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# An Investigation of ink usage in offset process printing

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# An Investigation of Ink Usage in Offset Process Printing

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**Abstract**

With the trend of sustainable printing in the print industry, reducing ink usage is considered a win-win solution for printers who are seeking sustainable printing strategies, and in the meantime, a way of cutting costs. This research focuses on ink-saving strategies for process printing using color management technology in the prepress stage.

Two ink-saving methods are discussed in this research. First method is reducing the AIC (Average Ink Coverage) in graphic design. A case study is carried out and verifies the rule that high AIC requires more ink usage than low AIC does. However AIC and ink usage are not committed to a linear relationship; instead, AIC variance, as a result of different graphic designs, will be amplified in terms of ink usage variance during the printing. Graphic design significantly affects the ink usage.

The second method is processing images that have same graphic designs, with optimized GCR (Gray Component Replacement). The result is high GCR results less AIC and ink usage; normal GCR results higher AIC and ink usage. AIC variance, as a result of different GCR levels, will be diminished in terms of the ink usage variance during the printing. GCR affects ink usage within a certain range. GCR does affect the ink usage, but not as significant and direct as graphic design does.

# Chapter 1

# Introduction

## Sustainable Printing and Reducing Ink Usage

This section brings out the topic of reducing ink usage under the sustainable printing industry trend. Merits and approaches of reducing ink usage are discussed in detail.

### *Sustainable Printing*

Sustainable printing and environmental concern continue to be news. Solutions for sustainable printing cover various fields from environmentally friendly ink to recycled paper, from workflow improvement to waste treatment. However, do administrative management groups in printing companies aware the importance of being environmentally responsible? How many printing factories have budgets to minimize their environmental impact? And when there is a conflict between profit and environment protection, what will choices be? Most of the time it seems that there is tradeoff between pursuing profits and behaving in an environmentally responsible manner.

### *Reducing Ink Usage*

The well-known concept of 3-R (Reduce, Reuse, and Recycle) is practical when comes to sustainable printing. This research focuses on the concept of "reduce" in terms of ink

usage. Reducing ink usage can be a win-win solution for printing manufacturers seeking a way of cutting costs, improving production efficiency, and in the mean time, getting certification for sustainable printing.

*Merits of Reducing Ink Usage*

Adopting a reasonable inking strategy has three major merits as listed below.

*Cost Saving.* Ink is usually 2% to 5% of the average cost of a print job (Ruggles, 2008). It seems a small portion relative to the total job cost, but when it comes with a high-volume print job, the cost of ink could be considerable. For example, during 1980 and 1990, Procter & Gamble Co. was seeking methods to become low-cost manufacturers. One of the strategies was to use less ink on the Tide package. This strategy realized an annual savings of about $2 million (*Rising Tide*, 2004).

*Production Efficiency.* Reducing ink usage by means of Gray Component Replacement (GCR) helps to shorten drying times, and to improve both color stability and gray balance stability (Pritchard, 2009).

*Sustainable Printing.* In the paper recycling process, using less ink enables more efficient and thorough ink removal (Grossmann, 2006).

## Approaches for Reducing Ink Usage

Corresponding to printing workflow from prepress to press, there are various strategies for ink usage reduction. In the graphic design and prepress stage, there are the two most effective approaches for reducing ink usage:

1. Reducing the colored area and tone level of the graphic content
2. Replacing chroma ink with relatively less expensive black ink, known as Gray Component Replacement (GCR) technology.

Both approaches take place in the digital file stage with the same goal: to reduce Total Area Coverage (TAC) of the digital file. When graphic content is printed with less TAC, ink usage consumed during the printing process will be reduced as a result.

## Reasons for Interest in Ink Saving

As stated above, considering ink saving has the merits of cutting costs, improving production efficiency, and stabilizing product quality; it is meaningful to take a further step to study ink saving methodology, its potential impact to image quality and magnitude of real ink saving in practical printing process.

This study focuses on ink saving strategies happen in the prepress stage. Prepress is at the very beginning of the workflow, so any operation and optimization applied during prepress has the largest effect in determining ink usage afterward. It would be very interesting to see how graphic content and digital file optimization strategies affect the final ink usage in process printing.

# Chapter 2

# Theoretical Background

The following paragraphs elaborate on how graphic content and gray component replacement (GCR) plays an important role in determining ink usage. Additionally, concepts of total area coverage (TAC), average ink coverage (AIC), and gray component replacement (GCR) are defined and explained in terms of their relationship differences with ink usage.

## Role of Graphic Contents in Ink Saving

In the process of print production, the first determination is the graphic content. Images and typefaces jointly determine the graphic content, printing area, and tone level. As a result, the graphic designer has the largest impact on deciding how much ink will be consumed in order to print the graphic content. Graphic content designed in an environmentally responsible way can lower ink costs by avoiding unnecessary inverse designs or large shadow areas in the packaging design. Graphic design like this can be recognized as sustainable graphic design, whose definition is "the application of sustainability principles to graphic design." This concept considers the environmental impacts of a graphic design product (such as packaging, printed materials, publications,

etc.) throughout a life cycle that includes raw material, transformation, manufacturing, and disposal (Refer to Wikipedia).

Ink saving can also be realized by using color management technology. Even though the graphic content is designed with heavy ink coverage, still there is room left for ink reduction if GCR technology is employed.

## Role of GCR in Ink Saving

In order to explain how GCR functions in ink saving, the concept of total area coverage and average ink coverage are defined; and their differences are discussed.

### *GCR — Gray Component Replacement*

The definition of gray component replacement (GCR) is "a method of black generation that replaces an amount of CMY with equivalent amount of K" *(Real World Color Management)*. GCR is an ink optimization methodology in color management, and it can be integrated into ICC profiles or device link profiles. The kernel of GCR is a CMYK-to-CMYK Look Up Table (LUT) embedded in the Device Link conversion process. Before explaining how GCR works in terms of ink savings, there are two concepts that need to be clarified. They are total area coverage and average ink coverage.

*TAC — Total Area Coverage*

In process printing, colors are generated by overprinting C, M, Y, and K process inks. The maximal dot area sum of the four color (C, M, Y, and K) permitted in the darkest area is defined as total area coverage (TAC), expressed as a dot percentage. For a print job, the magnitude of TAC depends on the printing process type. The TAC value determines how much ink is allowed to print the darkest point of one page. For example, typical TAC is 320-340% for sheet-fed offset; 300-320% for web offset; 300% for SWOP. (Refer to http://www.colourphil.co.uk/gcr_ucr_total_ink.html). TAC does not indicate ink usage of a print job; it reflects the maximal ink coverage of the darkest point for a pictorial color image.

*AIC — Average Ink Coverage*

Average ink coverage (AIC) is a new concept that can be defined as the average inked area of each CMYK ink amount on a page, meaning an estimation of ink coverage per color per page. AIC is also expressed as a dot percentage. Ideally, AIC and ink usage are in direct proportion, meaning ink usage increases as AIC increases. In practice, ink usage can be estimated based on AIC value.

