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Evaluation of the press calibration methods by simulation

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Evaluation of the Press Calibration Methods by Simulation

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Abstract

Press calibration is an approach to adjust the behavior of ink, paper, and press with the use of a CTP platemaking system to achieve a specified reference printing condition.

Reference printing condition defines a common color space for color image data exchange between various output devices. The advantage of a reference printing condition is to improve color image quality and reduce cost and time. Corner points of the color gamut, TVI curves, and grey reproduction are the three significant elements in a reference printing condition, which make them essential in press calibration.

There are usually two press runs in press calibration. The first press run (Run 1) is to adjust ink system of a press to achieve the color gamut conformance to the reference aims with linear plates. The second press run (Run 2) is to either adjust tonality or neutrality of the press with curved plates based on the Run 1 printing condition.

Thus, the question is "whether the two press calibration runs can meet the three requirements achieving *full* conformance according to the reference aims?"

This research assessed two cases starting with two real Run 1 printing conditions. In the both cases, ISO Type 1 paper was used and the color gamut was in conformance to the reference CGATS TR006 printing condition.

Run 2 was a simulated calibration press run with the adjustment of either tonality or neutrality of the press. The use of A-to-B tag and B-to-A tag of the Run 1 ICC profile with absolute colorimetric rendering intent was the essential idea to simulate a calibrated Run 2 printing condition. The advantage is that no printing drafts would occur in the simulation approach, which guarantees repeatability from Run 1 to Run 2.

The calibration results were verified to be in conformance first before other assessments. In other words, TVI curves of the TVI-based calibrated results were verified to be in conformance first before grey reproduction conformance was assessed; and grey reproduction of G7-based calibration results was verified to be in conformance first before TVI curves' conformance was assessed.

The research results show that (1) if deviations of TVI curves and grey reproduction in Run 1 printing conditions are close to the reference aims, either of the two calibration methods can achieve *full* conformance; and (2) if discrepancies of TVI curves and grey reproduction conformance in Run 1 printing conditions are far from the reference aims, a third requirement may not be in conformance unless adjustments will be iterated within specified tolerances.

Chapter 1

Introduction

This chapter describes the study's background and scope followed by the research statement and its significance to the printing industry. Last but not least, it elaborates the reasons that drive the researcher to conduct the study.

Background

In today's digitized graphic arts world, designers start the workflow by creating designs and delivering colorful graphics to printers who make proofs and produce prints. Colors are encoded in numbers used to represent them on displays, proofers, printers, and other relevant devices.

The correlation between these encoded numbers and the output colors produced by devices either within the workflow or between various workflows can be inconsistent due to the devices' reproducibility and the way they represent color. In this situation, significant variance of color communication can occur.

One way to solve this problem is to use a reference printing condition for each device since printing production is the final stage of the whole printing process workflow.

The advantage of using a reference printing condition is to reduce cost and time by eliminating miscommunication. In printing, the printer's ability to match a reference printing condition depends on press calibration, which is the focus of this paper.

The scope of study

Press calibration is a fundamentally important step in standardizing the printing process workflow. The objective of press calibration is to adjust the press according to printing aims, which are described by color gamut, tonality, and neutrality. The descriptions of these three terms are detailed in the following paragraphs.

Color gamut

The range of colors that can be reproduced by a device is called *color gamut*. In a four-color printing system, the process ink solids (cyan, magenta, yellow, and black) and their overprints (red, green, and blue) define the boundary of the device color gamut.

The size of the device color gamut is limited by the saturation of the colorants. Paper white can be considered as a fifth color since it affects the saturation and hue of the colorants. For example, it has been investigated that cyan and magenta become more blueness on an OBA (Optical Brightness Agency) paper than a without OBA paper (Chung, R. & Tian, Q, 2011, March).

Tonality

The relationship between input values of the colorants and resulting output values is called *tonality*. The approach of adjusting tonality according to tone value increase (TVI) is a common approach to calibrate press.

Tone value increase (TVI) is the difference between the input digital tone value and the output tone value. The adjustment of TVI curves in press calibration, also known as dot gain compensation, uses four one-dimensional curves to match obtained TVI values to specified ones.

Neutrality

Neutrality of a press can be defined by either maximum mid-tone spread or grey reproduction.

The value of mid-tone spread is used to assess press's grey balance in the TVI calibration method. It is specified on the balance proportions of cyan, magenta, and yellow inks at mid-tone region, which details in Chapter 2.

Grey reproduction is used to adjust tonality according to a CMY combination grey scale. The grey reproduction calibration method adjusts the press aims to achieve a consistent grey scale to human eyes, which yields a pleasing color reproduction.

Aim values of color gamut, tonality, and neutrality in the form of numeric targets are extracted from a reference printing condition. Conformance to these specified aims is judged by comparing the values achieved in printing to the aims and determining if the difference is within the tolerance.

The topic statement

As stated above, color gamut, tonality, and neutrality are the three requirements which must be achieved in press calibration. Two press calibration runs are evaluated. The first press run calibrates the colorimetric values of the colorants, which establishes the boundaries of the color gamut; the second press run adjusts tonality and neutrality of the press using either TVI or grey reproduction method.

The objective of press calibration is to allow the press to print to reference aim values of color gamut, tonality, and neutrality.

Now the question is "since TVI or grey reproduction can be applied to adjust the second press run, will either approach be effective in achieving *full* conformance (to TVI and grey reproduction) when applied to the same color gamut?"

Significance of the topic

Press calibration is essential for achieving color repeatability in printing reproduction. Color gamut, TVI, and grey reproduction are three elements used to determine the conformance of the press.

TVI adjustment of tonality has been used globally for many years in the printing industry. Its aim values and tolerance are well defined in ISO 12647 standards.

Although grey reproduction has also been studied and applied in printing for an extended period of time, due to lack of internationally approved aims and tolerance in press calibration, this approach is not well defined. Despite this shortcoming, thanks to IDEAlliance's promotion of the G7 calibration method, the grey reproduction approach is being accepted and applied in press calibration by more and more printers.

Since both TVI and grey reproduction methods can be used to adjust the second calibration press run, a study of the comparison of the two methods with respect to conformance can be helpful in providing a basis for filling in the blanks of aims and tolerances for the grey reproduction approach.

Thus, this research uses an ideal press condition and several real press conditions to simulate calibrated states. The results may indicate the differences between the two approaches to press calibration conformance.

ICC profiles are used to simulate a printing condition, creating a no-printing-drift environment between the two calibration press runs. Since printing drift generates

unpredictable variance, which may hide differences between the TVI and G7 calibration methods, the simulation approach is preferred for this study.

Reason of interest

The researcher has been interested in printing and color reproduction since entering college. In addition, the researcher's exposure to the development and use of printing standards at RIT added another dimension to her interests.

As the researcher deepened her understanding of her study, she realized the importance of standardization. If two standards cover the same area, it will reduce the value of the both standards. Various types of electronic plugs can be a good example. On the other hand, if a standard is not comprehensive, it will limit its application.

In the printing industry, there are two press calibration methods popular in use, TVI and grey reproduction methods. The both methods are used to adjust press in conformance to printing aim values specified in *ISO 12647-2*. However, the aim values specified in the ISO standard have limitations with respect to grey reproduction.

This scenario inspired the researcher to explore more on the grey reproduction calibration method. Moreover, after she reviewed numbers of literatures, the researcher found that few researches are focused on the correlation between the TVI and grey reproduction calibration methods in terms of press conformance.

This thesis topic is, therefore, an opportunity for her to pursue her personal interests while simultaneously producing new insights for the printing industry.

Definition of Terminology

The following defines some important terms in this research:

Delta C_h (ΔC_h): a parameter used to compute a chroma difference between the achieved gray balance and the reference grey balance. It can be computed by the following equation:

$$\Delta C_h = \sqrt{(a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \qquad (1)$$

Grey: a combination color consists of cyan, magenta, and yellow inks that results in a near-neutral color appearance to the human eye.

Grey balance: a set of tone values of the data that appears as an achromatic color under specified viewing conditions if printed under specified printing conditions. (*ISO/WD 12647-1:2011, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 1: Parameters and measurement methods*)

Grey reproduction: a set of colorimetric values of the print that appears as an achromatic color under specified viewing conditions if printed under specified printing conditions to be used for process control. (*ISO/WD 12647-1:2011*)

Mid-tone spread: a metric defined by Equation 2 according to *ISO 12647-1:2004*:

$$S = \max[(A_c - A_{c0}),(A_m - A_{m0}),(A_y - A_{y0})] - \min[(A_c - A_{c0}),(A_m - A_{m0}),(A_y - A_{y0})] \quad (2)$$

where

A_c is the measured tone value of the cyan process color image.

A_{c0} is the specified tone value of the cyan process color image.

A_m is the measured tone value of the magenta process color image.

A_{m0} is the specified tone value of the magenta process color image.

A_y is the measured tone value of the yellow process color image.

A_{y0} is the specified tone value of the yellow process color image

Neutral Print Density (NPD): a lightness metric adopted for the three-color, near-neutral tone scale.

Printing condition: a set of printing process conditions which fully describe the condition required to produce a specific printed output, usually associated with characterization data measured from an ISO 12642 or similar target (*ISO 12647-1:2004*).

Tone value increase (TVI): the difference between a tone value on the print and the tone value in the digital data file (*ISO 12647-1:2004*).

Chapter 2

Theoretical Basis

Press calibration is the process of adjusting a press's current printing condition to match a set of printing aims. Printing conformance is the process of verifying that the result of press calibration conforms to the specified aim values and tolerances.

The printing aims are derived from a reference printing condition. Specifically, color gamut, TVI, and grey balance are three essential aspects of a specified printing condition. Their aim values are extracted and regarded as printing aims.

Two press calibration runs are conducted to adjust the press to the printing aims of these three aspects. The first calibration run (Run 1) calibrates the primary ink solids, and the second calibration run (Run 2) calibrates TVI curves or grey reproduction based on Run 1 results.

The following paragraphs detail calibration aims, calibration approaches, and calibration verification with respect to color gamut, TVI method, and grey balance method. Since this study focuses on offset lithographic press calibration for commercial printing on ISO coated paper (Paper Type 1), only the relevant aims and tolerances are discussed.

Color gamut

Color gamut is the range of colors that can be reproduced using a specified printing condition. The corner points of the color gamut are specified by the process colors (cyan, magenta, and yellow) and their overprints (red, green, and blue). Since process inks are transparent, the color of the paper can affect the colors printed at the corner points, and thus it is also an important factor in determining the print gamut.

Paper color (or white point) is usually considered first since its color affects the saturation and hue (Chung, R. & Tian, Q., 2011, March) of ink colorants. Table 1 shows the colorimetric aim values and tolerance for an ISO coated paper (Paper Type 1). This research only uses this type of paper.

Table 1. CIELAB coordinates, gloss and tolerance for ISO Type 1 paper. The colorimetric values are measured on the white backing with D50 illuminant, 2° observer.

Source: *ISO 12647-2:2004/Amd 1:2007.*

	L^*	a^*	b^*	Gloss
ISO Type 1 paper	95	0	-2	65%
Tolerance	+/-3	+/-2	+/-2	+/-5

Color gamut aims

Color gamut aim values are specified in *ISO 12647-2:2004/Amd 1:2007, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes. Amendment 1.*

Table 2 lists the aim values for process inks solids and their overprints based on ISO Paper Type 1 with respect to CIELAB color space.

Table 2. CIELAB coordinates for process inks on ISO Type 1 paper with white backing measurement and D50 illuminant, 2˚ standard observer condition.

Source*: ISO 12647-2:2004/Amd 1:2007*.

Color	L*	a*	b*
Black	16	0	0
Cyan	55	-37	-50
Magenta	48	74	-3
Yellow	89	-5	93
Red, M+Y	47	68	48
Green, C+Y	50	-68	25
Blue, C+M	24	17	-46

Color gamut calibration approach

The color gamut is adjusted to match target aims in the first press calibration run (Run 1). An ink starvation form (shown in Figure 1) is used to calibrate the process ink solids.

