L7	4.39	A3	4.33	L9	5.61	M9	3.81	C4	6.44
Rank 133	K1	4.42	A2	4.59	L8	5.84	K5	4.73	L7	7.07
Rank 134	B7	4.67	D7	5.05	M3	5.98	E9	5.30	B6	7.12
Rank 135	K2	4.71	I8	5.22	C6	6.48	K3	5.33	C8	7.85
Rank 136	G1	4.78	J7	5.38	M8	6.51	I7	5.72	C5	8.05
Rank 137	D1	4.81	H3	5.65	B5	6.57	B8	6.28	B8	8.36
Rank 138	A1	4.89	L7	5.99	I8	6.61	C8	6.41	B5	8.42
Rank 139	M1	4.98	B7	6.90	B7	7.70	C6	6.90	C6	11.50
Rank 140	J1	5.16	M3	7.01	L7	8.58	B7	9.44	B7	12.61

Figure 6–10: ΔE_{00} Results for 'Scene-Specific' and 'Camera-Specific' Samples Under 'F10' and 'A' Illuminants

From *Figure 6–10*, we can see that the best color accuracy was achieved in the 'D_{50}/D_{50}' sample, the scene-specific 'F10/F10' and 'A/A' samples, and, the camera-specific 'F10/D_{50}' and 'A/D_{50}' samples. The overall ΔE_{00} averages were 2.45, 2.01, 2.14, 2.79, and 3.15, respectively. It can be observed that employing scene-specific profiles yields results that are more accurate than when employing a camera-specific profile in both cases. Yet, the accuracy is degraded even with scene-specific profiles based on the illuminant. This is noticeable when comparing the 'F10/F10' and the 'A/A' samples to the 'D_{50}/D_{50}' sample.

The effectiveness of the camera-specific profiles can be analyzed by calculating the amount of error in ΔE_{00} value, against their more accurate scene-specific counterparts.

	F10/F10 vs. F10/D_{50}	A/A vs. A/D_{50}
Average ΔE_{00} Error	0.78	1.01
Maximum ΔE_{00} Error	1.57	3.17

Figure 6–11: Differences in ΔE_{00} between Scene-Specific and Camera-Specific Samples Under 'F10' and 'A' Illuminants

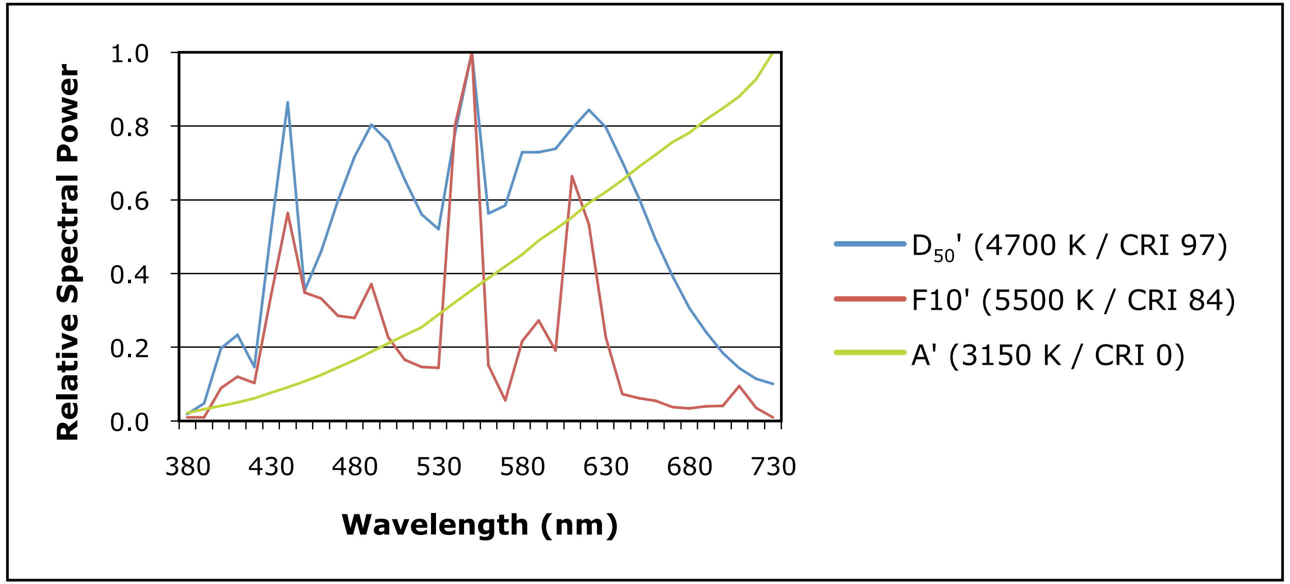
From *Figure 6–11*, it can be seen that the color accuracy between the Scene-Specific and Camera-Specific variants of both 'F10' and 'A' are different. Under F10, the difference is about a ΔE_{00} of 1.57 for the worst patch and the difference in the overall average is around 0.78. This can be considered an adequate, but not the best, level of color accuracy in cases where generating a profile is impractical. Under illuminant 'A', the difference is more intense, with a ΔE_{00} of 3.17 between the worst patches and an overall average difference of around 1.01. This would make the camera-profile less accurate for use under an 'A' illuminant than under 'F10'.