AIC is obtained by averaging the dot percentage of each CMYK channel on one page. Tools such as Photoshop's "Blur – Average" can achieve this manipulation. To read the AIC of a digital file, open the file in Photoshop. First, ensure the page is in CMYK mode.

If not, select “Image/Mode/ CMYK Color” to change into CMYK mode. Second, select “Blur - Average” from the “Filter” menu. This operation allows Photoshop to take an average calculation of the dot percentage of each pixel on that page. Lastly, to read the AIC of each color for that page, select “Info” from the “Window” menu and place the cursor on the blurred area. The info panel will show the AIC of the page.


*Figure 1. Image: “CMYK Pach” before and after averge blur, and AIC reading*

Figures 1 shows the “Blur – Average” concept with a simple vector image. Before blurring, 40% C, M, Y, and K each occupies one quarter of the area (shown as Figure 1-Left). After processed via “Blur – Average”, CMYK colors are averaged as one single color and filled in the whole area. (Figure 1-Middle). CMYK percentage reading on info panel (Figure 1 – Right) is the AIC of this CMYK patches image.


*Figure 2. Image: "Seafood" before and after averge blur, and AIC reading*

Figure 2 shows the application of "Blur – Average" with a pictorial image. Photoshop displays their appearances before and after applying average blur, and their AIC values. The original images is presented on the left, its appearance after average blurring is as shown in the middle, and the info panel that displays the AIC readings is shown on the right. Table 1 displays the readings of CMYK patches and Seafood. Those numbers are considered as AIC value of that picture.

Table 1. AIC readings for image "CMYK patches and "Seafood"

| | Cyan | Magenta | Yellow | Black |
|---|---|---|---|---|
| **CMYK Patches** | 25 | 25 | 25 | 25 |
| **Seafood** | 44 | 62 | 69 | 33 |

*Ink Saving by GCR*

How does GCR work in ink saving? Theoretically, GCR works mainly in two aspects. First, GCR decreases TAC, and thus the upper limit of total consumed ink weight is

reduced accordingly. (Remember TAC represents the dot area sum of the darkest point of a page). Second, GCR decreases CMY ink coverage by increasing K ink coverage while maintaining the color appearance. Since black ink is relatively less expensive than chroma ink, changing the proportion of process inks in the prepress stage appropriately will result in decreasing ink cost without obvious color appearance shifts.

# Chapter 3

# Literature Review

This literature review intends to summarize previous relevant research of three topics:

1. For a typical offset printing job, what is the average unit price of process inks? In addition, how is the ink cost estimated?
2. How does graphic content affect ink usage?
3. How does GCR affect ink usage?

## Ink Usage Estimate Methods and Ink Unit Price

For a typical print job, the ink cost is usually 2% to 5% of the average cost of the job (Ruggles, 2008). In the book *Printing Estimating*, Philip (2008) elaborated on offset ink weight estimating methods using printing coverage area constants. In Table 2, the numbers represent the approximate size that one pound of ink covers with 100% area on a litho-coated substrate.

Table 2. Printing coverage area constants

| | Cyan | Magenta | Yellow | Black |
|---|---|---|---|---|
| **Litho Coated** | 340 | 345 | 355 | 380 |
| **Unit (per square inch)** | $1 \times 10^3$ | $1 \times 10^3$ | $1 \times 10^3$ | $1 \times 10^3$ |

The following are steps to calculate ink weight for a job with a known AIC of each color.

*Step One – Calculate the total printing size.*

Total printing size ($Inch^2$) = Single page size ($Inch^2$) × pages × copies

*Step Two – Convert the total inked area*

Convert the total inked area in certain percentage of AIC to the solid (100% dot) print in corresponding size. In the above equation, AIC is obtained as stated on page 6.

Corresponding size of solid print = AIC × total inked area

*Step Three – Find the ink weight.*

Total ink weight = Corresponding size of solid print / constant

According to industry research, the average unit prices for process inks are as shown in the following Table 3.

Table 3. Average unit price of process ink

| | **Cyan** | **Magenta** | **Yellow** | **Black** | **Average** |
|---|---|---|---|---|---|
| **Unit Price ($) per lb.** | 4.09 | 4.93 | 4.24 | 3.49 | 4.18 |

The unit prices for individual CMYK ink are slightly varied, and black is the least expensive of the four. This fact is a critical prerequisite that supports GCR's ink-saving idea. GCR saves ink costs in two ways. GCR reduces the AIC, which results the total ink

usage and cost being reduced accordingly. And the other way is to use less expensive black ink to replace cyan, magenta, and yellow inks. Having done calculating the total ink weight, ink cost is calculable using the formula in Step Four.

*Step Four – Find the ink cost.*

Ink cost (per color) = Total ink weight × Ink unit price

**Graphic Content and Ink Saving**

Spranq has developed a new font that claims to save up to 20% of the cost of ink according to Anon's paper "Economic font: new cost effective font" published in 2009. The new Ecofont has small holes in the letter strokes to decrease the use of ink or toner. The inventor hopes the new font can increase users' environmental and cost awareness regarding ink and toner consumption. This is a good example of how typeface designers can reduce ink consumption by simply changing the typeface design. In addition, the design concept behind the font is: less inked area requires less ink usage.

This report reflects designers' awareness of sustainability. If adding holes in type strokes can save ink, what improvement is applicable to pictorial color image to save ink? Hence, it is meaningful to see how pictorial color image with continuous tone affect ink usage based on real production data.

**GCR and Ink Saving**

Eric Neumann, Greg Radencic and Dr. Mark Bohan (2008) have published an article titled "An Evaluation of Different Strategies for Ink Savings on Press." In this article, their research focused on "ink reduction strategies available in prepress stage and how they impact the print quality and ink usage" (pg.1). The ink reduction strategy employed in their research is GCR, which is integrated into different color management workflow software. Conventional, synthetic, and composite images are used as test targets to evaluate the performance of different software vendors' GCR optimizing function. The ink saving is computed by comparing digital files processed with and without GCR for different workflows. There are two most valuable conclusions that any further research in GCR can use as references. 1) All workflows do display overall ink savings when GCR is employed. 2) The amount of ink saved is affected by graphic content and type. Images with heavy coverage can achieve the largest savings. Besides the above two conclusions, this research also pointed out that environmental factors (e.g., graphic contents and ink density) need to be kept equally. As the research objective, GCR has to be the only factor that determines the ink usage in the experiment. In this research, the ink savings are evaluated based on the digital file limited in prepress stage. There is no discussion about real ink mileage consumed in printing production.

In the article *Device Link Profiles/Repurposing CMYK*, Ben Starr (2005) introduced an experiment that assessed several device link profiles creating software including Alwan

LinkProfiler 1.8, X-Rite MonacoPROFILER4.6, ProfileMaker 5.01, etc. GCR is part of the function in device link profiles. The experiment tested device link profiles along with GCR in several aspects including colorimetric, visual appearance, and ink coverage. The result shows that Alwan LinkProfiler is "capable of achieving good colorimetric and visual results while limiting the amount of ink used" (pg.15). In summary, this paper provides the background knowledge of device link carrying with GCR. In addition, the finished research suggested using Alwan Link Profile as the application software to optimize digital files with GCR.