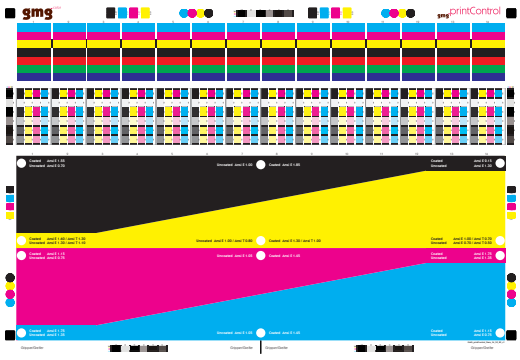

Figure 1. The ink starvation form used to calibrate ink solids

In this procedure, the first step is to adjust all ink keys of the press to produce the same ink film thickness. Next, printing wedge-shaped color solids as shown in Figure 1 result in different ink film thickness printed on the color control bars located on the top of the form. The wet densities of these ink films are measured after printing.

Twenty-four hours later, after inks are dried, the ink densities and colorimetric values are measured for the second time. The process inks densities with smallest color difference between printed and aim values are selected. Their wet densities then become the target wet ink densities used in subsequent press runs (Run 2).

Color gamut conformity verification

Following calibration, conformance is verified by calculating the color differences between printed and aim values. These differences are compared to the specified tolerances for the process ink solids and overprints. The tolerance according to *ISO 12647-2:2004/Amd 1:2007* is 5 ΔE^*_{ab} for the process ink solids.

If the colorimetric values of primary solids are within the specified tolerance, then the Run 2 calibration, which is to adjust TVI curves or grey production of the press, follows.

TVI method

TVI curves of cyan, magenta, yellow, and black are specified by the differences between input tone values and output tone values. The TVI calibration method is used to adjust achieved TVI values of the press to match the reference TVI aim values.

TVI aims

TVI values can be calculated from tristimulus values. Equations 3, 4, and 5 show the calculation of TVI curves from the reference printing condition.

For Magenta and Black printing colors:

$$\mathrm{TVI} = 100 \times \frac{(Y_p - Y_t)}{(Y_p - Y_s)} - TV_{Input} \qquad (3)$$

For the yellow printing color

$$\mathrm{TVI} = 100 \times \frac{(Z_p - Z_t)}{(Z_p - Z_s)} - TV_{Input} \qquad (4)$$

For the cyan printing color

$$\mathrm{TVI} = 100 \times \frac{(X_p - C \times Z_p) - (X_t - C \times Z_t)}{(X_p - C \times Z_p) - (X_s - C \times Z_s)} - TV_{Input} \qquad (5)$$

Where

X_p = X value of the paper

Y_p = Y value of the paper

Z_p = Z value of the paper

Y_t = Y value of the tint

X_t = X value of the tint

Z_t = Z value of the tint

X_s = X value of the solid

Y_s = Y value of the solid

Z_s = Z value of the solid

C = The value of 0.55 was picked for the constant in the cyan calculation.

Source: *ISO/TS 10128:2009, Graphic technology – Methods of adjustment of the colour reproduction of a printing system to match a set of characterization data*.

TVI calibration approach

In this research, Adobe Photoshop CS4 is used to apply TVI correction values to simulate Run 2. The graph below shows the workflow.

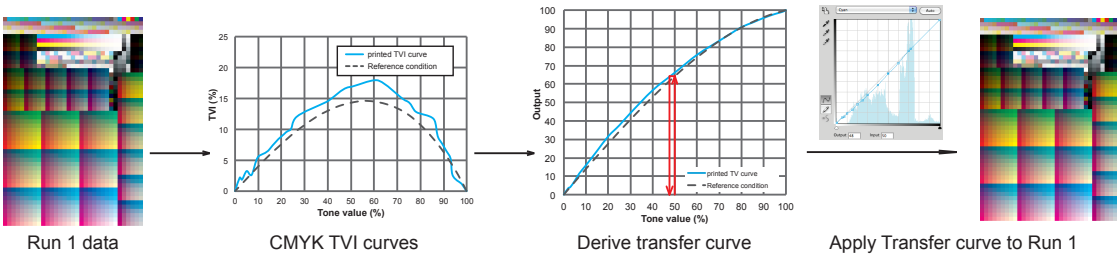

Figure 2. TVI calibration workflow

First, the TVI curves are calculated from the initial press (Run 1) characterization data. Then, transfer curves are derived from the relationship between the Run 1 tone value curves and the tone value curves of the reference printing condition. Figure 3 gives an example of deriving TVI transfer curves using both Microsoft Excel 2011 and Adobe Photoshop CS4, which is the approach used in this research.

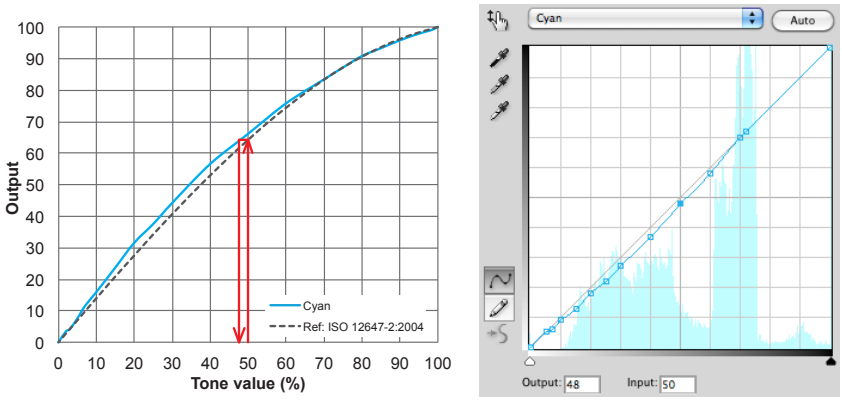

Figure 3. An example of the TVI calibration application

In this example, the 50% cyan tint of the reference condition will output the same value as the printed 48% cyan tint does. The input value 50% and output value 48% are then entered in the curve adjustment dialog box in Adobe Photoshop (as shown in Figure 3). The same approach is used to adjust from 0% to 100% tint area for cyan, magenta, yellow, and black tonalities.

TVI calibration conformity verification

The deviation tolerances between printed and aim TVI values at the mid-tone (40% or 50% tint) and shadow (75% or 80% tint) both establish the first requirement for TVI conformance. The tolerance values are listed in Table 3 according to *ISO 12647-2:2004, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes*.

Table 3. Deviation tolerances for TVI curves

Tone value of control patch	Deviation tolerance
40 or 50	4%
75 or 80	3%

The second TVI conformance requirement is mid-tone spread conformance. Mid-tone spread is specified to balance proportions of cyan, magenta, and yellow inks at the mid-tone area. The tolerance of mid-tone spread specified in *ISO 12647-2:2004* is 5%.

Grey reproduction method

According to *ISO/WD 12647-1:2011*, the grey reproduction is a set of colorimetric values of the print that appears as an achromatic color under a specified viewing condition.

The CIELAB values of predefined near-neutral triplets should match the reference CIELAB values with respect of ΔL^* and ΔC_h values. ΔL^* is used to adjust tone reproduction, and ΔC_h is used to adjust grey balance.

IDEAlliance G7 calibration method is a calibration approach to adjust the grey balance of the press. IDEAlink Curve 2 is common software to generate the transfer curves based on measurement values from the P2P test target (shown in Figure 4).

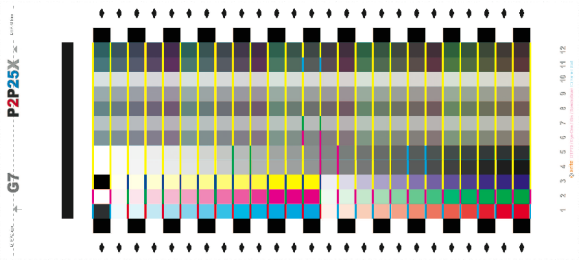

Figure 4. The P2P25x Target includes the K-only scale (column 4) and the CMY grey scale (column 5). Source: *G7 How to* (IDEAlliance, 2009)

Aims and calibration approach

IDEAlink Curve 2 is software used in this research to achieve the G7 calibration. It automatically calculates the calibration aims based on the measurement of the P2P25x

test target and then generates the tone correction values for cyan, magenta, yellow, and black.

Grey reproduction conformity verification

The substrate-corrected printing aims are applied to assess grey reproduction conformance. Equation 6 is used to compute aim values for near-neutral triplets from the reference dataset based on the paper color.

$$X_2 = X_1(1 + C) - X_{\min}C$$

$$C = \frac{X_{w2} - X_{w1}}{X_{w1} - X_{\min}} \qquad (6)$$

The tolerances for the grey conformance assessment are listed in Table 4, which is according to *Printing Conformance Assessment – Harmonizing Grey Reproduction and Tolerance* (Chung, R., 2011, March) and *Statistical Analyses of the IDEAlliance G7 Master Printer Database* (Chung, R. & Wang, Y., 2011, April).

Table 4. The tolerances used for grey conformance assessment

Near-neutral triplet	ΔL^*	ΔC_h
(25C, 19M, 19Y)	2.5	2.0
(50C, 40M, 40Y)	2.5	3.0
(75C, 66M, 66Y)	2.5	4.0

The Simulation Approach

Simulation is the imitation the appearance or character of a real thing, state of affairs, or process. Simulation can be used when a real system cannot be engaged.

The simulation approach used in this research is to simulate the behavior of a press system before and after a certain press calibration in order to minimize printing noise, in other words, to maintain press repeatability. Thus, the results are able to unveil the characteristics of a certain press calibration method imposed on either TVI or grey reproduction conformances.

An ICC profile is an essential tool in the simulation approach. The ICC profile works as a lookup table that contains a set of device-dependent values (e.g. CMYK) and another set contains device-independent values (e.g. CIEXYZ or CIELAB) (Fraser, B., Murphy, C., & Bunting, F, 2005, p. 100). The absolute colorimetric rendering intent function in assigning a profile can keep source paper color values and reproduce all the in-gamut colors.

Thus, if the data set of CGATS TR006 describes the current printing condition and an ICC profile is generated based on the data set, then the CIELAB values of a set of CMYK values can be obtained by assigning the profile using absolute colorimetric rendering intent. Accordingly, the colorimetric values of ink solids and near-neutral triplets can be obtained as well as TVI values.

Chapter 3

A Review of the Literature in the Field

This literature review begins with the introduction of standardization and its importance in industries and then follows press calibration and methods. The researcher also conducted some researches on the history of grey reproduction applications in halftone printing.

Standardization

Business is a bilateral practice. Manufacturers are taking all methods to satisfy different customers' demands and customers are always looking for manufacturers who have capabilities to meet their expectations.

Standardization can be an approach to link both manufacturers and customers. It is defined as "activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context" (*ISO/IEC GUIDE 2:2004 (E/F/R), Standardization and related activities – General Vocabulary*, p.4).

Standardization ensures that manufacturers meet their declared specification and deliver on their promise; on the other hand, it provides customers with a basis for selecting products.

The evidence of demands on setting standards for commodities can be found as early as the 13th century in England from Chapter thirty-five of the *Magna Carta* (1215):

> "Let there be one measure of wine throughout our whole realm; and one measure of ale; and one measure of corn, to wit, 'the London quarter'; and one width of cloth (whether dyed, or russet, or 'halberget'), to wit, two ells within the selvedges; of weights also let it be as of measures." (McKechnie, 1914)

This chapter confirmed the provisions of various ordinances and sought to regulate the sale of commodities, which not only overcame the inconvenience experienced by traders who were faced with various standards as they moved from one place to another, but also prevented frauds from being perpetrated on buyers due to ambiguous weights and measures.

Measures standardization continues the specification of components size, such as batteries, CDs, etc. It is undoubtedly promoting communications between industries.

With the advent of the scale-manufacturing era, process standardization becomes a key strategy that often leads a company to success.

The Coca-Cola Company, established in 1886, is operating in more than 200 countries and marketing nearly 500 brands and 3000 beverage products (The Coca-Cola

Company, 2011). They attribute these achievements to the Coca-Cola system, a management system that monitors and standardizes manufacturing processes that concentrate production to bottling and distribution.

According to the Coca-Cola company's website, the latest Cora-Cola management system is called Coca-Cola Operating Requirements (KORE). It manages bottling operations and across supply chain, defines problem solving methods and tools to drive consistent quality with improvements, and incorporates with Hazard Analysis and Critical Control Points (HACCP) (The Coca-Cola Company, 2011).