These results cannot guarantee the performance of profiles under conditions where the scene has contamination with multiple light sources, or if the lighting conditions are of poor light dispersion. But given the limitations of employing scene-specific profiling for such scenes, it might still be beneficial to employ camera-specific profiles.

Figure 6–12: Camera-Specific Profiled Samples Under 'D_{50}' (left), 'F10' (middle), and 'A' (right) Illuminants

Based on these results, it can be inferred that lighting conditions, specifically the illuminant, will have a great effect on the potential for color accuracy, regardless of the use of ICC profiles. This is evident in the increased maximums and standard deviation values for the 'F10' and 'A' illuminants, when compared to the 'D_{50}' results. A relationship between the illuminant and the accuracy of color with a single camera-specific profile may also be concluded, relating to either the color temperature, the color rendering index, and/or the relative spectral power distribution (*Figure 6–13*) of the illuminant used for generating the profiles and that used for generating the rendered samples. This is evident in the fact that illuminant 'A' resulted in a larger ΔE_{00} error, when employing a camera-specific profile, compared to the error observed under 'F10'.

Figure 6–13: Relative Spectral Power Distribution of Used Illuminants, their Color Temperature and Color Rendering Index



The expected color variation levels from having illuminants that are not ideal for color accuracy applications — having a low color rendering index or uneven spectral power distribution — may, in fact, outweigh the level of accuracy degradation that occurs when using a single camera-specific profile. The fact that illuminant 'A' resulted in less color accuracy when using a scene-specific profile while comparing to the camera-specific 'F10' sample substantiates this theory.

In such uncontrolled situations, the ability to capture the color target accurately may hardly be a consistent practice, which will result in color profiles of indefinite validity. As such, the use of a camera-specific profile may ultimately be beneficial for situations where it is impractical to capture the target and it is safe to conclude that the results will be of acceptable range, unless the illuminant is of a very poor color rendering index, i.e. illuminant 'A'.

CONCLUSION

The tests conducted in this research support the need for using ICC profiles in digital photography applications. Comparing the effects of using an ICC profile and color corrections has shown that better color accuracy is achieved when images are first corrected for white-balance and the data is spread to an optimal amount of the tonal range, then assigned a respective ICC profile. This was true as long as the ICC profile was generated from an image that was corrected in an identical manner.

The practice of measuring and adjusting the target definition file with the actual readings of the color target was shown to be ineffective and may result in inconsistent results due to error.

Scene-specific profiles and camera-specific profiles may both be employed, but under different conditions. Scene-specific profiles, although preferred, will yield inaccurate color under illuminants with decreased color rendering index resulting in higher overall and maximum variation levels. Camera-specific profiles are also susceptible to the quality of the illuminant in the same way, but may be comparable to scene-specific profiles. They may yield highly satisfactory results, but less accurate than those achievable with scene-specific profiles. This would be true if the illuminant has a good color rendering index, the relative spectral power distribution has a similar distribution to that of the illuminant used for generating the camera-specific profile, and the images were corrected for tonal range and white-balance.

Color accuracy in digital cameras is best achieved in controlled situations under proper 'D_{50}' lighting conditions with minimal tonal range, white-point corrections and a valid scene-specific profile. Camera-specific profiles may be used to achieve satisfactory color when the situation prevents the production of scene-specific profiles or if the color accuracy requirements are not high.

The findings of this research suggest that further investigation in the color management of digital cameras is needed to reach better results in ideal situations where scene-specific profiles are used. Camera-specific profiles may not entirely replace scene-specific profiles at the current time and with the current technology, yet, this remains a paradigm for further exploration.

ACKNOWLEDGEMENTS

This research was based on methodologies and practices used in research by Jason Lisi, with consent. It utilized some MatLab functions that were developed while assisting him. This research project was made possible with the amazing guidance and support of many members of the faculty at the School of Graphic Communications Management, Ryerson University, including, Dr. Rich Adams, Dr. Martin Habekost, Jason Lisi, and Dr. Abhay Sharma

REFERENCES

Field, G. (2004). *Color and its Reproduction (2nd edition).* Sewickley, PA: GATFPress.