The report *Use of Device Link Profiles for Graphic Arts Industry* published by French Paper and Printing Engineering School, discussed the effect of Dynamic Device Link Profile (Dynamic DVLP) and Conventional Device Link Profile (DVLP). The major difference between a conventional and dynamic device link profile is that conventional device link applies a pre-set calculation model to adjust CMYK percentage (mainly decrease CMY percentage and increase K percentage) regardless of the image content, meaning all images will be processed with the same manner as far as GCR level is decided. Dynamic device link gives opportunity to have the application analyzed the image characteristic first, and then optimize the CMYK percentage with a proper GCR level to decrease CMY percentage, increase K percentage, yet maintain the color, contrast and details to the greatest level.

In this research, both dynamic and conventional DVLP are color management tools developed by Alwan. They convert images between two CMYK spaces with different levels of GCR. Dynamic DVLP claims to achieve higher GCR and more ink saving than conventional DVLP. This report describes the methodology and results of this comparison experiment of Dynamic DVLP and conventional DVLP. Colorimetric accuracy was first assessed. Average and maximum Delta E and gamut mapping are taken into account for determining the dynamic and conventional DVLP's colorimetric accuracy performance. The conclusion is that dynamic DVLP, carrying higher GCR, achieves better color accuracy than conventional DVLP. The amount of ink saved is calculated using Alwan CMYK Optimizer Ink Statistics, a digital count-based software. As a result, the conclusion is still based on digital file pixel count instead of real printing ink mileage. This experiment proved GCR does help save ink (at least the digital counts), but it did not discuss the amount of each individual CMYK ink saved, thus was not able to reflect the GCR merits of using cheaper black ink to replace CMY ink. In addition, there is no discussion on ink saving in real printing when GCR technology is used.

# Chapter 4

# Research Questions

## Research Question #1 – AIC and Ink Usage

It goes without saying that reducing ink coverage in the graphic design and prepress stages helps reduce ink consumption in printing. It will be meaningful to see the real cost difference between light ink coverage content and high ink coverage content in practical printing. The first research question is: how does graphic content difference (high AIC vs. low AIC) affect ink usage in practical printing?

## Research Question #2 – GCR and Ink Savings

Previous research did prove that the use of GCR results in ink savings. However, all existing ink-saving estimation methods are mostly based on simulation, which is counting the pixel value of images using a software application. Some ink saving application advertisements claim that the ink usage reduced can be as much as 30% when proper GCR settings are applied.

Here comes a question on whether the pixel counting saving indicates accurate ink cost usages? Author found no published article reports the practical ink-saving effect of GCR.

As a result, the second research question is: how much ink can actually be saved in the press run with GCR being used?

# Chapter 5

# Methodology

## Methodology for Research Question #1 – AIC and Ink Usage

A case study was discussed to get an explanation for research question #1. In this case study, an "AIC - ink usage" model was built to reveal the relation between AIC and ink usage. In this model, two different printed magazines are borrowed as testing objects. One magazine carried heavy ink coverage (high AIC) and the other carried low ink coverage (low AIC). Their production information such as AIC, ink usage, and printing volume were collected and listed against each other to display the ink usage difference caused by the different AIC level.

An offset company provided the printed magazines and production data, which were considered to represent a general printing situation. Connecting with this case study, the model revealed the magnitude of AIC in affecting the actual ink usage. The model building procedures were composed of four steps. Figure 3 displays this four steps workflow.

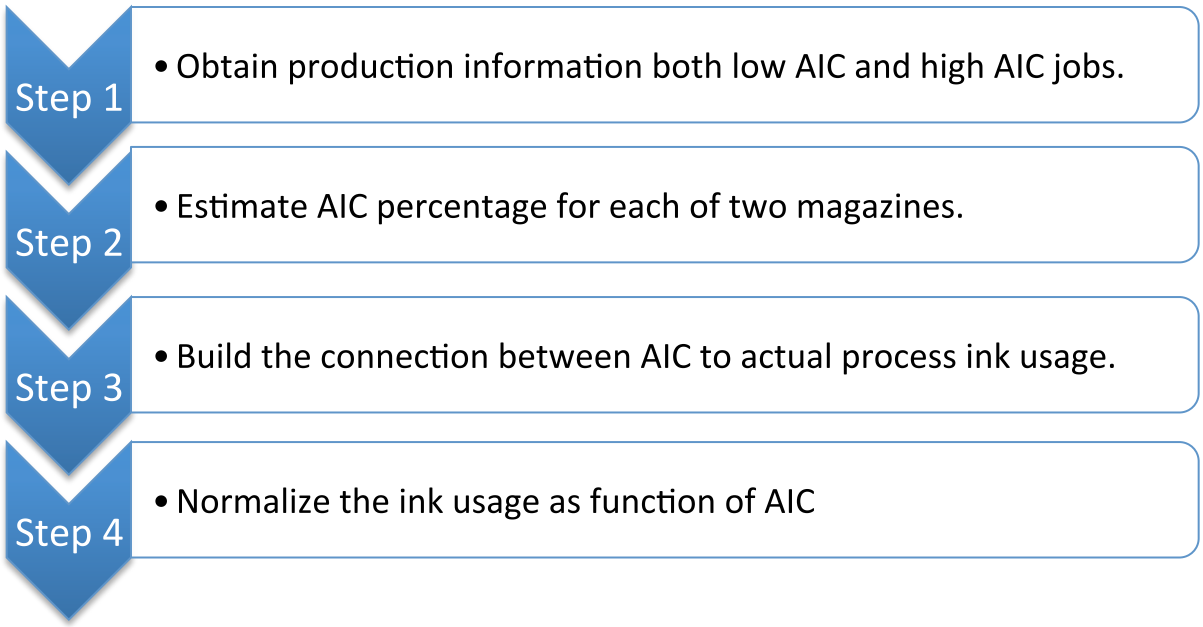


*Figure 3 Four steps to build an AIC-Ink usage model*

*Step One – Obtain production information both low AIC and high AIC jobs.*

An offset printing company provided the hard copy of magazines and production information. The known production information including page size, publication pages, printing qualities, and process ink usage is shown in Table 4.

Table 4. AIC-Ink usage model - production information

| | High AIC | | | | Low AIC | | | |
|---|---|---|---|---|---|---|---|---|
| **Page size** | 8.5"x11" | | | | 8.5"x11" | | | |
| **Pages** | 82 | | | | 118 | | | |
| **Copies** | 7000 | | | | 38000 | | | |
| | **C** | **M** | **Y** | **K** | **C** | **M** | **Y** | **K** |
| **Ink usage (lb.)** | 16 | 25 | 6 | 20 | 36 | 30 | 26 | 45 |

The AIC was unknown temporarily because none of the magazines' digital files were provided to author. Hence, the next step was to sample the AIC from two hard copy magazines.