HACCP principles are specified in *ISO 22000:2005, Food safety management systems – Requirements for any organization in the food chain*. According to this ISO standard, conducting a hazard analysis assists in organizing the knowledge required to establish an effective combination of control measures.

Due to this advanced management system, the whole manufacturing process is standardized to guarantee a high standard of product safety, quality, and consistency, which is directly linked to steady increases since 2007 and a 92.6 rating in 2010, according to its Company Global Package Quality Index (The Coca-Cola Company, 2011).

Thus, standardization can maintain product quality while simultaneously improving internal efficiencies, thus increasing the printer's profitability.

International organization for standardization (ISO)

ISO (International Organization for Standardization) is a global non-governmental organization that promotes international standardization. It "identifies which international standards are required by business, government, and society, develops them in partnership with the sectors that will put them to use, adopts them by transparent procedures based on national, multi-stakeholder input, and delivers them to be implemented worldwide." (ISO Central Secretariat, 2010, p.1)

Since each ISO member represents a certain country or region and their inputs "come from those closest to the needs for the standards and also to the results of implementing them" (ISO Central Secretariat, 2010, p.1), ISO standards are widely respected and accepted internationally. In other words, being in compliance with ISO standards can help manufacturers reduce regional technical barriers and provide them access to global markets.

There are many ISO printing standards, e.g. ISO 12647, ISO 15339, ISO 15311, etc. Generally speaking, printing standards specify inks, paper and process control parameters in colorimetric terms (D. Q. McDowell, 2007, p.194).

Press calibration

Calibration is defined as:

> "Operations that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication." (*JCGM 200:2008 (E/F), International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*, p.28)

There are two press runs in press calibration. One is to adjust color gamut and the other is to adjust TVI or grey reproduction.

According to McDowell (2007), reference characterization regarded as an aim printing conditions would be a trend in the printing industry (p.193). Printing aims with the respect to color gamut, TVI curves, and grey reproduction are extracted from reference printing conditions and regarded as aim values for press calibration.

In today's printing industry, traditional halftone films are gradually replaced with digital data. Inks, papers, presses, and printing processes vary between different companies. In order to compensate for these variances, modification of digital data is applied.

Characterization, or profiling, "is the process of recording a device's behavior into a profile" (B. Fraser, C. Murphy, & F. Bunting, 2005, p. 114). It can define the relationship between input CMYK digital values and colorimetric values, which serves as a color exchange space.

Under this context, the use of a Look-Up Table from CMYK to CIELAB is able to represent a virtual printing condition whereby color repeatability is assumed and no printing drifts occur (Chung, personal communication, 2011).

Press calibration methods

According to McDowell (2007), ISO Technical Committee 130 "Graphic technology" identified three general methods to accomplish press calibration (p.193).

These three methods are use of (1) tone value increase (TVI), (2) near-neutral scales (grey balance), and (3) CMYK-to-CMYK transform (device link), which are described in *ISO/TS 10128:2009, Graphic technology – Methods of adjustment of the colour reproduction of a printing system to match a set of characterization data*, which is also detailed in Chapter 2 – Theoretical Basis.

These three calibration methods are globally used in the printing industry. As the results shown in *Printing Standards: A 2010 Survey Report* (Chung, R. & Jensen, S., 2011, January), there were 47% printers using grey balance method, 32% using TVI

method and 11% using CMYK-to-CMYK transform methods among a total of 90 printing companies while 79% of them from US (p.12).

TVI and grey reproduction calibration methods

It is noteworthy that as described in *ISO/TS 10128:2009*, two of the calibration methods – the TVI and grey balance methods – use tone-value correction curves to adjust the press.

The TVI method adjusts four one-dimensional tone-value curves to match the specified curves. The reference TVI curves and tolerances are defined in *ISO 12647-2:2004, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes*.

The grey balance method is to achieve the colorimetric match between near-neutral scales values and that of the reference values.

As stated in *Gray Balance Control in Offset Printing with the ECI/bvdm Gray Control Strip*, the colorimetric values of near-neutral scales are extracted from characterization data or ICC profiles (p.4).

Until now there were no published grey reproduction aim values or tolerances in the ISO/TC 130 standards.

The history of grey balance and its applications in halftone printing

G*rey balance* is not a new term in the printing industry. Neugebauer (1952, October) illustrated the theoretical requirement to achieve neutral grey in halftone printing using the Neugebauer equations. Archer (1954) stated that a four-color printing system should be adjusted to produce a neutral scale without black first and then the black can replace the neutral component in the reproduction in his paper *Reproduction of Gray with Halftones* (p. 180).

Moreover, Archer and Elyjiw (1972) demonstrated a method using the *RIT Gray Balance Chart* and the density of original against that of a reproduction diagram to achieve grey balance and tone reproduction in their paper *A Practical Approach to Gray Balance and Tone Reproduction in Process Color*. Today's G7 calibration method is quite close to this method (IDEAlliance, 2009).

The journey of *grey* exploration never ends. Lo and Chiang (1998) pointed out that grey balance was an important parameter in the characterization of multi-colored printing process (p.253). Enoksson and Ullberg (2008) found that grey balance could be used as a control parameter of sheet-fed printing.

Furthermore, the proposal of grey balance aim values and tolerance appeared on the latest working draft *ISO/WD 12647-2:2010, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes*.

McDowell (2007) assumed that the grey balance method had advantages over the TVI approach, especially when the reference characterization data could produce good grey balance and grey balance is used in process control.

International Color Consortium and the ICC profile

The International Color Consortium (ICC) was established in 1993 for the purpose of creating, promoting, and encouraging the standardization and evolution of an open, vendor-neutral, cross-platform color management system architecture and components (International Color Consortium, 2011). The founding members of this consortium were Adobe System Inc., Agfa-Gevaert N.V., Apple Computer, Inc., Eastman Kodak Company, FOGRA (Honorary), Microsoft Corporation, Silicon Graphics, Inc., Sun Microsystem, Inc., and Taligent, Inc (International Color Consortium, 2004).

With the effort of this cooperation, the ICC profile was developed to maintain consistency in imagery viewed, displayed, or printed on various devices, such as scanners, monitors, or printers. The ICC profile describes color characteristics of a device. As illustrated by Wallner (2000, April, p. 6), the file contains text descriptions of specific devices and their settings along with numeric data describing how to transform the device's color values. The numeric data includes matrices and tables that are used to convert the device's color results to a common color space, or the profile connection space (PCS) using a color management module (CMM). The PCS is a device-

independent color space which is currently defined by either CIELAB or CIEXYZ color space.

According to *Toward Better Image Reproduction in Offset*, if the input and output transforms are based on the same PCS definition, they can be paired arbitrarily and will yield consistent and predictable results when applied to color values (p. 16). Thus, the ICC profile enables the optimization of printing simulations (p. 13).

Conclusion

Printing standardization benefits both printers and buyers. There is a trend that a reference printing condition that can be used to extract reference aims for color gamut, TVI, and grey reproduction values. Press calibration is a process to modify input digital data to match those reference values using the TVI, grey reproduction, or CMYK-to-CMYK transform method. Both TVI and gray reproduction methods adjust input digital data through tone-value correction curves. So far, the TVI aim values and tolerance are well defined in ISO standards, while those of grey reproduction are not, although *grey* has a long history of application in printing. Due to the characteristics of the ICC profile structure, an ICC profiles can be used to simulate a consistent printing condition.

Chapter 4

Research Questions

Color gamut, tonality, and neutrality are three requirements in press calibration.

There are only two press runs conducted in press calibration. Run 1 aims to correct ink solids to the printing aims within the specified tolerance ($5\Delta E^*_{ab}$). Run 2 either adjusts tonality using the TVI method or adjusts neutrality using the grey reproduction method.

The question is that "will the two press calibration runs be able to achieve the three requirement aims? In the other words, (1) will the TVI method be able to achieve grey reproduction requirements within a specified tolerance, and (2) will the grey reproduction method be able to achieve TVI aims within a specified threshold?"

Chapter 5

Methodology

This research aims to compare the conformance of two press calibration methods, the TVI and grey balance methods. Three requirements were assessed in this research: (1) colorimetric values of process ink solids, (2) TVI curves, and (3) grey reproduction of the near-neutral triplets (25C19M19Y, 50C40M40Y, and 75C66M66Y).

Two cases were studied in this research. Case 1 was a PSA test run using Sappi Flo paper and Case 2 was a Printing Standard Audit (PSA) submission. Run 1 and 2 were two printing conditions described in each case. Run 1 was an initial printing condition. In this printing condition, colorimetric values of ink solids were adjusted within specified tolerances. Run 2 was a calibrated printing condition based on Run 1. Run 2 was adjusted by either TVI or grey reproduction method.

This chapter details information on procedures, equipment, and materials that were used in this research.

Procedures

The following paragraphs describe the procedures used in this research. There are generally three steps in each case: Step 1 describes the Run 1 printing conditions; Step 2 describes TVI-based calibration workflow; and Step 3 describes a grey reproduction based calibration workflow.

Step 1: Description of Run 1 printing condition

Three aspects were evaluated in the Run 1 printing condition: (1) color gamut, (2) TVI curves and its mid-tone spread, and (3) grey reproduction. The reference aims for grey reproduction were calculated based on the color of substrates. Equation 6 in Chapter 2 was used to compute the reference aims for grey reproduction.

Step 2: TVI-based calibration workflow

Step 2 calibrated the press using the TVI calibration method. There were three parts in this workflow, (1) TVI based calibration, (2) Verification of TVI based calibration via simulation, and (3) assessment of grey reproduction conformance.

a) TVI-based calibration

Figure 5 shows the TVI-based calibration workflow. First, Run 1 TVI curves were extracted from Run 1 characterization data set. Second, the four-color TVI transfer curves

were generated using ray-tracing method. Third, the generated TVI transfer curves were applied to Run 1 characterization data in Photoshop, which was the simulated TVI-based calibration result.

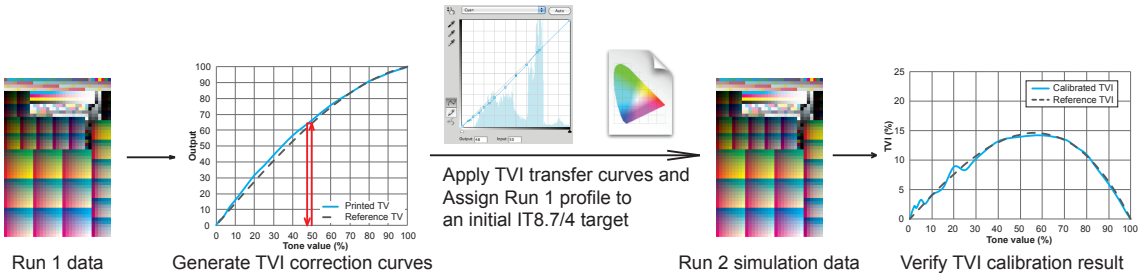

Figure 5. The TVI-based calibration workflow

b) Verification of TVI-based calibration via simulation

CHROMix ColorThink 3.0 pro was used to obtain the calibration results under absolute colorimetric rendering intent.

Two TVI requirements were assessed in the TVI-based calibration verification. First, the deviation values were assessed between the obtained values and reference aims at the 50% and 80% tint. Second, the mid-tone spread was assessed.

If either of the two requirements was not within the specified tolerances, then redo the TVI-based simulation.

c) Assessment of grey reproduction conformance

Figure 6 shows the assessment workflow for grey reproduction conformance. First, an initial P2P25x test target was applied with the generated TVI transfer curves in Photoshop. Second, CHROMix ColorThink 3.0 pro was used to obtain the calibration data. Third, the values of ΔL^* and ΔC_h of the three near-neutral triplets (25C19M19Y, 50C40M40Y, and 75C66M66Y) were assessed.

Figure 6. Grey reproduction conformance assessment workflow

Step 3: G7-based calibration workflow

Similarly, there were three steps in the G7-based calibration workflow.

a) G7-based calibration

Figure 7 shows the G7-based calibration procedure. First, Run 1 profile was assigned to an initial P2P25x test target. Second, Curve 2 was used to generate G7 transfer curves.