Grey, T. (2006). *Color Confidence: The digital Photographer's Guide to Color Management.* Indianapolis, IN: Wiley Pub.

Kennedy, B. (2006). *The Photographer's Guide to the Digital Darkroom.* New York: Allworth Press.

Lisi, J., & Sharma, A. (2007). *Analysis of Color Rendering in Digital Cameras.* TAGA, 59th Annual Technical Conference, Proceedings, 2007. pp. 349.

Lukac, R., & Plataniotis, K. (Eds.). (2007). *Color Image Processing: Methods and applications.* Boca Raton, FL: CRC/Taylor & Francis.

Padova, T., & Mason, D. (2006). *Color Correction for Digital Photographers only.* Hoboken, NJ: Wiley Publishing Inc.

Rodney, A. (2005). *Color Management for Photographers: Hands on Techniques for Photoshop Users.* Oxford: Focal.

Sharma, A. (2004). *Understanding Color Management.* New York: Thomson Delmar Learning.

Rao, P., Rosen M., & Berns R. (2005). *Performance evaluation of profile maker professional 5.0 ICC profiling softwareMunsell Laboratory [Internal].* Retrieved December 22, 2007 from http://www.cis.rit.edu/mcsl/research/reports.php#ProfileMaker

ADDITIONAL READINGS

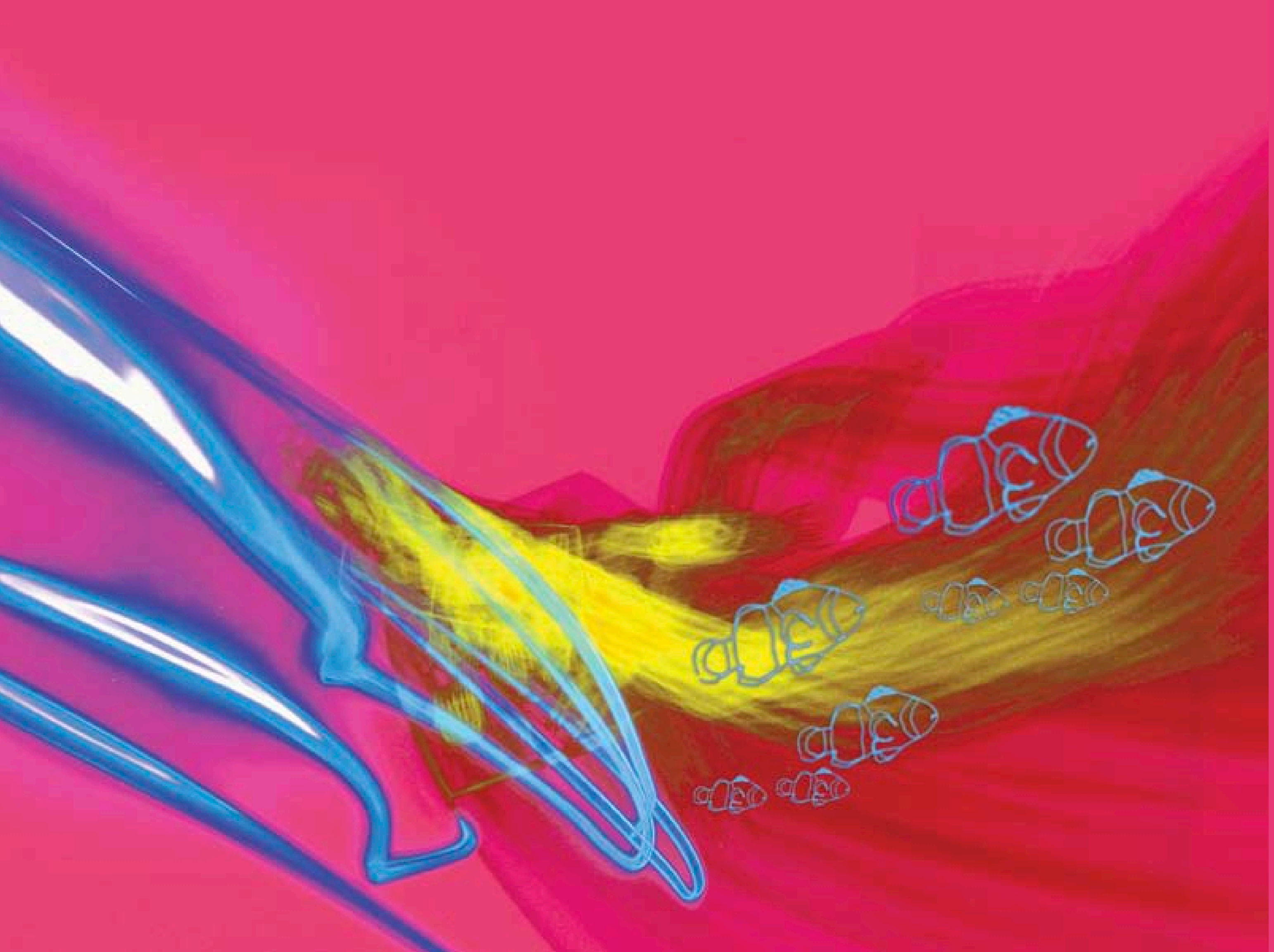
Adams, R., & Weisberg, J. (2000). *The GATF Practical Guide to Color Management (2nd edition).* PA: GATFPress.