*Step Two – Estimate AIC percentage for each of two magazines.*

First, the researcher randomly selected 10 pages from each magazine and scanned these pages into digital files using an Epson flatbed photo scanner. Figure 4 shows the selected pages for both high AIC and low AIC magazines.

*Figure 4. Pages selected from high AIC (upper) and low AIC (lower) publication*

Then, the researcher opened the scanned pages in Photoshop and converted color space from the original RGB color space to CMYK SWOP v2 color space. In order to get the AIC of each page, the "Blur – Average" filter (see Figure 5) was used to blur all pages. This operation allows Photoshop analyzing the color of each pixel for that page to determine an average value, and then filling the whole page with that color of the average value (Richard, 2009 Understanding Adobe Photoshop CS4). Figure 6 shows the average blur filter effect on one page.

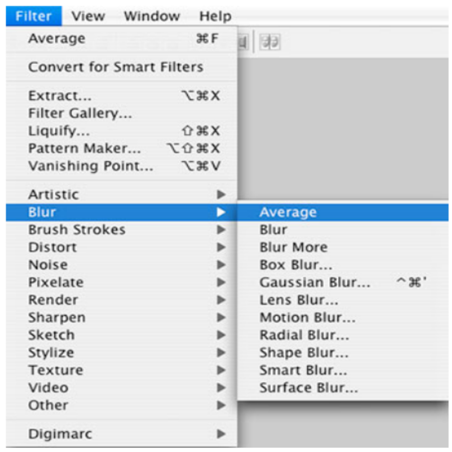


*Figure 5. Blur – Average filter in Photoshop*

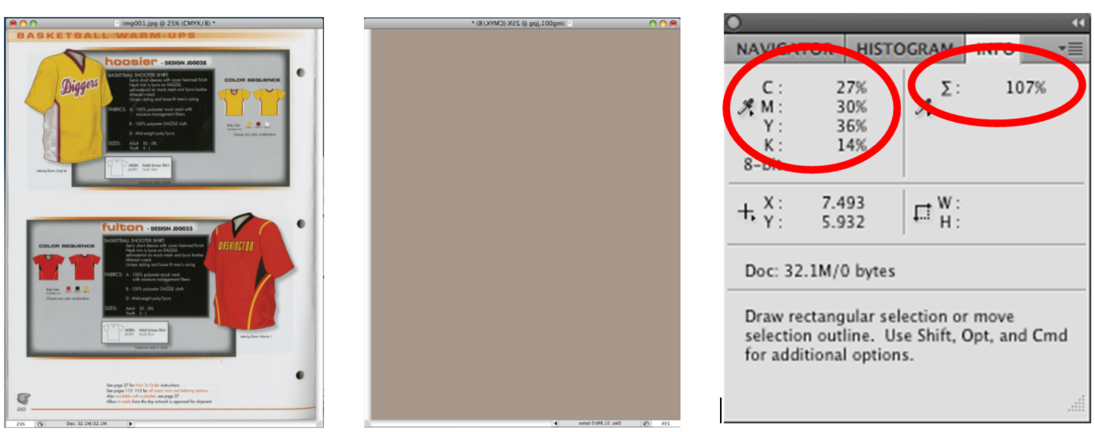


*Figure 6. Before average (right), after average blur (middle) with readings (left)*

To read the AIC of each CMYK ink, info panel was called from the "window" menu (Figure 5) with the cursor on the blurred page, the info panel displayed the separated CMYK ink printing area (left circle) as well as the total ink amount (right circle).

The researcher repeated the above procedures to obtain the AIC of ten pages in each of two publications. Table 5 shows the AIC for each of 10 pages. The average AIC represents that magazine's AIC.

Table 5. AIC per page per color and average AIC for each publication

| | High AIC | | | | Low AIC | | | |
|---|---|---|---|---|---|---|---|---|
| Page # | **C** | **M** | **Y** | **K** | **C** | **M** | **Y** | **K** |
| 1 | 30 | 31 | 35 | 16 | 16 | 10 | 5 | 1 |
| 2 | 31 | 25 | 29 | 20 | 38 | 58 | 57 | 27 |
| 3 | 45 | 44 | 49 | 32 | 21 | 18 | 11 | 4 |
| 4 | 25 | 22 | 20 | 10 | 18 | 17 | 22 | 11 |
| 5 | 33 | 31 | 33 | 18 | 7 | 7 | 7 | 1 |
| 6 | 28 | 23 | 25 | 9 | 22 | 18 | 23 | 10 |
| 7 | 34 | 29 | 32 | 17 | 18 | 17 | 25 | 11 |
| 8 | 32 | 40 | 53 | 23 | 13 | 12 | 16 | 7 |
| 9 | 34 | 28 | 32 | 17 | 33 | 29 | 35 | 22 |
| 10 | 49 | 49 | 44 | 34 | 18 | 41 | 49 | 16 |
| **Average** | **34.1** | **32.2** | **35.2** | **19.6** | **20.4** | **22.7** | **25** | **11** |

*Step Three – Build the connection the AIC with the process ink usage*

Knowing the AIC for each magazine, the next step was to list the production info and AIC together to reveal the relation between AIC and ink usage. Table 6 shows the

production information as well as the AIC percentages for both high and low AIC magazines.

Table 6. Production information and AIC

| | High AIC | | | | Low AIC | | | |
|---|---|---|---|---|---|---|---|---|
| **Page size** | 8.5"x11" | | | | 8.5"x11" | | | |
| **Pages** | 82 | | | | 118 | | | |
| **Copies** | 7000 | | | | 38000 | | | |
| | **C** | **M** | **Y** | **K** | **C** | **M** | **Y** | **K** |
| **AIC(%)** | 34 | 35 | 35 | 20 | 20 | 22.7 | 25 | 11 |
| **Ink usage (lb.)** | 16 | 25 | 6 | 20 | 36 | 30 | 26 | 45 |

In Table 6, high AIC publication had an overall higher AIC value for CMYK than low AIC magazine had, which is obvious and understandable. However, the process ink usage of the high AIC magazine was even less than that of the low AIC magazine. The reason is that the process ink usage for each of the two magazines was not compared under the fair condition.

In printing production, factors other than AIC, such as page size, page numbers, and printing volume also affect the total ink usage. The page counts and copy quantity for two magazines in Table 6 are different, meaning the AIC is not the only factor determining the final ink usage. In order to make the ink usage of two publications comparable to each other, it is critical to normalize the ink usage to an equal printing condition: the same number of pages and copies.

*Step Four – Normalize ink usage as a function of AIC*

The normalization logic is to divide the process ink usage in Table 6 into a unit weight, that is pounds per square inch, and then, to multiply the unit weight with a standard page size of 8.5 inch by 11 inch, 100 pages and 1000 copies.

The following equations show the procedures of normalization.