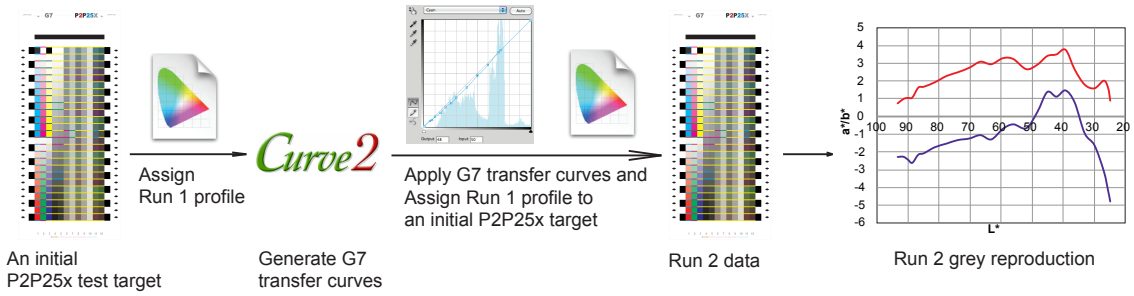

Figure 7. G7-based calibration workflow

b) Verification of G7-based calibration via simulation

The values of ΔL^* and ΔC_h of the three near-neutral triplets (25C19M19Y, 50C40M40Y, and 75C66M66Y) were assessed to verify the G7-based calibration results. If either of the grey reproduction requirements was not within specified tolerances, then the G7-based calibration would be re-conducted.

c) Assessment of TVI conformance

Figure 8 shows TVI conformance assessment workflow. First, an initial IT8.7/4 characterization target was applied with G7 transfer curve in Photoshop. Second, Run 1 ICC profile was assigned to the IT8.7/4 target with absolute rendering intent. Third, CHROMix ColorThink 3.0 Pro was used to extract the TVI values. Forth, TVI conformance was assessed with the respect to (1) TVI values at 50% and 80% tint area and (2) the mid-tone spread.

Figure 8. TVI conformance assessment of the G7-based calibration method

Equipment and materials

This section discusses materials used in Run 1 condition of the two cases and equipment used to collect the press run data, to analyze the data, and to conduct color management for the data.

Materials used in Run 1 condition

In Case 1, Sappi Flo Gloss 80# Text and Biolocity ink were used. The press runs were conducted on a Heidelberg Speedmaster SM 74.

Case 2 is a sheetfed offset lithographic submission for PSA project. ISO Type 1 paper was used.

Equipment and materials used for data collection

ProfileMaker 5 Measure Tool (Version 5.0.10) was used to collect measurement data for Run 1. Spectral data from the printed sheets was collected using an X-Rite i1 iSis spectrophotometer under white backing measurement conditions and then converted into colorimetric values with D50 illuminant, 2-degree standard.

ProfileMaker 5 was used to generate Run 1 ICC profile. The parameters' settings are shown as below:

- Profile Size: Large
- Perceptual Rendering Intent: Paper-colored gray
- Gamut Mapping: Logo Colorful
- Separation: Offset, GCR2

Applications used for data analyses

IDEAlink Curve 2 software was used to generate G7 correction curves. CHROMix ColorThink 3.0 Pro software was used to read the image data. Microsoft Excel 2011 was used to analyze the data.

Applications used for color management

ProfileMaker 5 (Version 5.0.10) was used to make ICC profiles and Adobe Photoshop CS4 was used to apply the tonality correction curves.

Chapter 6

Results

This chapter shows the results based on the preceding methodology described in Chapter 5. Run 1 printing conditions (the initial printing conditions) of the two cases are described first and then followed by TVI and G7 calibration results and assessments according to reference aims. The reference aims of color gamut, TVI values, and grey reproduction of near-neutral triplets, are extracted from CGATS TR006.

Case 1

The following paragraphs describe the Run 1 printing condition assessment results, TVI based calibration results, and G7 based calibration results in Case 1.

Run 1 printing condition

Color gamut, TVI curves, and grey reproduction are the three aspects assessed in the Run 1 printing condition.

a) Color gamut

The color of paper white and process ink solids are used to describe the corner points of the color gamut. As seen in Table 5, the color of paper is within the specified tolerance (+/-3 for L^* and +/-2 for a^* and b^*), and the color difference of the cyan, magenta, yellow, and black solids are also within the specified 5 ΔE^*_{ab} tolerance. Thus, the color gamut of Case 1 is within the requirements specified in *ISO 12647-2:2004/Amd 1:2007*.

Table 5. The color gamut of the Run 1 printing condition

	CGATS TR006			Run 1			
	L^*	a^*	b^*	L^*	a^*	b^*	ΔE^*_{ab}
Paper	95.0	0.0	-2.0	93.1	0.6	-2.4	2.0
Cyan	55.0	-37.1	-50.0	56.9	-33.5	-49.5	4.2
Magenta	47.9	74.1	-3.0	49.5	73.8	-2.3	1.7
Yellow	88.9	-5.0	93.2	88.1	-5.2	90.8	2.6
Black	15.0	0.2	-0.1	17.1	0.8	0.9	2.5

b) TVI curves and mid-tone spread

Figure 9 shows the TVI curves of the Run 1 printing condition in Case 1. As seen from the graphs, TVI curves of the Run 1 printing condition is very close to aim TVI curves.

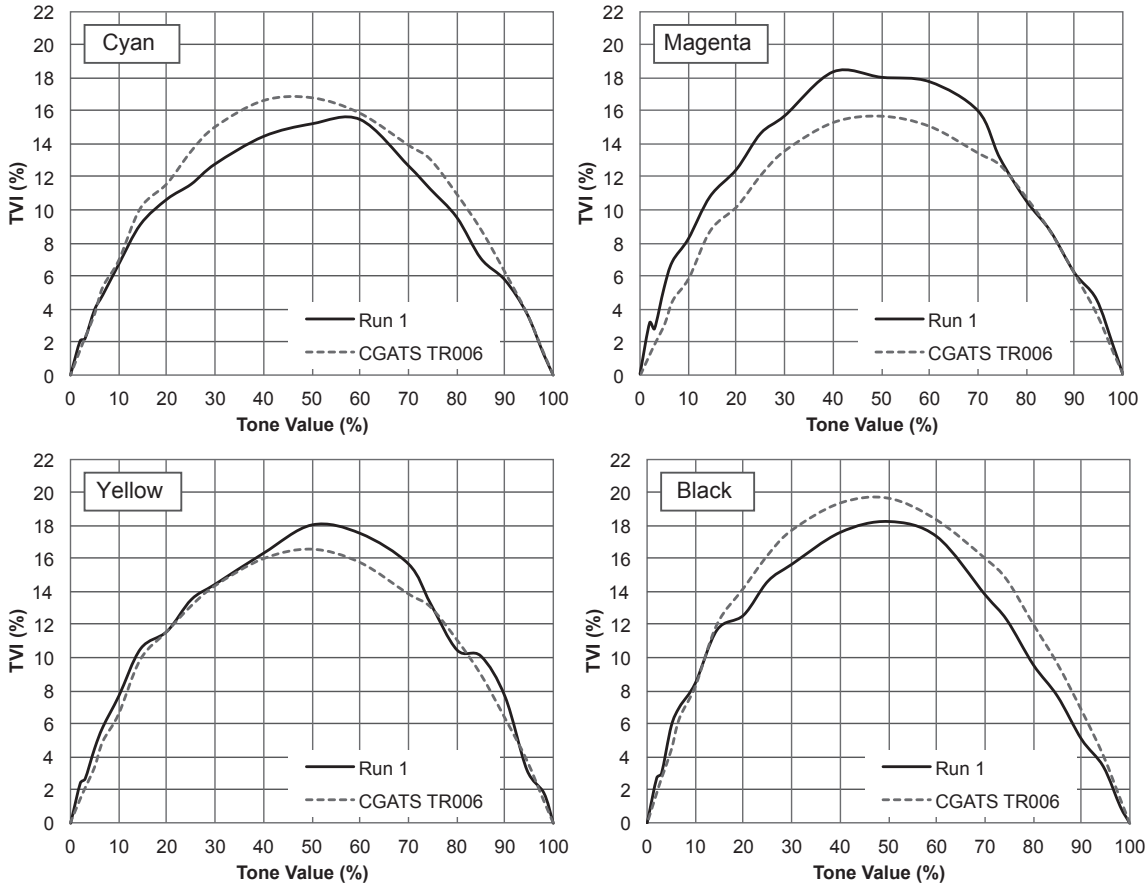

Figure 9. TVI curve of Run 1 in Case 1

According to *ISO 12647-2:2004*, the TVI values at mid-tone and shadow are the two requirements for TVI conformance. Table 6 lists the deviation values between the printed TVI values and the reference values from CGATS TR006 data set. The results indicate that the TVI values of Run 1 conform to the standard.

Table 6. The deviation at 50% and 80% tint areas between the printed TVI values and aim values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

Tone value of control patch	Run 1_C	Run 1_M	Run 1_Y	Run 1_K	Tolerance
50	2	2	1	2	4
80	1	1	0	2	3

The mid-tone spread is another requirement for the TVI conformance assessment. It is used to indicate the press grey balance of cyan, magenta, and yellow at the mid-tone area. Table 7 shows the mid-tone spread value of the Run 1 printing condition in Case 1. According to the specified tolerance (5%), the maximum mid-tone spread of the Run 1 TVI curves are also within the tolerance.

Table 7. The mid-tone spread value of the Run 1 printing condition in Case 1. The listed tolerances are specified in *ISO 12647-2:2004*.

	C	M	Y
Aim Values	17	16	17
Measurements	15	18	18
Differences	-2	2	1
Mid-tone spread	4		
Tolerance	5		

c) Grey reproduction

Since grey reproduction is affected by the color of paper white, the substrate-corrected colorimetric aims (SCCA) are used. Equation 6 listed in Chapter was used to calculate SCCA for the three near-neutral triplets, (25C, 19M, 19Y), (50C, 40M, 40Y), and (75C, 66M, 66Y).

Figure 10 shows the grey reproduction of Run 1 condition against the reference aims by plotting tone value versus a^*/b^*. As seen from the figure, the printed b^* values follows between than a^* values before mid-tone area.

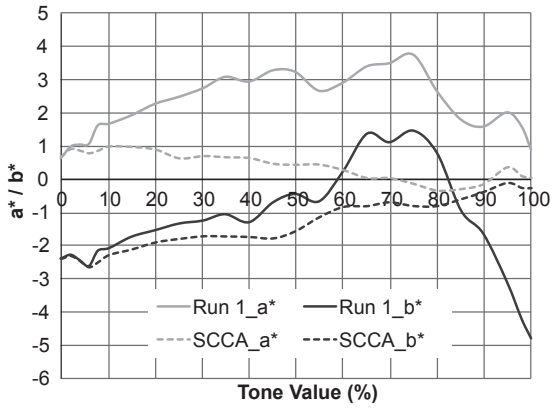

Figure 10. The grey reproduction conformance of the Run 1 printing condition in Case 1

Table 8 lists the grey reproduction conformance assessment results for the three near-neutral patches. As seen from the results, all the printed L^* values are within the specified tolerances. The ΔC_h values of (25C, 19M, 19Y) and (50C, 40M, 40Y) are within the tolerance, but the ΔC_h value of (75C, 66M, 66Y) is out of tolerance.

Table 8. The assessment of the Run 1 grey reproduction conformance

	SCCA			Run 1			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.1	0.6	-2.4	93.1	0.6	-2.4	0.0	-	-	0.0	-	-
25C19M19Y	74.0	0.6	-1.8	74.0	2.5	-1.3	0.0	2.5	Yes	2.0	2.0	Yes
50C40M40Y	56.5	0.4	-1.6	56.1	3.2	-0.4	0.5	2.5	Yes	3.0	3.0	Yes
75C66M66Y	38.9	-0.1	-0.8	39.2	3.8	1.5	0.4	2.5	Yes	**4.5**	4.0	**No**

d) Summary of the Run 1 printing condition in Case 1

In Case 1, the color of paper white and process ink solids are within the specified tolerance when compared to the reference printing condition (CGATS TR006).

The TVI values of the Run 1 printing conditions also conform to the reference printing condition based on the assessments of TVI curves and the mid-tone spread.