Malacara, D. (2002). *Color Vision and Colorimetry.* Washington: The International Society for Optical Engineering.

Ohto, N., & Robertson, A. (2005). *Colorimetry: Fundamentals and Applications.* England: Wiley.

Rivard, P. (2006). *Digital Color Correction.* New York: Thomson Delmar Learning.

Sheppard, R. (2007). *Adobe Photoshop Lightroom for Digital Photographers only.* Hoboken, NJ: Wiley Publishing Inc.



COLOUR SHIFT DURING INKJET DRYING PERIODS

Mateusz Serwin

INTRODUCTION

"Color profiling ensures the accuracy of critical data needed for consistent and repeatable reproduction. Increasing color consistency from print to print and process to process, as well as from one media type to the next, enables printers to preserve the integrity of their clients' brands" (Staff, 2005). In order to achieve colour accuracy printers must understand their workflows, output devices and gather quantitative characteristics of those devices. When fingerprinting presses and matching their printing gamut to that of another machine or digital output device, such as an inkjet printer, the data must be collected accurately.

As this experiment shows it is important to give printed pieces adequate time to dry in order for the colour of the ink to set. We measure and evaluate colour difference through the use of the ΔE_{ab} equation which measures the difference of colour in the L*a*b* colour space. By measuring and evaluating two sets of what are supposed to be identical colours, we can determine the difference between those two colours. As a rule of thumb, the lower the ΔE_{ab} value the closer the colours are to one another in the L*a*b* colour space. "The idea is that a ΔE_{ab} of 1.0 is the smallest color difference the human eye can see. So any ΔE_{ab} less than 1.0 is imperceptible and it stands to reason that any ΔE_{ab} greater than 1.0 is noticeable " (Chromix, 2005). In this research colour patches were measured at different instances in time in a controlled environment to determine whether the colour patches record a significantly high ΔE_{ab} value. If the ΔE_{ab} records 1.0 and above, the colour change is significant enough to be visible to the human eye and a time needs to be determined for when measuring the data is appropriate.

In a printing environment, ΔE_{ab} is used not only to measure colours but also to set tolerances. If we look at the SWOP 2007 specifications released in May 2007 it specifies the average and maximum ΔE_{ab} for printers to which they must print in order to be SWOP certified. "If the difference between the characterization data set and the IT8.7/4 target is an average ΔE_{ab} <1 .5 for all patches and a maximum ΔE_{ab} <6 .0 for at least 95% of all patches " (SWOP, 2007). Setting tolerances is a good way of measuring quality control throughout the workflow. The tighter the tolerances set, the harder it becomes to achieve them.

TESTING CONDITIONS

- Room temperature: 22ºC (~72ºF)
- Relative Humidity 53%

EQUIPMENT USED

- Epson Stylus 4800 with 8-color Epson UltraChrome K3™ Ink
- Epson Semi Matte Proofing Paper
- GretagMacbeth Eye-One, no UV Filter, Spectrum type: Remission
- GretagMacbeth Eye-One Share Colorimetric Measuring software
- EFI ColorProof XF 3.0, Linearization, Profile and Optimization Tools

EQUATIONS

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

PROCEDURES

COLOUR SELECTION AND FILE CREATION

1. The colours were selected from The Macbeth Colour Checker, 2002 (random colours were selected)
2. 2.5" x 2.5" patches of the same colours were created in L*a*b* space using Photoshop CS2.
3. All patches were saved in L*a*b* colour space as *.tiff files.