1. Ink weight for each copy = Total ink weight / copies
2. Ink weight for each page = Ink weight for each copy/ pages
3. Ink weight for each square inch = Ink weight for each page / page size
4. Ink weight for one page in size of 8.5” × 11” = Ink weight for each square inch × 8.5” × 11”
5. Ink weight for 100 pages = Ink weight for one page × 100
6. Ink weight for 1000 copies = Ink weight for 100 pages × 1000

**Methodology for Research Question #2 – GCR and Ink Usage**

To answer research question #2, a test form carrying high ink coverage was processed by normal GCR and high GCR, generating two test forms: a normal GCR test form and a high GCR test form. The researcher printed the two forms to a standard printing condition on an offset press and recorded the ink usage of each test form. The differences

in the ink usage between the two test forms were compared and their relationship with GCR levels was discussed.

The following sections describe the whole process in three steps:

Step One – Printing condition standardization

Step Two – Test Form preparation

Step There – Press Run

*Step One – Printing condition standardization.*

In offset printing, many factors can affect the ink usage, including AIC, SID (solid ink density), TVI (tone value increase), etc. For testing the GCR effect on ink usage and ink saving, it was important to keep SID and TVI in the same condition and settings for both test forms' printing. Hence, performing an initial and characterization run before running the GCR test forms is necessary. This run was composed of two parts: initial run and characterization run.

*Initial run.* The goal of an initial run was: 1) to adjust the ink density to conform to colorimetric aim point of solids per ISO 12647-2; 2) to obtain the initial TVI and generate the transfer curve to adjust the TVI to conform to aim point of TVI per ISO 12647-2. Firstly, the characterization test form (IT8.7/4) was printed using linear plates to conform to colorimetric aim point of solids per ISO 12647-2. Then, the IT8.7/4 was

measured to derive the initial TVI. By comparing the initial TVI and ISO standard TVI, the transfer curve was generated and applied to the second set of plates, named “curved plate”

*Verification run.* The goal of the verification run was to verify the conformity to the ISO 12647-2 standard. Firstly, the test form (IT8.7/4) was printed with curved plates to achieve both the SID and TVI aim points per ISO 12647-2. Then, the test form (IT8.7/4) was measured ; color difference was calculated between the printed test form (IT8.7/4) and FOGRA39 characterization dataset. It turned out that the press was in good conformity to the ISO 12647-2, and as a result, the FOGRA39 was considered as a reasonable output space to process the two GCR test forms in the following experiment.

*Step Two – Test Form Preparation*

GCR’s ink saving effect is very image-dependent. Theoretically, ink usage has the most obvious decrease when apply a level GCR is applied to the high AIC. To expect a noticeable GCR ink saving in the press run experiment, the test form was designed with high AIC pictorial images and background. Appendix A shows the layout of the test forms. The following paragraphs elaborate the workflow of preparing the high GCR and normal GCR test from. Figure 7 is the workflow chart.

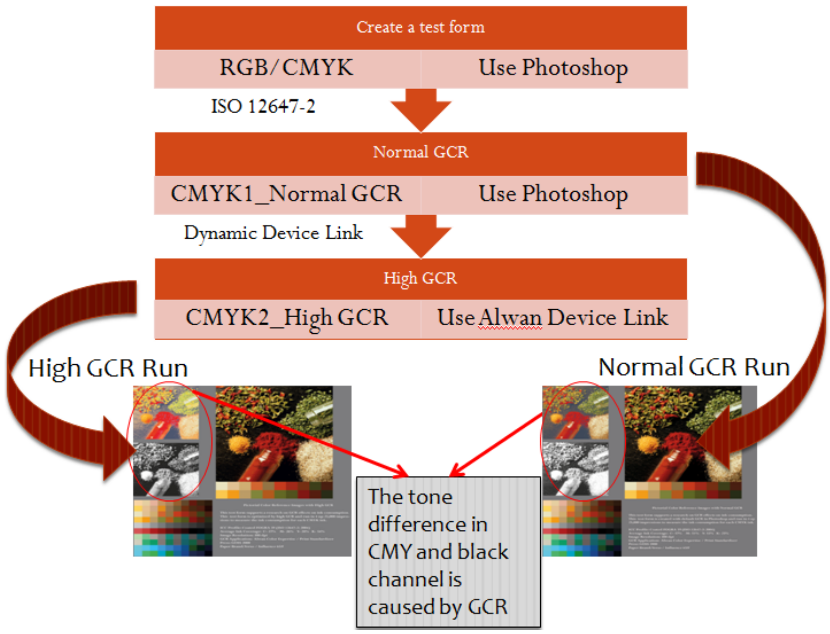


*Figure 7. Test form preparation workflow*

First, the researcher composed the test form using Photoshop, which transferred pictorial images from RGB or CMYK into FOGRA39 space. The normal GCR level was employed during the transfer. The output file was then named “normal GCR test form” which was embedded with FOGRA39.

Second, the researcher processed the normal GCR test form using the Alwan CMYK Optimizer. Both input and output spaces were maintained as FOGRA 39. Figure 8 displays the CMYK Optimizer interface where the Dynamic maximum black was applied to the file. The output file was named “High GCR test form”.

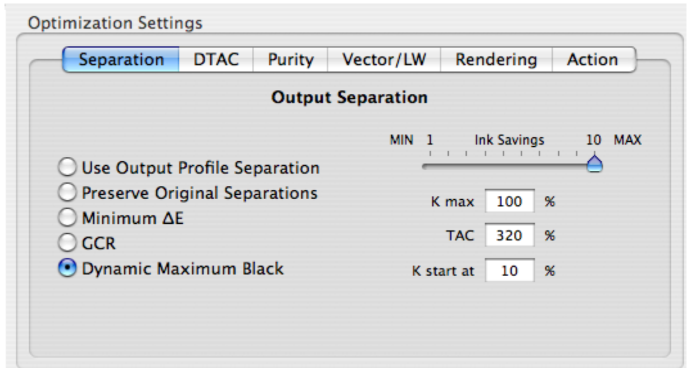


*Figure 8. Dynamic maximum black setting*

*Step Three – Press Run*

*Materials and Devices.* The experiment pressrun was executed on web offset press with Sun Chemical ink and NewPage 80# Sterling Ultra Matte text. The GOSS Sunday 2000 was used to run the experiment because it is installed with an ink meter that can track ink usage on the press. In printing, the ink flow through the meter causes rotation of a positive displacement gear. The rate of rotation is monitored by a sensing device and transmitted to a counter, which provides a read out of the amount of ink passing through the meter. The unit of the ink meter is 1 pound, meaning that the minimum detectable ink usage increase is one pound.

*Pressrun.* The press length was 24,000 impressions for each test form. Ink usage was read every 2 minutes, after the press went into a stable condition until it achieved the anticipated impressions. In this way, the increasing ink usage was recorded for each process color during the two GCR runs.

*Data Collection.* The collected data included the AIC of two versions of the test form and ink usage measured from the pressrun.

# Chapter 6

# Results and Conclusions

## Result for Research Question #1 – AIC and Ink Usage

*AIC – Ink Usage Model*

To investigate the significance of graphic content difference (high AIC vs. low AIC) to ink usage, two publications with high AIC and low AIC were employed to build an "AIC – Ink usage" normalized model as displayed in Table 7.