The ΔL^* and ΔC_h values of the three near-neutral patches are the requirements for grey reproduction conformance assessment. The results show that only the ΔC_h value of (75C, 66M, 66Y) is out of the tolerance.

Thus, the question is "whether grey reproduction results will be in conformance when the TVI curves are adjusted closer to the reference aims via simulation approach."

TVI-based calibration results

The Run 2 printing condition is the TVI-based calibration resulting from the Run 1 printing condition via simulation.

There are three parts shown the TVI-based calibration result. First, it shows the transfer curves used to adjust the press via simulation. Second, it shows the verification of the TVI-based calibrated result by comparing the printed TVI curves to the reference aims. Third, it shows the assessment outcome on the grey reproduction conformance of the three near-neutral patches.

a) TVI-based calibration transfer curves

The transfer curves are used to adjust the press. In a real printing workflow, they are applied in the RIP to make curve-adjusted printing plates. In this research, the transfer curve values were applied in Photoshop to simulate a calibrated Run 2 printing condition. Table 9 shows the transfer curves used in the TVI based calibration in Case 1.

Table 9. The transfer curve values used in TVI based calibration

	C	M	Y	K
100	100	100	100	100
98	98	99	98	98
95	95	95	96	95
90	90	90	88	92
85	87	85	85	87
80	82	80	81	82
75	77	75	75	80
70	72	68	68	73
60	60	58	58	61
50	52	48	49	52
40	42	38	40	42
30	32	28	30	31
25	27	24	25	26
20	21	18	20	22
15	15	15	15	15
10	10	9	10	10
5	5	5	5	5
0	0	0	0	0

b) TVI-based calibration results verification

The TVI curves of the TVI-based calibrated results are shown in Figure 11. The solid lines with circles indicate the Run 2 printing condition. The solid lines represent the

Run 1 printing condition. Further, the dotted lines are the TVI curves of the reference printing condition.

As seen from the figure, the TVI curves of Run 2 are closer to the reference aims after TVI-based calibration. It is in conformance.

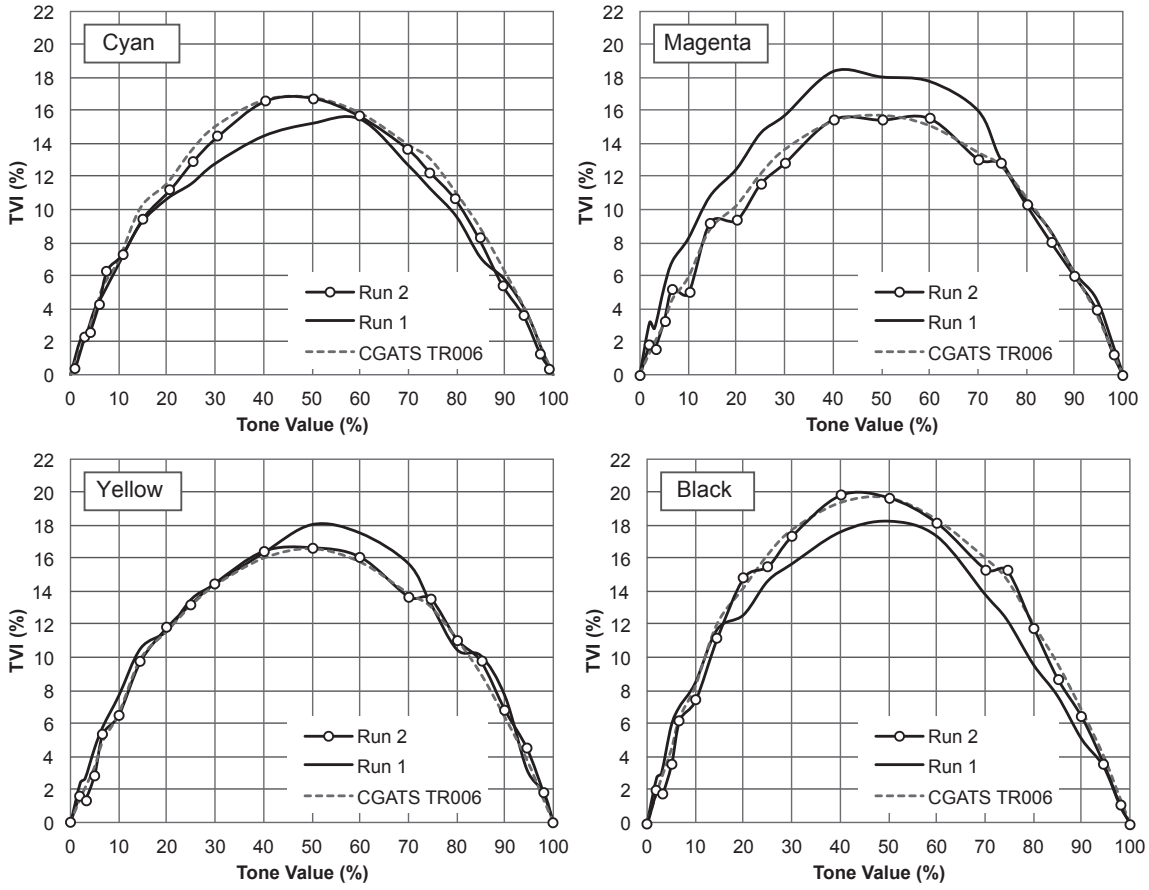

Figure 11. The TVI curves of the TVI-based calibration in Case 1

c) Assessment of grey reproduction conformance

In the Run 1 printing condition, only the ΔC_h value of (75C, 66M, 66Y) does not conform to the reference aims. Thus, the question is "whether the grey reproduction will achieve full conformance after the TVI-based calibration results."

Figure 12 shows the TVI-based calibration results. The solid lines with circles show Run 2 grey reproduction performance, the solid lines represent Run 1 grey reproduction, and the dotted lines are the substrate-corrected grey reproduction aims.

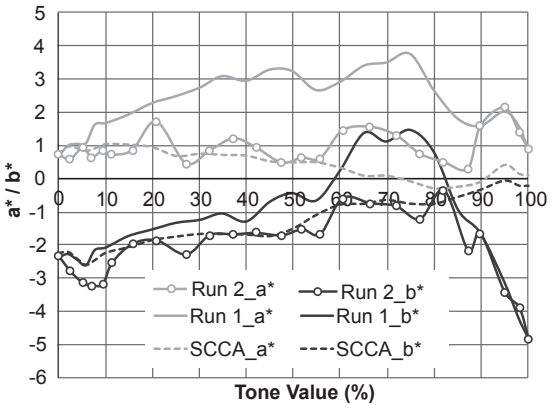

Figure 12. The grey reproduction of the TVI-calibrated Run 2 condition

As seen from the graph, the grey reproduction conformance of the Run 2 printing condition is closer to the reference aims. However, no adjustments are imposed on the three-color-overprint solids.

Table 10 lists the ΔL^* and ΔC_h conformance assessment results of the three near-neutral patches. As seen from the table, all the requirements are within the specified tolerance.

Table 10. The grey reproduction conformance assessment of the TVI-calibrated Run 2 printing condition

	SCCA			Run 2			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.1	0.6	-2.4	93.1	0.6	-2.4	0.0	-	-	0.0	-	-
25C19M19Y	74.0	0.6	-1.8	74.2	0.5	-2.3	0.1	2.5	Yes	0.5	2.0	Yes
50C40M40Y	56.5	0.4	-1.6	56.1	0.6	-1.5	0.4	2.5	Yes	0.2	3.0	Yes
75C66M66Y	38.9	-0.1	-0.8	39.6	0.8	-1.2	0.8	2.5	Yes	1.0	4.0	Yes

d) Summary of TVI-based calibration results in Case 1

After the press calibration via simulation approach, the results show that the TVI-based calibration not only improves the TVI conformance but also adjusts the grey reproduction from non-conforming to conforming results.

G7-based calibration results

The G7 calibration method is an approach to adjust grey reproduction of the press.

There are three sections in this part. The first section shows the transfer curves used in the G7-based calibration simulation. The second section verifies that the grey

reproduction is in conformance after using the G7-based calibration approach. The third section assesses the TVI curves conformance of the G7-based calibration results.

a) G7 based calibration transfer curves

The transfer curve values used in the G7-based calibration in Case 1 were generated by IDEAlink Curve 2, which are displayed in Table 11.

Table 11. The transfer curve values used in the G7-based calibration in Case 1

Tone value (%)	C	M	Y	K
100	100	100	100	100
90	91	89	96	92
80	82	80	82	84
70	72	69	70	73
60	61	57	58	62
50	52	47	48	52
40	42	37	40	42
30	32	28	31	32
20	22	18	21	21
10	11	9	10	10
0	0	0	0	0

Most of the values are close to the transfer curve values applied in the TVI-based calibration, except the value at 90% tint area. In the TVI based calibration approach, 88% is used as the output value for 90% tint area, while 96% is used as the output value in the G7-based calibration approach.

b) G7 based calibration verification

IDEAlink Curve2 software is used to calibrate the Run 1 printing condition according to the G7 press calibration method. Figure 13 shows the grey reproduction conformance of G7 based calibration results.

The solid lines with circles represent the Run 2 printing condition, the solid lines indicate the Run 1 printing condition, and the dotted lines are the substrate-corrected grey reproduction aims.

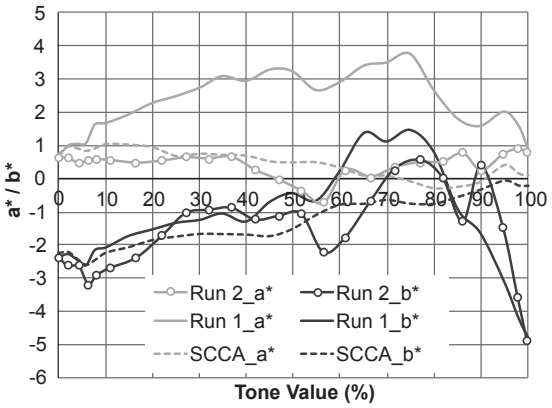

Figure 13. The grey reproduction conformance of the G7-calibrated results in Case 1

Table 12 lists the grey reproduction conformance results. As seen from the table, all values are within the specified tolerance.

Table 12. The assessment of the grey reproduction conformance of the G7-calibrated results

	SCCA			Run 2			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.3	0.7	-2.2	93.3	0.7	-2.3	0.0	-	-	0.0	-	-
25C19M19Y	74.2	0.7	-1.7	73.7	0.7	-0.9	0.1	2.5	Yes	0.8	2.0	Yes
50C40M40Y	56.6	0.5	-1.5	56.4	0.0	-0.7	0.6	2.5	Yes	0.9	3.0	Yes
75C66M66Y	38.9	-0.1	-0.7	39.4	0.4	0.5	0.3	2.5	Yes	1.3	4.0	Yes

c) Assessment of TVI conformance

In the Run 1 printing condition, all the TVI curves are within the specified tolerance. Thus, when the G7 calibration method has adjusted the grey reproduction within the tolerance, what influences will be imposed on the TVI curves.

Figure 14 shows the TVI conformance of the Run 2 printing condition. The solid circle lines represent Run 2 printing condition, the solid lines show the Run 1 printing condition, and the dotted lines are the reference printing aims.