PRINTING AND MEASURING

4. A new linearization was created to match the Epson 4800 and the media.
5. A new media profile was created based on the new linearization file using the IT8.7/4 Random test chart.
6. The media profile was optimized with the EFI ColorProof XF Optimize Profile Tool to a 98.4% accuracy using the IT8.7/4 Random test chart.
7. Eye-One was calibrated.
8. The printer was altered to allow access to the printed media overtop the print head.
9. A 2.5" x 2.5" square patch of the selected colour was printed.
10. The time-watch was started after the eighth pass of the print head.
11. The printer was paused and after 30 seconds the area that was exposed without printing was measured for the first time.
12. The same spot was measured every 30 seconds until the ten minute mark after which the area measured was marked and the printer was taken off pause.
13. After the print was complete, a measurement of the same relative area was measured at the 20 and 30 minute intervals.
14. The process was repeated for each colour.

RESULTS

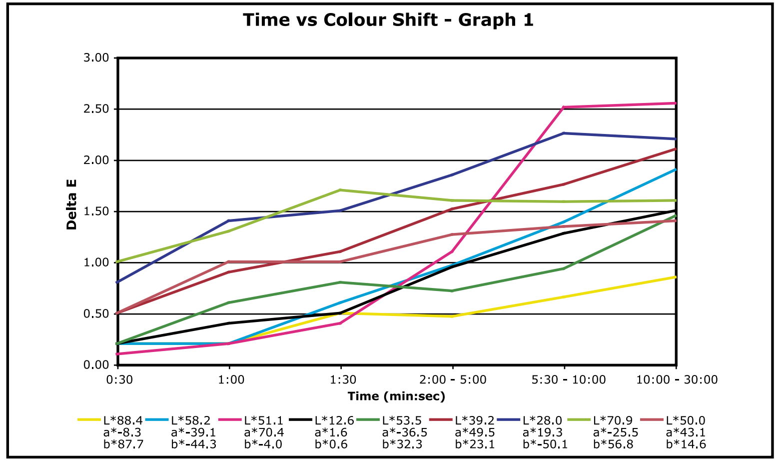


Figure 7–1: Time vs. Colour Shift - Graph 1

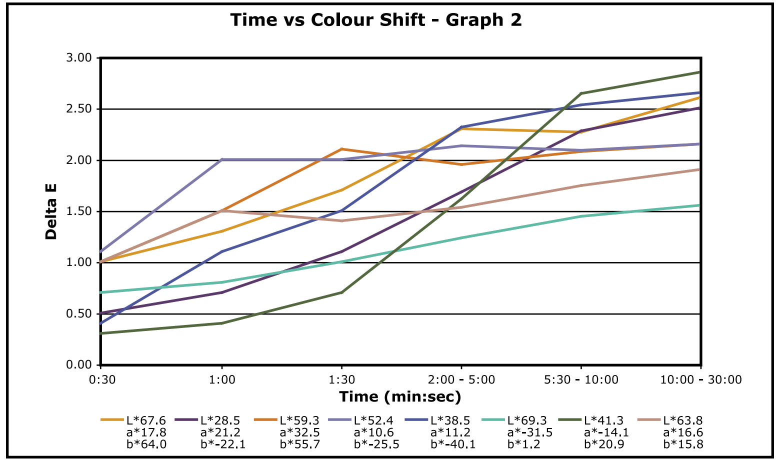


Figure 7–2: Time vs. Colour Shift - Graph 2

TIME (MIN:SEC)	L*88.4 a*-8.3 b*87.7	L*58.2 a*-39.1 b*-44.3	L*51.1 a*70.4 b*-4.0	L*12.6 a*1.6 b*0.6	L*53.5 a*-36.5 b*32.3	L*39.2 a*49.5 b*23.1	L*28.0 a*19.3 b*-50.1	L*70.9 a*-25.5 b*56.8	L*50.0 a*43.1 b*14.6
0:30	0.20	0.20	0.10	0.20	0.20	0.50	0.80	1.00	0.50
1:00	0.20	0.20	0.20	0.40	0.60	0.90	1.40	1.30	1.00
1:30	0.50	0.60	0.40	0.50	0.80	1.10	1.50	1.70	1.00
2:00 - 5:00	0.47	0.97	1.10	0.95	0.72	1.52	1.85	1.60	1.27
5:30 - 10:00	0.66	1.39	2.51	1.28	0.93	1.76	2.26	1.59	1.34
10:00 - 30:00	0.85	1.90	2.55	1.50	1.45	2.10	2.20	1.60	1.40