Table 7. AIC – Ink Usage normalized model

| | High AIC | | | | Low AIC | | | |
|---|---|---|---|---|---|---|---|---|
| **Page size** | 8.5"x11" | | | | 8.5"x11" | | | |
| **Pages** | 100 | | | | 100 | | | |
| **Copies** | 1,000 | | | | 1,000 | | | |
| | **C** | **M** | **Y** | **K** | **C** | **M** | **Y** | **K** |
| **AIC (%)** | 34 | 35 | 35 | 20 | 20 | 23 | 25 | 11 |
| **Ink usage (lb.)** | 2.8 | 4.4 | 1.0 | 3.5 | 0.8 | 0.7 | 0.6 | 1.0 |

This model provides an equivalent printing condition, in which ink usage of two magazines, one with high AIC and one with low AIC, were compared against each other. In this model, AIC is considered to be only factor causing a difference in ink usage.

*Data Analysis*

For the high AIC publication, each individual color AIC is: C -34%, M - 32%, Y - 35% and K - 20%. After printed, the ink usage is: C - 2.8 lb.; M - 4.4 lb.; Y - 1.0 lb.; and K - 3.5 lb.

For the low AIC publication, AIC for each individual color is: C - 20%, M - 23%, Y - 25% and K - 11%. After printed, the ink usage is: C - 0.8 lb.; M - 0.7 lb.; Y - 0.6 lb.; and K -1.0 lb.

Table 8. Ink usage comparison for high AIC and low AIC

| | Cyan | | Magenta | | Yellow | | Black | |
|---|---|---|---|---|---|---|---|---|
| | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** |
| **High AIC** | 34 | 2.8 | 35 | 4.4 | 35 | 1 | 20 | 3.5 |
| **Low AIC** | 20 | 0.8 | 23 | 0.7 | 25 | 0.6 | 11 | 1 |
| **Ratio** | 1.7 | 3.5 | 1.5 | 6.3 | 1.4 | 1.7 | 1.8 | 3.5 |

To investigate the way AIC affects ink usage, the AIC and ink usage ratio between high AIC design and low AIC design is shown in table 8. The cyan AIC ratio is 1.7, and the cyan ink usage ratio is 3.5, which means that for every 1 lb. of cyan used in the low AIC design, there should be 3.5 lb. of cyan used in the high AIC design. Following the same logic, the magenta AIC ratio is 1.5, and the ink usage ratio is 6.3; yellow AIC ratio is 1.4, and the ink usage ratio is 1.7; the black AIC ratio is 1.8, and the ink usage ratio is 3.5. For all four colors, the AIC variance in the digital file is amplified in ink usage after printing.

*Conclusion*

To answer the first research question — how does graphic content difference (high AIC vs. low AIC) affect ink usage — the rule is that high AIC always requires more ink usage and low AIC always requires less ink usage. AIC variance, as a result of different graphic designs in the digital files, will yield to an amplified ink usage difference in printing. Hence, graphic design significantly affects ink usage.

**Result for Research Question #2 – GCR and Ink Savings**

As discussed in the methodology section, a high level GCR applied to a test form decreases AIC. Then two versions of test forms are sent to the press to capture the actual ink usage. In this section, the author will share the AIC before and after being applied with GCR and ink usage collected on the press.

*Data Analysis*

With GCR employed, the AIC of cyan, magenta, and yellow decreases, while the AIC of black increases. AIC is decreased by 48% for cyan, 43% for magenta, and 43% for yellow. The AIC of black is increased by 49%. The overall area coverage is decreased by 26%. The conclusion for this table is that applying GCR to a high AIC test form certainly results in a drease in AIC for cyan magenta and yellow, while resulting in an increase for black. The overall area coverage is decreased by 26% due to the GCR.

Table 9. AIC for normal GCR and high GCR

| AIC (%) | Cyan | Magenta | Yellow | Black | Total |
|---|---|---|---|---|---|
| **Normal GCR** | 50 | 46 | 47 | 35 | 178 |
| **High GCR** | 26 | 26 | 27 | 52 | 131 |
| **Delta AIC** | 24 | 20 | 20 | -17 | 47 |
| **AIC decreased by** | 48% | 43% | 43% | 49% | 26% |

Table 10 shows the final ink usage for both test forms. Ink usage decreases by 27% for cyan, 30% for magenta, and 39% for yellow. The usage of black increases by 32%. The total ink usage decreases by 20%. Applying GCR to a high AIC test form results in an obvious reduction in ink usage of cyan, magenta and yellow, while resulting in an increase for black. The overall ink usage is decreased by 20% as a result of GCR.

Table 10. Ink usage for Normal GCR and High GCR

| Weight (lb.) | Cyan | Magenta | Yellow | Black | Total |
|---|---|---|---|---|---|
| **Normal GCR** | 41 | 27 | 28 | 28 | 124 |
| **High GCR** | 30 | 15 | 17 | 37 | 99 |
| **Delta lb.** | 11 | 8 | 11 | -9 | 25 |
| **Ink saved by (%)** | 27% | 30% | 39% | 32% | 20% |

Table 11. Ink usage comparison for normal GCR and high GCR

| | Cyan | | Magenta | | Yellow | | Black | |
|---|---|---|---|---|---|---|---|---|
| | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** | **AIC** | **Ink Usage** |
| **Normal GCR** | 50 | 41 | 46 | 27 | 47 | 28 | 35 | 28 |
| **High GCR** | 26 | 30 | 26 | 15 | 27 | 17 | 52 | 37 |
| **Ratio** | 1.9 | 1.4 | 1.8 | 1.8 | 1.7 | 1.6 | 0.7 | 0.8 |

To investigate the way GCR affects ink usage, AIC and ink usage ratio between the normal GCR test form and the high GCR test form is as shown in Table 11. The cyan AIC ratio is 1.9 (cyan AIC of normal GCR divided by cyan AIC of high GCR), and the ink usage ratio is 1.4 (cyan ink usage of normal GCR divided by cyan ink usage of high GCR). The ratio 1.4 means that for every 1 lb. cyan used in the high GCR test form, there should be 1.4 lb. of cyan used in the normal GCR test form. Following the same logic, the magenta AIC ratio is 1.8, and the ink usage ratio is 1.8; the yellow AIC ratio is 1.7, and the ink usage ratio is 1.6; the black AIC ratio is 0.7, and the ink usage ratio is 0.8. For all four colors, the AIC differences that exist in the high GCR and normal GCR digital file is diminished in ink usage after printing.

*Conclusion*

To answer the second research question — how does GCR variance (high GCR vs. normal GCR) affect ink usage — the rule is that a high GCR results in less AIC and ink usage; and a normal AIC results in higher AIC and ink usage. AIC variance, as a result of different GCR levels, will yield a diminished ink usage variance in printing. Hence, GCR affects ink usage within a certain range, but not as significant as graphic design does.

# Chapter 7

## Discussion and Summary

### AIC and Ink Usage

Comparing the AIC and ink usage of the two test forms, the researcher finds that although ink usage and AIC both decreased, they do not decrease proportionally. For example, while the cyan AIC of the normal GCR test form is 48% higher than that of the high GCR test form, it does not necessarily mean that the cyan usage of the normal GCR test form will also be 48% higher than that of the high GCR test from. Instead, it is 27%. The ink estimate method that used AIC to represent the ink usage is not accurate enough.