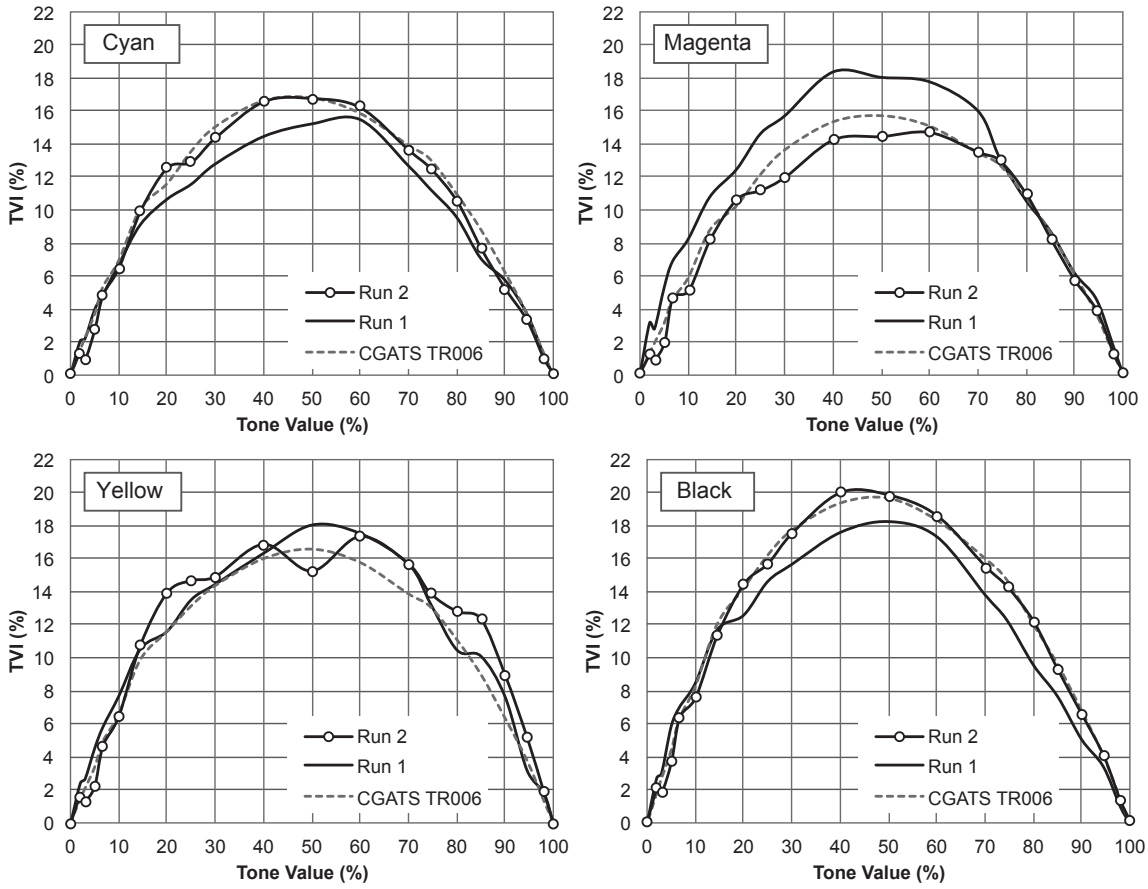

Figure 14. The TVI conformance of the G7-calibrated Run 2 printing condition

Table 13 shows the TVI conformance assessment at mid-tone (50%) and shadow (80%) areas. As seen from the table, all the values are within the tolerance.

Table 13. The deviation values at 50% and 80% tint area between the obtained TVI values and those values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

Tone value of control patch	C	M	Y	K	Tol.
50	0	2	2	0	4
80	1	0	2	0	3

Table 14 lists the mid-tone spread value of Run 2 printing condition. The value of 2 indicates that the mid-tone spread of Run 2 is within the specified tolerance.

Table 14. The deviation values at 50% and 80% tint between the printed TVI values and aims values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

	C	M	Y
Aim Values	17	16	17
Measurements	17	14	15
Differences	0	-2	-2
Mid-tone spread	2		
Tolerance	5		

d) Summary of G7-based calibration results in Case 1

In conclusion, the results indicate that the G7 calibration method corrects the grey reproduction of the press and meanwhile it adjusts the TVI curves to achieve better conformance.

Case 2

The data of Case 2 collects from one of the PSA submissions. The following paragraphs start with the Run 1 printing condition assessment, and then the TVI-based calibration assessment, and finally the G7 base calibration assessment results.

Run 1 printing condition

As illustrated in Case 1, color gamut, TVI curves, and grey reproduction are the three essential aspects in the Run 1 printing condition. The assessment results of these three elements are discussed in Case 2 Run 1 printing condition as well.

a) Color gamut

The corner points of color gamut in Run 1 printing are listed in Table 15. Compared with the reference aims, the process ink solids are in conformance.

Table 15. The color gamut of the Run 1 printing condition in Case 2

	CGATS TR006			Run 1			
	L^*	a^*	b^*	L^*	a^*	b^*	ΔE^*_{ab}
Paper	95.0	0.0	-2.0	93.4	0.0	0.5	2.9
Cyan	55.0	-37.1	-50.0	53.5	-37.4	-49.2	1.7
Magenta	47.9	74.1	-3.0	48.3	75.1	-3.3	1.1
Yellow	88.9	-5.0	93.2	89.3	-7.4	90.5	3.6
Black	15.0	0.2	-0.1	11.4	1.0	2.3	4.4
Red	47.4	68.3	48.8	47.8	69.1	43.1	5.7
Green	50.1	-68.4	25.0	47.5	-71.0	24.7	3.7
Blue	24.1	17.2	-46.1	21.4	20.5	-48.3	4.8

b) TVI curves and mid-tone spread

The TVI curves of Run 1 condition in Case 2 are plotted in Figure 16. As seen from the graphs, the mid-tone deviation of black ink at mid-tone region is large.

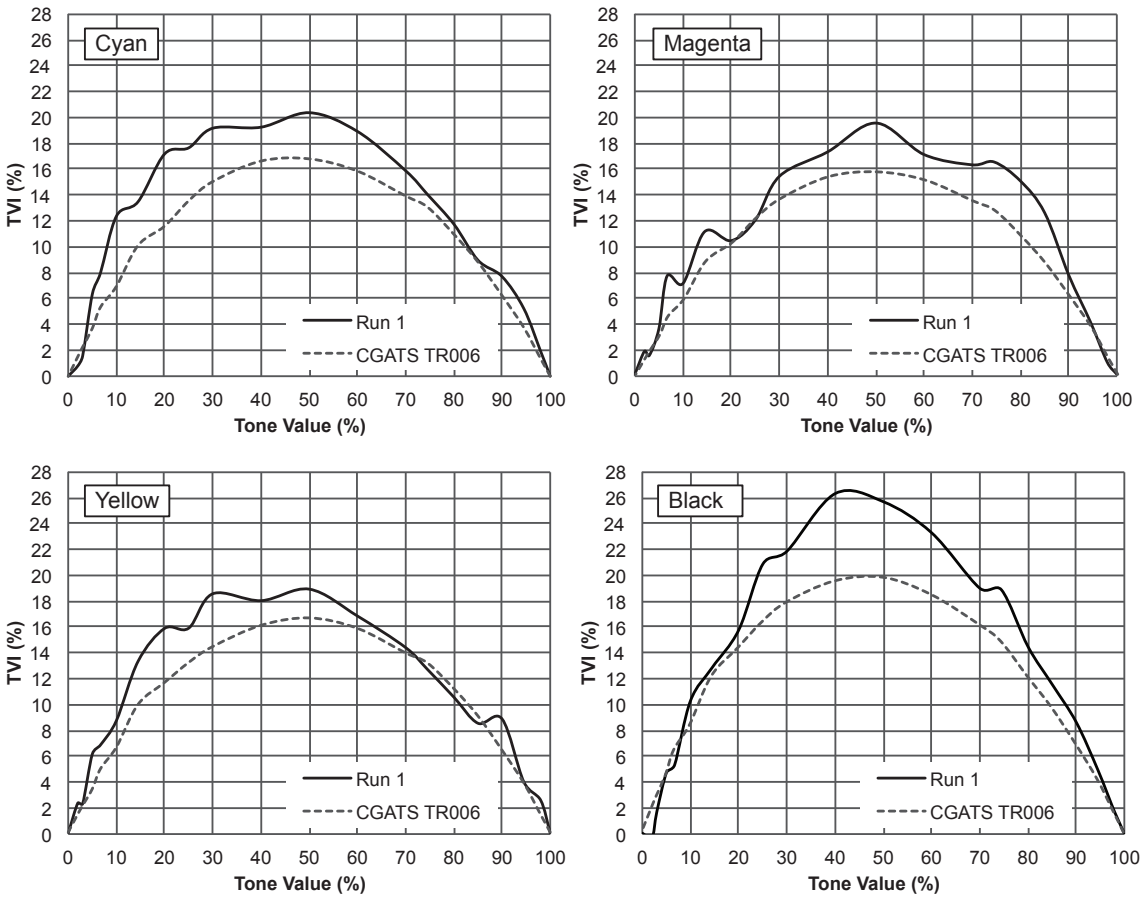

Figure 15. The TVI curves of the Run 1 printing condition in Case 2

Table 16 lists the deviation values of the press at 50% and 80% tint areas. The results indicate that the TVI curves of the Run 1 printing condition are out of conformance.

Table 16. The deviation values at 50% and 80% tint area between the obtained TVI values and those values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

Tone value of control patch	Run 1_C	Run 1_M	Run 1_Y	Run 1_K	Tolerance
50	3	3	2	**6**	4
80	1	**4**	0	2	3

The mid-tone spread value of the Run 1 printing condition is listed in Table 17. The value shows that it is in conformance.

Table 17. The maximum mid-tone spread of Run1 in Case 2

	C	M	Y
Aim Values	17	16	17
Measurements	20	19	19
Differences	3	3	2
Mid-tone spread	1		
Tolerance	5		

c) Grey reproduction

Grey reproduction of the Run 1 printing condition is shown in Figure 16. The solid lines represent printed grey reproduction and the dotted lines indicate the substrate-corrected grey reproduction aims. The figure shows large discrepancy occurs at three-quarter-tone region.

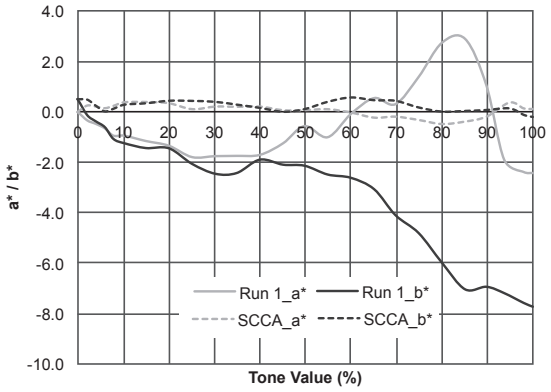

Figure 16. The grey reproduction of the Run 1 printing condition in Case 2

As seen from the conformance assessment results listed in Table 18, the grey reproductions of the near-neutral patch (50C, 40M, 40Y) is in conformance, and the patches of (25C, 19M, 19Y) and (75C, 66M, 66Y) are out of conformance.

Table 18. The assessment of the grey reproduction of the Run 1 printing condition in Case 2

	SCCA			Run 1			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.4	0.0	0.5	93.4	0.0	0.5	0.0	-	-	0.0	-	-
25C19M19Y	74.3	0.1	0.4	72.9	-1.8	-2.1	1.3	2.5	Yes	**3.1**	2.0	**No**
50C40M40Y	56.7	0.1	0.1	54.6	-0.6	-2.1	2.1	2.5	Yes	2.3	3.0	Yes
75C66M66Y	39.0	-0.3	0.2	35.3	1.4	-4.8	**3.7**	2.5	**No**	**5.3**	4.0	**No**

d) Summary of the Run 1 printing condition in Case 2

In Case 2, Run 1 is printed on an ISO-compliant Type 1 paper. The colorimetric values of the process ink solids conform to the reference aims extracted from CGATS TR006. Both the TVI and grey reproduction of the Run 1 printing condition are out of conformance.

The following paragraphs show the results after TVI and grey reproduction adjustments based on the Run 1 printing condition. The question is "whether either of the methods would correct the press to achieve full conformance."

TVI-based calibration results

Three sections are described in the following paragraphs. The first section shows the transfer curves used in the TVI-based calibration via simulation approach. The second section verifies whether the TVI curves conformance to the reference aims. The third section assesses the grey reproductions of the three near-neutral patches based on TVI calibration results.

a) TVI-based calibration transfer curves

The transfer curves used in the TVI-based calibration in Case 2 are shown in Table 19. They were applied in Photoshop CS 4 to simulate a calibrated Run 2 printing condition.

Table 19. The transfer curves used in the TVI-based calibration approach in Case 2

Tone value (%)	C	M	Y	K
100	100	100	100	100
98	93	98	98	98
95	92	95	95	91
90	89	84	88	88
85	85	79	85	83
80	79	74	80	74
75	74	72	75	72
70	68	68	70	65
60	56	58	59	53
50	47	47	48	44
40	38	39	38	36
30	28	29	28	26
25	21	25	24	23
20	17	20	17	19
15	13	14	14	15
10	9	10	9	10
5	5	5	5	5
0	0	0	0	0

b) TVI-based calibration verification

Figure 17 shows the TVI curves of the TVI-based calibration results. The solid lines with circles indicate Run 2 printing condition, the solid lines indicate the Run 1 printing condition, and the dotted lines represent the reference printing condition.