TIME (MIN:SEC)	L*67.6 a*17.8 b*64.0	L*28.5 a*21.2 b*-22.1	L*59.3 a*32.5 b*55.7	L*52.4 a*10.6 b*-25.5	L*38.5 a*11.2 b*-40.1	L*69.3 a*-31.5 b*1.2	L*41.3 a*-14.1 b*20.9	L*63.8 a*16.6 b*15.8
0:30	1.00	0.50	1.00	1.10	0.40	0.70	0.30	1.00
1:00	1.30	0.70	1.50	2.00	1.10	0.80	0.40	1.50
1:30	1.70	1.10	2.10	2.00	1.50	1.00	0.70	1.40
2:00 - 5:00	2.30	1.68	1.95	2.13	2.32	1.23	1.62	1.53
5:30 - 10:00	2.27	2.28	2.08	2.09	2.53	1.44	2.64	1.74
10:00 - 30:00	2.60	2.50	2.15	2.15	2.65	1.55	2.85	1.90

*Figure 7–3: Colour deviation from original L*a*b* values expressed in ΔE*

DISCUSSION

As the graphs show, all colours changed over time and one did not change significantly enough that the human eye would notice the difference. For the most part the colours underwent significant colour shifts. The changes in the colours are most drastic in the first 10:00 minutes after which they still continued to change but not as drastically. A further analysis of individual ΔL*, Δa* and Δb* values revealed that the variable or direction in which colours shifted in the most is in the + ΔL*-axis. All the colours experienced the highest shift in lightness as time passed and as the inks dried.

The reason why the inks changed most in the ΔL*-axis is due to the nature of the paper. Paper today is manufactured with many additives to make it appear brighter, more absorbent and coated in a variety of effects like glossy or matte. An ink droplet that is printed onto the paper mixes with the coatings and chemicals as part of its setting process. *Figure 7–4* shows a diagram of ink droplets, as they would appear after being ejected from a print head. This image however is on an uncoated stock unlike the paper that was used for this experiment. The droplet is absorbed by the paper and with time it flattens, as shown in *Figure 7–5*. Although *Figure 7–5* is an image of a droplet of ink that was pressed down by a cylinder, it is still a very good representation of what a dried droplet of ink would look like under a microscope.

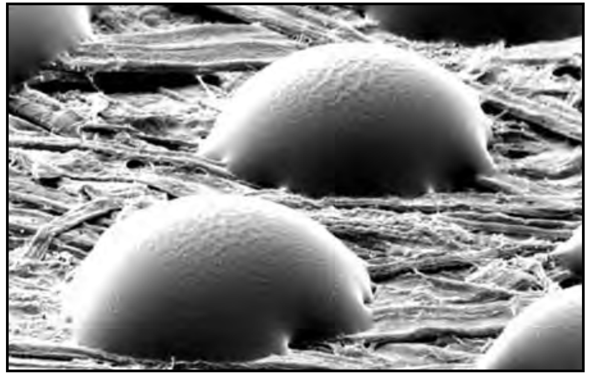


Figure 7–4: Ink droplet on paper
(Image Source: Journal of Imaging Science and Technology)

Figure 7–5: A dried droplet of ink
(Image Source: Journal of Imaging Science and Technology)

The process that ink droplets undergo after being ejected, is quite simple. The ink falls onto the media after being ejected from a moving print-head at high speeds. It comes into contact with a ceramic coating (clay), which is often used in paper manufacturing to give the paper a coated finish. The droplet continues its way into the paper during its penetration and absorption stage, at which time it begins to dry. Once it is fully absorbed by the surrounding agents and fibers, the droplet has dried out and solidifies into its pigment base.