This result further verifies the conclusions from the "AIC-Ink usage model", which is that AIC and ink usage, are not linear in their linear relationship. The resulting ink usage variance by the GCR level (high GCR vs. normal GCR) is actually smaller than the AIC variance in the digital file.

### Accuracy of AIC-based Ink Estimate Method

For each version of the test form, AIC percentage was captured from the digital file and actual ink usage was recorded during the press. Following the previously-discussed AIC-

based ink usage estimate method, it is possible to estimate ink usage. Estimated ink usage and actual ink usage are compared against each other in Table12

Table 12 Estimated ink usage vs. actual ink usage

| Normal GCR | Cyan | Magenta | Yellow | Black |
|---|---|---|---|---|
| AIC(%) | 50 | 46 | 47 | 35 |
| Estimated Ink Usage (lb.) | 45.77 | 41.5 | 41.2 | 28.67 |
| Actual Ink Usage (lb.) | 41 | 27 | 28 | 28 |
| **High GCR** | **Cyan** | **Magenta** | **Yellow** | **Black** |
| AIC(%) | 26 | 26 | 27 | 52 |
| Estimated Ink Usage (lb.) | 23.8 | 23.45 | 23.67 | 42.59 |
| Actual Ink Usage (lb.) | 30 | 15 | 17 | 37 |

Actual ink usage of cyan and black are close to the predicted amount, while magenta and yellow are off from the estimate. The estimate method is logically correct, but the printing coverage area constants have an issue. These constants are calculated based on a press experiment. The press, substrate and printing condition jointly determine the printing coverage area constant. Technically, if the GCR press run is done under the same printing condition as Philip's experiment, the estimated ink usage should match the actual amount. However, although the estimate method claimed to be applicable to offset printing, the press, substrate, and printing condition results Philip's constant are not accurate enough, which explains the mismatch between the estimated ink usage and the actual amount used in GCR press run.

**Run Length and Ink-Saving**

Ink cost might comprise only 2% - 5% of the total material cost. And the ink cost saving, as a result of AIC decrease, might reduce the total ink usage by 10% - 50%, depending on whether AIC is decreased as result of varying graphic designs or high level GCR. But who cares about a 50% ink cost saving within a mere 2% of the total material cost? The big print corporations with millions of dollars in production costs care! In the real world, assume a printing company receives a routine print job that happens every month. The AIC difference in the digital file will end up accumulating a considerable ink usage variation by end of the year.

For any print job, graphic design is the primary factor that determines the final ink usage. In high-volume printing companies, such as packaging printing, the most effective way to save ink is to eliminate the art design for a low AIC design. However, printers do not usually make decisions on art design; instead, they are more likely to receive art from the clients and print what the clients want them to print. In this case, GCR can be employed to decrease the AIC to a certain level, which satisfies the ink-saving purpose without hurting the image quality and color accuracy.

The test form press run experiment proves the GCR effect in ink saving. With 24,000 impressions, there is a noticeable ink usage variance between the high GCR test form and the normal GCR test form. Figure 9 displays the ink usage increase for each test form

press run per process color. The x-axis is the time length starting from 0 to 55 minutes, when the press run ended. Y-axis is the ink usage read every two minutes. The graphics shows increasing ink usage along the timeline.

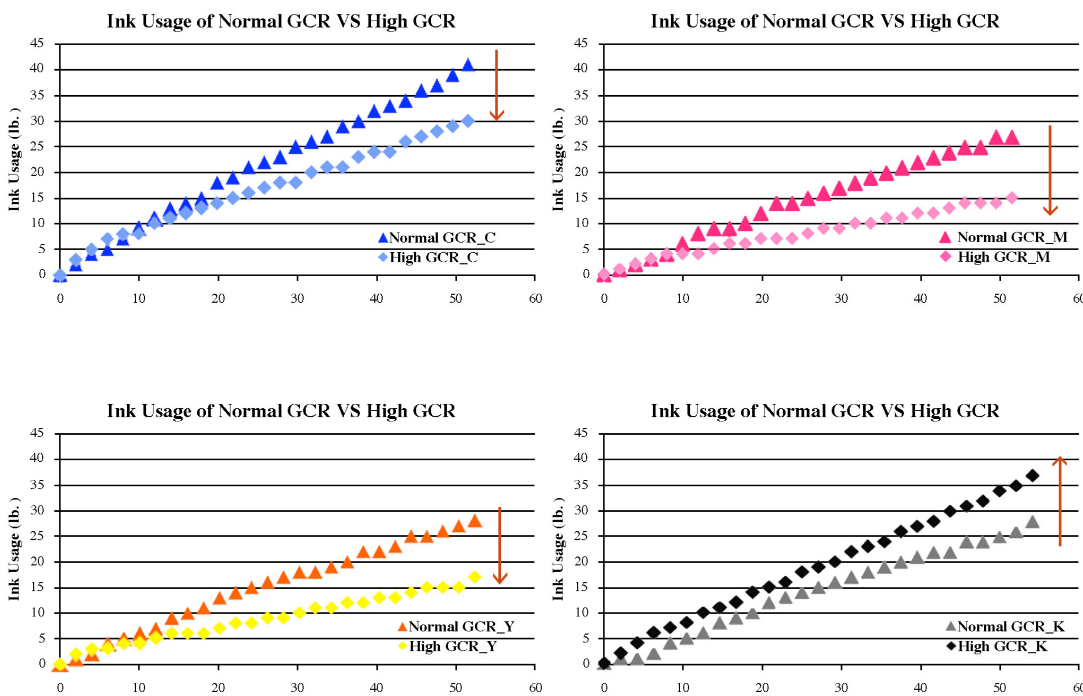


*Figure 9. Ink usage increasing curve*

For all four colors, there is no significant ink usage difference (between normal GCR and high GCR) within the first 20 minutes. The high GCR advantage became obvious after 30 minutes. GCR is helpful only for long press runs. The longer the press run is, the more ink is saved. For a short run and a small quantity job, a high level GCR doesn't show its ink-saving benefit very well.

GCR saves ink costs in two ways. Firstly, as concluded above, GCR decreases the overall AIC and total ink usage, which, of course, causes a savings in ink costs. Secondly, the unit prices for cyan, magenta, and yellow inks are usually higher than they are for black ink. GCR manipulates a digital file by decreasing cyan, magenta, and yellow inks, and by increasing black ink, so that the color appearance is kept unchanged. Hence, replacing relatively expensive cyan, magenta, and yellow inks with less expensive black ink saves ink cost.