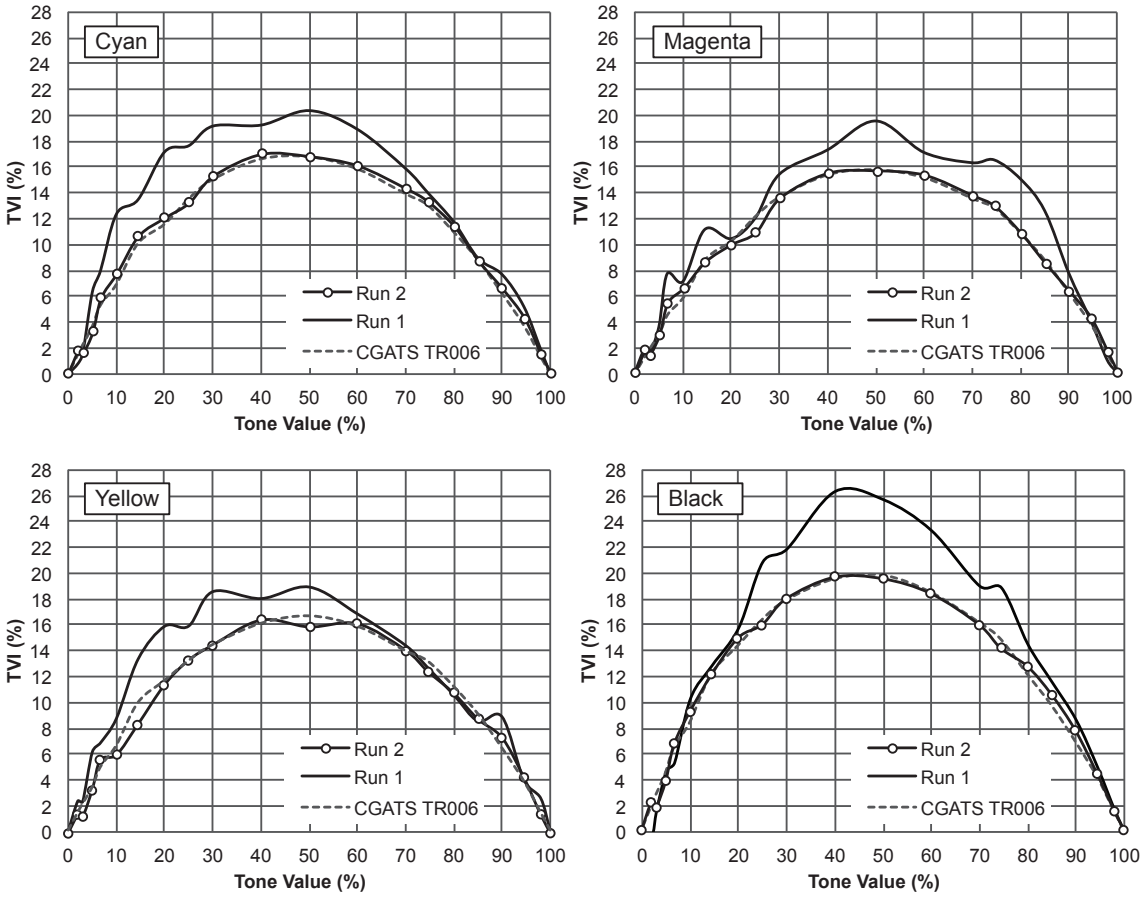

Figure 17. The TVI curves of the TVI-based calibration results

As seen from the graphs in Figure 17, the TVI curves of cyan, magenta, yellow, and black follow the reference TVI curves very well after the adjustment. They are in conformance according to the reference aims.

c) Grey reproduction

Figure 18 shows the grey reproduction conformance based on the results of the TVI based calibration. The solid lines with circle show the grey ramp of the Run 2 printing condition; the solids lines are Run 1 grey ramp; and the dotted lines are the substrate-corrected aim grey ramp.

As seen from the graph, the TVI-based calibration simulation adjusts the discrepancies in the shadow region.

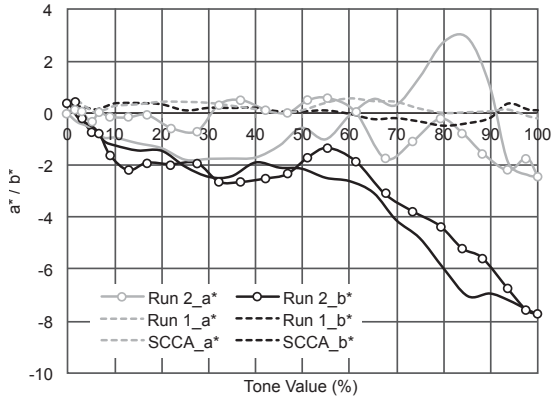

Figure 18. The grey reproduction of the TVI-calibrated Run 2 printing condition in Case 2

Table 20 shows the grey reproduction assessment of the three near-neutral patches of the TVI-based calibration results. All the values, except the ΔC_h value of (25C, 19M, 19Y), are within the tolerance.

Table 20. The assessment of the grey reproduction conformance of the TVI calibrated results

	SCCA			Run 2			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.4	0.0	0.5	93.4	0.0	0.5	0.0	-	-	0.0	-	-
25C19M19Y	74.3	0.1	0.4	74.7	-0.6	-2.0	0.4	2.5	Yes	**2.5**	2.0	**No**
50C40M40Y	56.7	0.1	0.1	56.6	0.0	-2.4	0.1	2.5	Yes	2.5	3.0	Yes
75C66M66Y	39.0	-0.3	0.2	37.4	-1.1	-3.8	1.6	2.5	Yes	4.0	4.0	Yes

Comparing the grey reproduction assessment results of TVI calibrated Run 2 with the initial Run 1 printing condition (as shown in Table 21), although the ΔC_h value of (25C, 19M, 19Y) is out of the specified tolerance, its conformance has been improved after the adjustment.

The ΔC_h value of (50C, 40M, 40Y) increases by 0.2, however, within the specified tolerance. This can be because of rounding issues in the software.

Table 21. Comparison between Run 1 and 2 on the ΔL^* and ΔC_h values in Case 2

	ΔL^*			ΔC_h		
	Run 1	**Run 2**	**Tol.**	**Run 1**	**Run 2**	**Tol.**
Paper White	0.0	0.0	-	0.0	0.0	-
25C 19M 19Y	1.3	0.4	2.5	3.1	**2.5**	2.0
50C 40M 40Y	2.1	0.1	2.5	2.3	2.5	3.0
75C 66M 66Y	3.7	1.6	2.5	5.3	4.0	4.0

d) Summary of TVI-based calibration results

In summary, the TVI-based calibration results via simulation approach indicate that the adjustment corrects the TVI values of the press to conform to the reference aims.

The grey reproduction of the press has better conformance to the reference. Although the ΔC_h value is out of the specified tolerance, its conformance has been improved.

G7-based calibration results

There are three parts in the G7-based calibration results, (1) the G7-based calibration transfer curves, (2) the G7 calibration results verification, and (3) the assessment of TVI curves.

a) G7-based calibration transfer curves

IDEAlink Curve 2 generated the transfer curves for the press using the G7 calibration method. Table 22 shows the results. Compared with the TVI-based transfer curve values in Table 19, the G7-based calibration compensates more in yellow tonality.

Table 22. The transfer curve values used in the G7-based calibration in Case 2

Tone value (%)	C	M	Y	K
100	100	100	100	100
90	89	87	98	88
80	77	74	89	73
70	68	66	73	65
60	57	57	62	53
50	47	49	51	44
40	36	39	42	35
30	27	30	31	27
20	17	20	21	19
10	9	10	10	10
0	0	0	0	0

b) G7-based calibration verification

Figure 19 shows the grey reproduction conformance after the transfer curves were applied to simulate G7 calibrated Run 2 printing condition. As seen from the graph, the G7 calibration adjusts the grey reproduction close to the substrate-corrected reference aims.

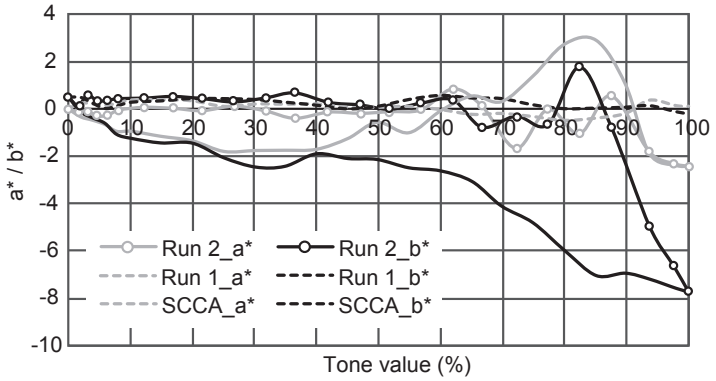

Figure 19. The grey reproduction of the G7-calibrated Run 2 printing condition

The grey reproduction assessment results listed in Table 23 indicate that the grey balance of the press conforms to the reference aims.

Table 23. The grey reproduction assessment of the G7-calibrated Run 2 condition in Case 2

	SCCA			Run 2			ΔL^*	Tol. (ΔL^*)	OK?	ΔC_h	Tol. (ΔC_h)	OK?
	L^*	a^*	b^*	L^*	a^*	b^*						
Paper White	93.4	0.0	0.5	93.4	0.0	0.5	0.0	-	-	0.0	-	-
25C19M19Y	74.3	0.1	0.4	74.3	-0.1	0.4	0.0	2.5	Yes	0.2	2.0	Yes
50C40M40Y	56.7	0.1	0.1	56.1	-0.2	0.2	0.6	2.5	Yes	0.3	3.0	Yes
75C66M66Y	39.0	-0.3	0.2	37.4	-1.7	-0.3	1.5	2.5	Yes	1.4	4.0	Yes

c) Assessment of TVI conformance

Based on the G7 calibration results, Figure 20 shows the TVI conformance assessment results. The TVI curves of cyan, magenta, and black are closer to the reference after the adjustment. However, the yellow tonality has more discrepancies due to IDEAlink Curve 2 made more compensation on the yellow transfer curve.