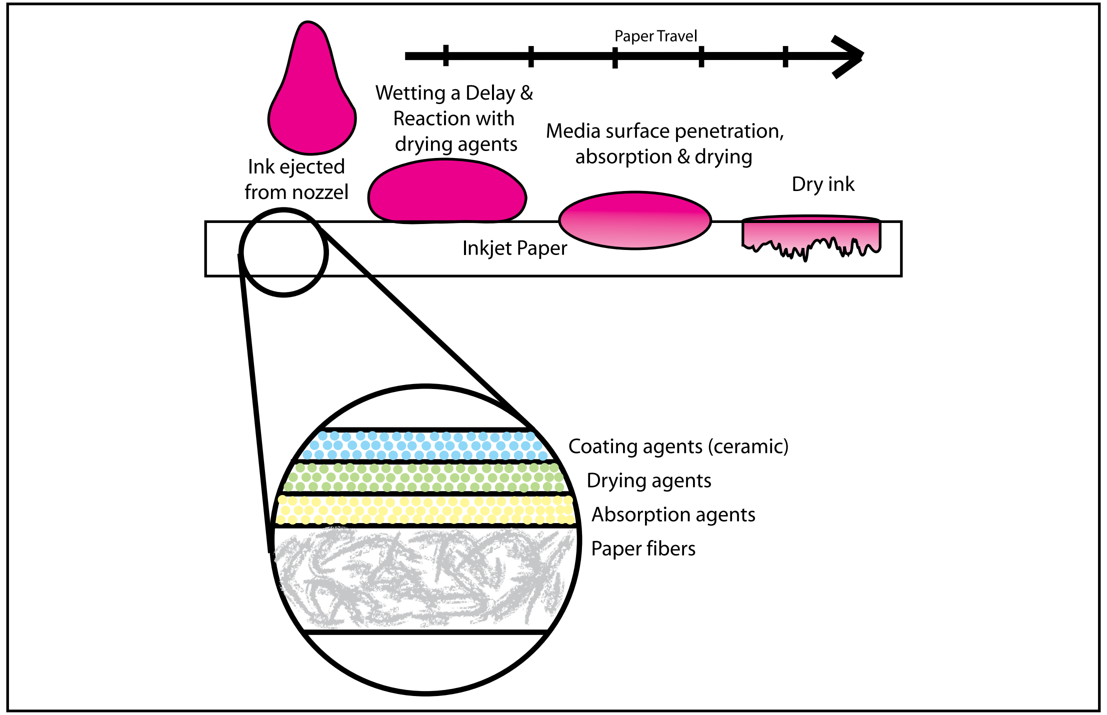


Figure 7–6: Layers of paper and ink droplet as it is absorbed

When analyzing the L*a*b* values of the colours, the striking similarity all colours had in common was the variable in which the colour shift occurred the most, ΔL*. On average all the colours had an increase of 1.5 or more in lightness. This transition can be explained by the ink droplets reaction and absorption into the paper. All of the agents and coatings that are present in paper have a very high level of brightness. As the drop is absorbed into the paper the whiteness of the paper begins to show through. The layer of ink that sits on top of the paper, becomes smaller and smaller until it is thin enough to allow for some of the paper's brightness to shine through when being read by a device.

Although the colours tested did record a high ΔE_{ab} values, it is important to note and understand the significance of the change in the ΔL*-axis. Based on this analysis it may be argued that in fact the inks used in the Epson 4800 series printer are very stable in colour. If the influence of the paper brightness was to be taken out of the equation the colours are not likely to have high ΔE_{ab} values, as they did not have significant changes in the Δa*-axis and Δb*-axis.

APPLICATION AND CONCLUSION

Based on the results two conclusions and practices should be generated from this research. The first practice is to allow for any kind of printed proofs to sit in a well-conditioned area in order to allow the ink to dry and come to a state of colour stability. This can be especially critical when inkjet proofs are used as press side comparisons. Colour consistency on press is critical for long runs and it would be a mistake to run a press job to a freshly printed proof, when 30 minutes into the pressrun a visible colour difference may be apparent, at which point an adjustment in colour would result in the first 30 minutes of run time to be a waste of material.

The second and more critical practice of the two is to allow for test targets to dry for a time period of 10 – 20 minutes before reading them into profiling software to generate a proof. Various papers will react differently as they may have different coatings and additives to improve their gloss, texture or other properties. When creating a profile time, must be allotted for the test targets to dry completely and not doing so will result in profiles that do not represent the finished product and will cause colour management problems within the workflow.

REFERENCES

Chromix: Feb 2005 Issue #17. Retrieved from http://www2.chromix.com/colorsmarts/smartNote.cxsa?snid=1145

Staff. *American Printer*. Chicago: Sep 2005. Vol. 122, Iss. 9; pg. 32, 4 pgs

SWOP 2007 Specification, Retrieved from http://www.swop.org/specification/

Journal of Imaging Science and Technology. Volume 42, Number 1, January/February 1998

PRODUCTION NOTES

This publication was produced by the students in the Ryerson TAGA Student Chapter. The printing and folding of the book block was completed by chapter members in Graphic Communications Management at Ryerson University. The printing and binding of the covers and printing of the sleeve was donated by Webcom Inc. in Toronto, ON. The die-cutting of the sleeve was donated by J&P Steel Rule Dies.

Software
Adobe Creative Suite v3
Kodak Preps 5.3

Typefaces
Baskerville SC
Garamond Premiere Pro

Paper
Book block: 80 lb Supreme Gloss FSC Certified
Cover and Sleeve: 12 pt Kalima CS1 FSC Certified

Ink
Rycoline Optimum Waterless Series Inks

In-House Production Equipment
Heidelberg 4-Colour Quickmaster DI 46-4
Heidelberg Stahlfolder 1220E

Design & Production Team
Diana Brown
Holly Chiborak
Nicola Kidd
Eden Kim
Scott Millward
Cayleigh Nichols
Ahmed Sagarwala
Jaclyn Sakaguchi
Matthew Serwin
Nathan Witt

Additional Art Contribution
Waneza Tam
Kathy Tsang
Lily Tsang
Jennifer Wong

ABOUT US - RYERSON STUDENT CHAPTER

Over the past year we have worked on a number of fundraising activities that have not only helped our chapter grow financially but have also brought more awareness to our organization.