**Ink savings in offset and other print methods**

This research only discusses the ink saving in the offset field. GCR is found to be the most effective for high AIC type images and lengthy offset production. For small quantity offset print jobs, the ink saving caused by GCR is very limited. According to the literature review, the total ink cost in an offset job is usually 2% to 5% depending on the printing specifications. The ink saving by GCR is ideally 20% based on the GCR press run experiment. The ink cost saving by GCR is approximately 0.4% to 1% of the total job cost. In conclusion, the ink cost saving in offset printing will be very dependent on the print volume. Overall, GCR's ink cost saving effect on offset jobs is limited because the ink cost is not the primary cost for an offset job.

For other print methods, such as wide format UV printer, ink cost can be one of the major factors relative to the total printing cost. Because only certified brand ink can be used on the printer, consumers usually have to pay more for proprietary inks. In this case, the ink saving by GCR is very meaningful and deserves further research. GCR also deserves further research in gravure and flexography printing, since these two methods are frequently used in package printing, meaning high volume and repeated print runs.

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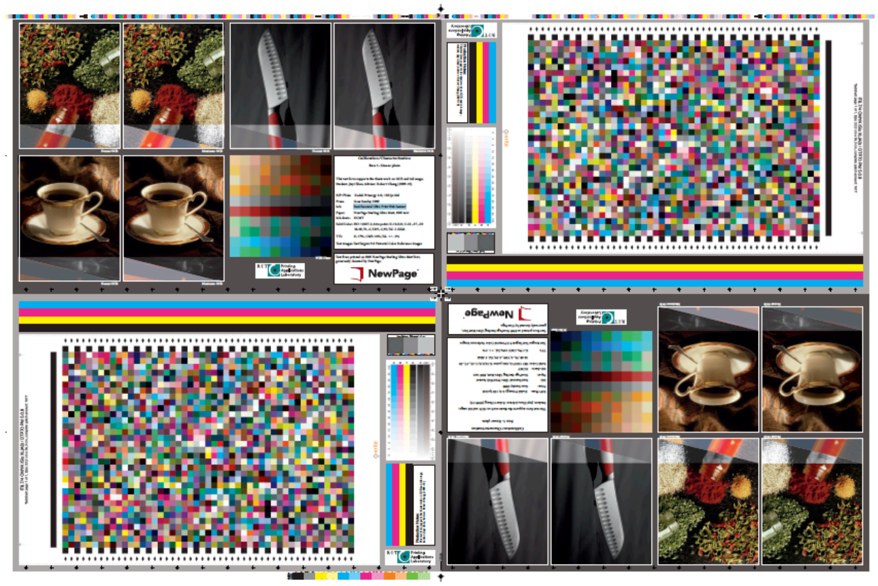
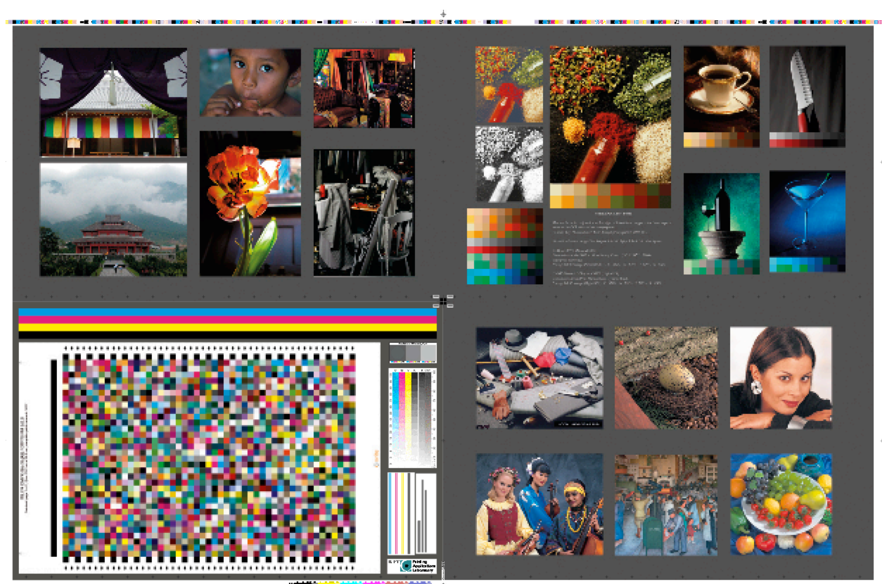
# Appendix A   Test Form



Test form for calibration and characterization run



Test from for GCR experiment press run

# Appendix B   Press Run Organizer

| | |
|---|---|
| Press date: | **2/23; 2/26** |
| Project description: | **GCR Comprision** |
| Project contact: | Jiayi Zhou |
| Telephone No: | 585-545-5903 |
| Today's date/time: | 8/6/12 |

Printing description: (1) Run_1 --Test from with normal GCR; Run_2 -- Test form with high GCR. (2) For each ru, record ink usage every 5,000 signatures per run, colleced 10 data during the production.

| Job Specifications | | | Production Notes / Quality Assurance |
|---|---|---|---|
| PREPRESS | Print on both sides | | |
| Signature contents: | (see description at right) | | Form_1 & 2: Same contents, differnet GCR levels |
| Image resolution: | 300 ppi | | |
| Color control bar: | RIT Color Control Bar | | |
| PROOF | | | |
| Manufacturer: | HP | | |
| Brand: | Designjet 5500 ps (Content only) | | |
| RIP/PLATE | Kodak Prinergy 4; 175 lpi AM | | |
| Manufacturer: | Kodak VLF | 2400 dpi | |
| Brand: | KPG(12mil); thermal Gold | | |
| PRESS | | | |
| Manufacturer: | GOSS web offset press | | |
| Brand: | GOSS Sunday 2000 | | |
| Size (max): | 57"; Repeat length: 22.75" | | |
| FOUNTAIN SOL'N | | | |
| Manufacturer: | Anchor | | |
| Brand: | #20047 Emerald Premium | | |
| pH/Conductivity: | pH 4.0 buffered; Conduct. 3050 | | |
| BLANKET | | | |
| Manufacturer: | Day International | | |
| Brand: | Gapless 3000 | | |
| Compliancy | (Top) K47, C43, M45, Y43 | | |
| INK | | | |
| Manufacturer: | Flint | | |
| Note: | Heatset | | |
| Temp/Tack | | | |
| PAPER | | | |
| Brand: | Verso | | |
| Basis weigh / Size: | 65# Text, 35" wide | | |
| Quantity: | **2 rolls** | | |
| PRINTING | Reference: ISO 12647-2 | | |
| Ink-down sequence: | KCMY | | |
| Density Aim Point | **K- 1.65** | **M- 1.45** | |
| (Tol.: $5\Delta E_{ab}$) | **C-1.35** | **Y- 0.95** | |
| %TVI at 50% dot area: | **K: 17** | **M: 14** | |
| (Tol: 4%) | **C: 14** | **Y: 14** | |
| Print Speed | **1,200 ft/min** | | |
| Quantity: | 100,000 impressions per run | | (See next tab for ink and paper estimate.) |
| | **50,000 signatures per run** | | |
| | **100,000 signatures two runs** | | |
| ICC PROFILE | Coated FOGRA39 | | |
| | (ISO 12647-2:2004) | | |
| Additional Notes | Process control: GMI ColorQuick | | |