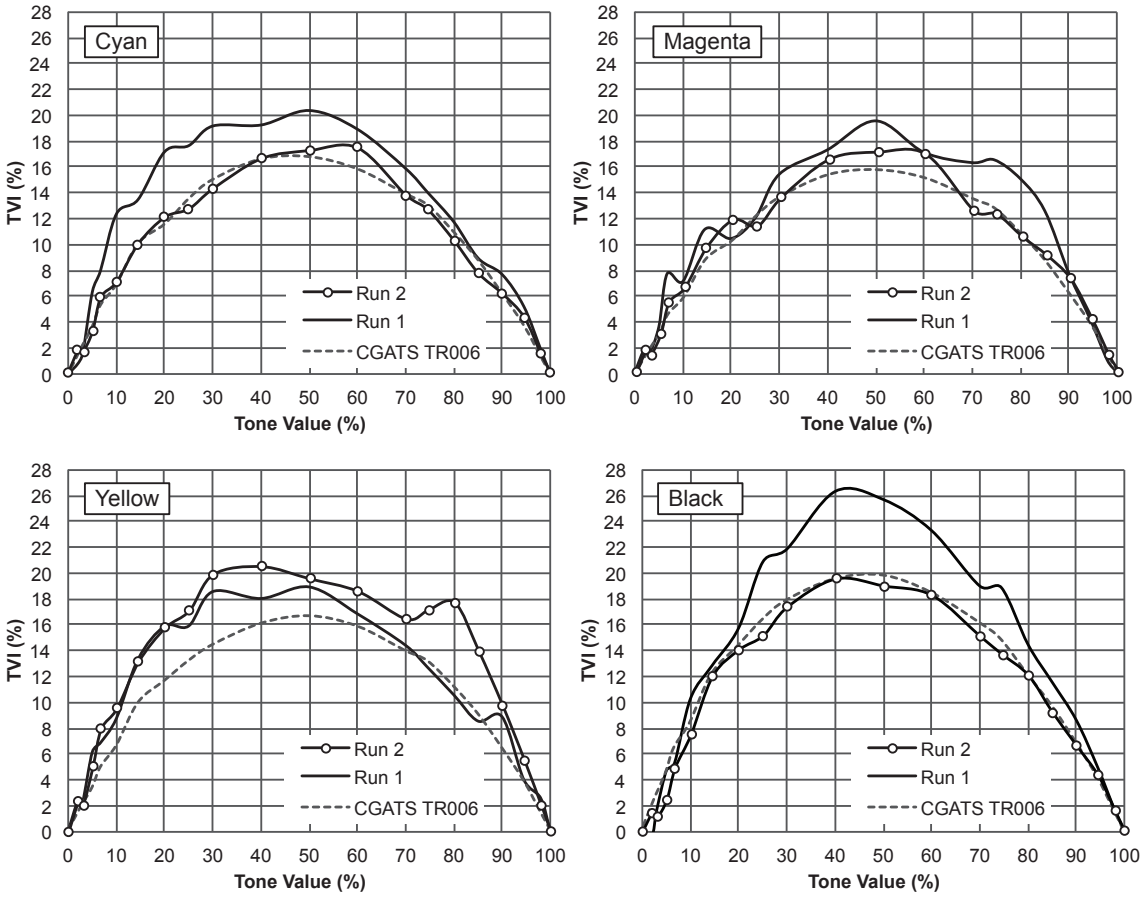

Figure 20. The TVI conformance of the G7-calibrated results in Case 2

The values listed in Table 24 show the comparison between the initial Run 1 and the G7 calibrated Run 2 printing condition at 50% and 80% TVI values. All the adjusted values achieve better conformance, except that the yellow TVI values at 80% tint area have 7% deviation off the aim.

Table 24. The deviation values at 50% and 80% tint area between the obtained TVI values and those values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

Tone value of control patch	Cyan		Magenta		Yellow		Black		Tol.
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	
50	3	0	3	1	2	3	6	1	4
80	1	1	4	1	0	7	2	0	3

As illustrated above, the mid-tone spread value also reflects the grey balance in the mid-tone region. Table 25 shows that the mid-tone spread of the press is 3%, which is in conformance with the standard.

Table 25. The deviation values at 50% and 80% tint between the printed TVI values and those values in CGATS TR006. The listed tolerances are specified in *ISO 12647-2:2004*.

	C	M	Y
Aim Values	17	16	17
Measurements	17	17	20
Differences	0	1	3
Mid-tone spread	3		
Tolerance	5		

d) Summary of G7-based calibration results in Case 2

In conclusion, the G7-based calibration approach adjusts the grey reproduction with the specified tolerance. Although there is a large discrepancy at 80% yellow tint, other TVI values are improved after the adjustment.

Chapter 7

Summary and Conclusions

This chapter discusses the results obtained in Chapter 6 and follows a further research agenda.

Analysis and Interpretation of the Data

As the results show in Chapter 6, the two simulated printing conditions using either TVI or grey reproduction method in Case 2 are not in conformance. Therefore, an assumption is that "if the transfer curves are iterated within the specified tolerance of the second requirement in order to meet the third requirement, then all three requirements can be achieved within the two calibration press runs." That is to say, (1) iterating the adjustment of TVI-simulated transfer curves according to the G7-based simulation results will achieve not only the G7 but also the TVI-based simulation results' conformance to the standards; and (2) if iterating the adjustment of the G7-based transfer curves according to TVI simulation results, it will yield both TVI and G7 requirements within conformance.

Iteration of TVI-based simulation transfer curves in Case 2

According to the results in Case 2 (shown in Table 20), the ΔC_h value of (25C, 19M, 19Y) is out of the tolerance and the ΔC_h value of (75C, 66M, 66Y) is at the brink of the tolerance. Thus, the output values of magenta and yellow in the 25% tint area were adjusted in the iteration. As shown in Table 26, 2% was added on the output value in the 25% magenta tint area, 1% was added on the output value of 25% yellow tint area, and 1% was decreased in the 75% magenta tint area.

Table 26. The modified transfer curves for the TVI-based calibration approach in Case 2

Tone value (%)	Magenta		Yellow	
	Before	After	Before	After
25	25	27	24	25
75	-	-	75	74

Figure 21 shows the TVI results after the modified transfer curves were applied to the Run 1 printing condition.

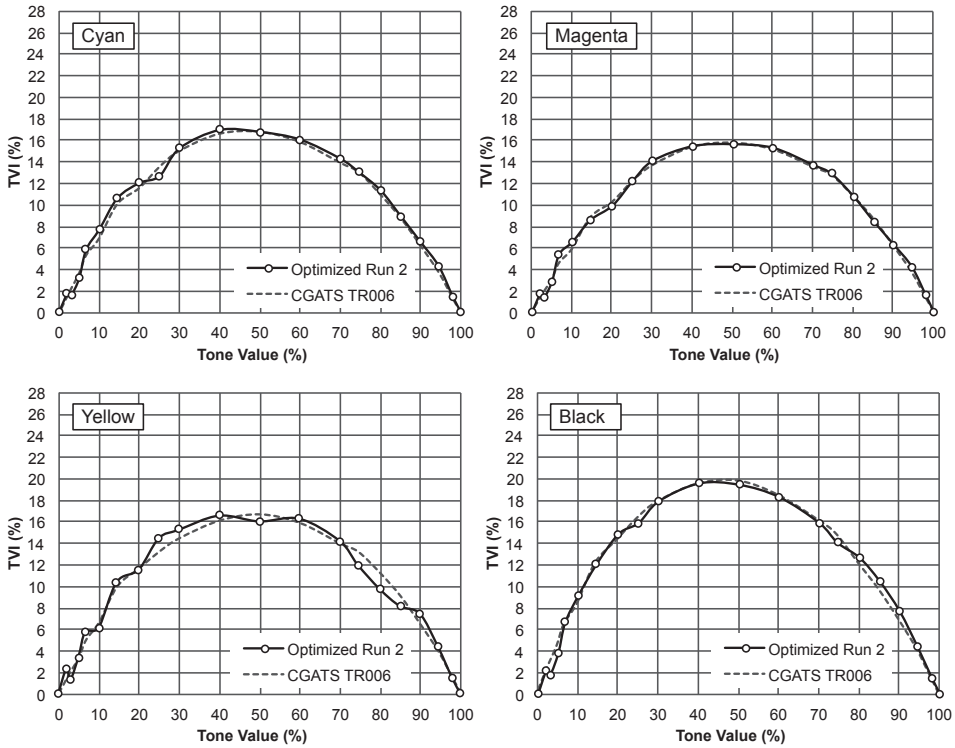

Figure 21. The TVI conformance based on the modified transfer curves

Comparing the conformance results of modified transfer curves in Figure 21 to Figure 17, the TVI curves have changed a little bit. However, the obtained curves are still very close to the reference curves and the results are within the tolerance.

The grey reproduction of the adjusted printing condition was assessed and is shown in Table 27. As seen from Table 27, the grey reproduction conformance assessment outcomes are within the specified tolerance. Then, the conformance of TVI values are assessed, the results of which are shown in Figure 21.

Table 27. The grey reproduction conformance assessment results based on the modified transfer curves

	Substrate-corrected aims			Modified Run 2			ΔL^*	Tol.	ΔC_h	Tol.
	L^*	a^*	b^*	L^*	a^*	b^*				
Paper White	93.4	0.0	0.5	93.4	0.0	0.5	0	-	0	-
25C 19M 19Y	74.3	0.1	0.4	74.8	-0.5	-1.5	0.5	2.5	2.0	2
50C 40M 40Y	56.7	0.1	0.1	56.6	0.0	-2.4	-0.1	2.5	2.5	3
75C 66M 66Y	39.0	-0.3	0.2	37.4	-1.0	-3.4	-1.5	2.5	3.6	4

Iteration of G7-based simulation transfer curves in Case 2

According to the TVI curves of the G7-based simulation results shown in Table 24, yellow ink has 7% discrepancy in the 80% tint area. Thus, the solution is to decrease the yellow output in the shadow region. Table 28 lists the results after the iteration adjustment: 1% decrease at 75% tint and 5% decrease in the 80% tint area.

Table 28. The modified transfer curve values for the G7-based calibration in Case 2

Tone value (%)	Yellow	
	Before	After
75	79	78
80	89	84

After applying the modified G7-based calibration curves to the Run 1 printing condition, the obtained grey reproduction was still within the tolerance as shown in Table 29.

Table 29. The grey reproduction assessment outcomes of the modified transfer curves for the G7-based calibration approach in Case 2

	Substrate-corrected aims			Modified Run 2			ΔL^*	Tol.	ΔC_h	Tol.
	L^*	a^*	b^*	L^*	a^*	b^*				
Paper White	93.4	0.0	0.5	93.4	0.0	0.5	0.0	-	0.0	-
25C 19M 19Y	74.3	0.1	0.4	74.1	0.1	0.6	-0.2	2.5	0.2	2.0
50C 40M 40Y	56.7	0.1	0.1	56.1	-0.2	0.2	-0.6	2.5	0.3	3.0
75C 66M 66Y	39.0	-0.3	0.2	37.3	-1.4	-0.1	-1.6	2.5	1.1	4.0

Moreover, the obtained TVI curves can be within the specified tolerance, which is shown in Figure 22.

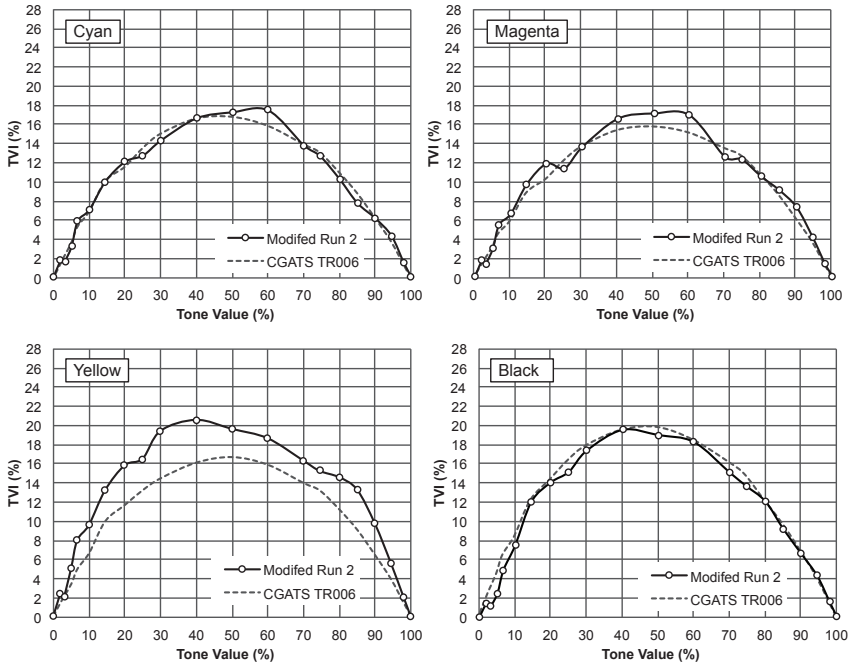

Figure 22. The TVI curves conformance based on the modified transfer curves in Case 2

Conclusion

The advantage of using simulation application in this research is that it ensures repeatability between the two press calibration runs, which has an effect on testing the two calibration methods. The results of the research indicate that if reference aims and tolerances are embraced in both calibration methods, full conformance can simultaneously be achieved in press calibration.

It is worth noting that the TVI and grey reproduction methods are limited to adjusting tonal reproduction and do not affect the solid ink colors. In both methods, the colorimetric values of the solid inks are established during the initial press calibration run (Run 1). The ink film thicknesses established during this run are maintained during the second press calibration run (Run 2) regardless of the method (TVI or grey reproduction) used in this press run.

Agenda for further research

In this research, no OBA papers were used in either case. Further research could take OBA affects into consideration.

Moreover, conducting the research methodology on a larger and more diverse sample size will increase the confidence of the experimental findings, e.g. universal datasets specified in *ISO 15339-1:2010*.

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