At the beginning of the year we sold starter kits to first year students in the Graphic Communications Program at Ryerson University. They contained all the printing essentials a new student would need such as a typeguage, loop and industry related magazines. A dedicated team of students silkscreened our logo onto a re-useable cotton bag that contained all the elements of the kits. As a result of their promotion and well-picked contents, the kits were a hit! Once the word was spread, we sold out within a couple days! What a great start to the year.

"Stripping"-
Month of June 2008 from the Between the Sheets calendar

This year was also the introduction to "Between the Sheets", a school-year calendar. It had four editions, one for each year, that had all the due dates for their GCM related courses. It brought together some of the more risqué print terms and paired them up with suggestive but tasteful images that reflected the layman's meaning of the word. For true authenticity the photos were taken on location in the GCM facility with our volunteer models. The photographs were taken by Kris Mullen, a fourth year student in the Photography program here at Ryerson University. The calendars created quite the buzz and brought some fantastic recognition to our student chapter. They were also taken and sold at the Print World trade show, they were received with much laughter and praise by all industry professionals.

Last but not least, we held "TAGAoke", which was a karaoke/social night for Ryerson students. As an extra incentive for students to attend, we even invited some special faculty guests to come along a sing a tune or two! It was an excellent way to promote our student chapter for the upcoming year and a great opportunity talk to students that are interested. Looking back at the year so far, all our project have met success and TAGAoke was no exception.

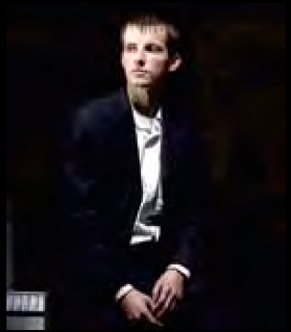
We have worked hard all year and are looking forward to attending the 60th TAGA conference in San Francisco. Our unique fundraising projects have opened the doors to some fantastic fundraising opportunities that can only continue to grown and develop into the future!

TEAM LEADERS

NICOLA KIDD
PRESIDENT

SCOTT MILLWARD
PRESIDENT

DIANA BROWN
PR & MARKETING



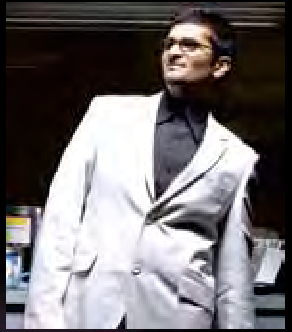
MATTHEW SERWIN
PR & MARKETING

NATHAN WITT
TREASURER

CAYLEIGH NICHOLS
FUNDRAISING

CRYSTAL WONG
FUNDRAISING

DR. MARTIN HABEKOST
FACULTY ADVISOR



AM SAGARWALA
MULTIMEDIA DIRECTOR

EDEN KIM
SECRETARY

TAGA MEMBERS

JACKIE SAKAGUCHI, DAN MILLER, HOLLEY CHIBORAK, CATHY TSANG, EMAD CHIBLI, JAMIE MACE, JENNIFER WONG, LILY TSANG, MARTIN SUDNICK, SALEH ABDEL MOTAAL, TIFFANY SINE, WANEZA TAM, ZEINAB PANAHI DORCHEH

Photographs taken by James Kachan

THANK YOU

We would also like to thank the following companies and people for their donations.

- J&P Steel Rule Dies Co.
- PaperlinX
- School of Graphic Communications Management
- Sun Chemical
- Faculty of Communication & Design
- Bob Dazig

PHOTOGRAPHY

- Kris Mullen [www.christinemullen.com]
- James Kachan [www.jameskachan.com]

SPICERS

Thank you to Spicers for supplying Supreme Gloss 80lb text stock used for the production of this journal.

Now containing 25% Post-Consumer Waste and available Carbon Neutral, Supreme is FSC, EMAS and ISO 13001 certified.

Simplicity / Solutions / Systems

WEBCOM

books and beyond

THANK YOU TO WEBCOM FOR THEIR GENEROUS DONATION. THEY HAVE GRACIOUSLY EXTENDED THEIR BINDERY SERVICES FOR OUR JOURNAL. THIS UNIQUE LAY-FLAT OTABIND™ TECHNIQUE DELIVERS AN ATTRACTIVE AND FUNCTIONAL BOOK THAT WITHSTANDS FREQUENT HANDLING.
WWW.WEBCOMLINK.COM