Using Gray-Balance Control in Press Calibration for Robust ICC Color Management in Sheet-Fed Offset

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Abstract: Coldset printers often use gray-balance fields for the adjustment and control of ink quantity during print runs. This method helps the printer to significantly reduce unwanted color cast in the printed product. A common way in sheet-fed offset to control the amount of ink is to decide upon target tone-value increase (TVI/dot gain) or density levels, with the intention to print the best subjective quality, even though the same quality cannot always be attained in every print run. Today, a predictable and equal quality is generally desirable, and therefore calibration and standardization are more in focus. Since there is no standardized way to calibrate a sheet-fed offset press, the possibility to produce an equal print quality in different print runs and printing presses is limited.

Gray-balance control is a way to calibrate printing presses. The presses will always be set to print one standardized combination of CMY halftones in the same way. Hopefully, this will create a similarity between print runs, presses and to some extent paper qualities, which gives the foundation for robust ICC profiles.

A study including print runs, evaluation of prints and creation of ICC profiles has been carried out. The use of gray-balance control in sheet-fed offset was primarily explored. It turned out to be possible to print without a color cast, and still keep print contrast, density, dot gain and CIELAB values for the secondary colors at an acceptable level. Prints on different coated papers were compared to investigate the similarities between these samples, when using this method and ICC profiles. The study showed that an ICC profile can give a similar print quality on different papers.

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Introduction

Color management, based upon ICC profiles, is widespread among printing houses today. When this is working correctly, color quality and predictability will be high. Unfortunately, there are too many cases when the printed results do not match the basic expectations. The confusion of ideas comes out quite strongly, which causes problems at the printing house as well as for the customer. Of course, lack of time and knowledge might be to blame. In some cases these are most certainly the true scapegoats, but would it not be easier if common guidelines were utilized? These should at least include calibration of the printing press. Further it would be preferable with a definition of how detailed ICC profiles ought to be: should there be one ICC profile per printing press and paper, or would it be enough with more general, and consequently fewer, ICC profiles?

When ICC profiles were first used, there was a tendency to make profiles for many different combinations of printing presses and papers. It has even been stated that a new ICC profile needs to be made for each new paper delivery. Naturally, this way of working would be overwhelmingly time consuming and expensive.
Today, it is becoming more common to decrease the number of ICC profiles, and most parties benefit from fewer profiles. How many profiles are needed, and which way of working is then required? The idea behind this paper was that the less the number of ICC profiles for sheet-fed offset, the better. To make this possible, calibration of printing presses was needed. Calibration was accomplished by combining target density levels and gray-balance control.

The Basics of Gray-Balance Control

Gray-balance control is a method for adjustment and control of the inking levels during print run. Rather than adjusting the amount of ink in accordance with target tone-value increase or density levels, the amount is determined by means of gray-balance fields. These fields are composed of two halves, which should have the same luminance and neutrality.

Table 1 CMY tone values in the gray-balance fields. Sheet-fed offset (ISO 12647-2:1996) and Coldset offset (ISO 12647-3:1998)

Three-color gray field	Sheet-fed C / M / Y (%)	Coldset C / M / Y (%)
Quarter tone	25 / 19 / 19	25 / 18 / 18
Mid tone	50 / 40 / 40	50 / 40 / 40
Three-quarter tone	75 / 64 / 64	75 / 64 / 64

One half is three-color gray (cyan, magenta and yellow) and the other consists of black. The halftone combinations of CMY, are given by the ISO standard, *Table 1*. The screen value in the black half is not standardized, but should be set individually for each printing press.

Possible Gains with Gray-Balance Control

First of all, gray-balance control should serve as calibration of the printing press. Consequently, ICC profiles should give stable results, on different papers and in various printing presses.

Calibration of the Printing Press

"To ensure a consistent product, gray balance is the most important variable to control" (Kimmelman, Zucca, 2001). When using gray-balance control, printing presses might not deliver the best subjective quality, but rather a predictable quality. The printing presses will always be set to print a predefined combination of cyan, magenta and yellow, in one way: neutral. This is independent of paper, press, screen ruling, ink etc. However, to some extent there will always be deviations, depending on the natural fluctuations of the printing presses.

When printing the conventional way there will be gray-balance shifts, due to screen ruling, printing press and paper (GATF, 2003). Instead of accepting, and in the prepress trying to correct this, the correction can take place in the printing press, by means of gray-balance control. This will minimize the color shifts and create a similarity between the print runs, and consequently function as a calibration, which indicates that the printing press is working correctly and in accordance with other presses and print runs.

Stable prints when using ICC profiles

A robust ICC profile gives equal results between two print runs and maybe also on various papers, with similar characteristics. The basic prerequisite for this is to create and use the ICC profiles in calibrated print runs, *section Color Management*.
When printing to target density levels or tone-value increase, the gray balance might not be neutral. Instead of printing neutral, the prepress system will have to make corrections for these color tints (Klaman, 2002). When ICC profiles are used, these will have to make the compensations. Inevitably, this will make the ICC profiles job-specific, for one print run, paper, printing press, screen ruling and/or dot shape (GATF, 2003). With

gray-balance control of the printing press, there will be no tint to compensate for.
The more similar the prints, the less ICC profiles will be needed. Since gray-balance control creates a similarity among printing presses and papers, it could be enough with just a few and universal ICC profiles.

Course of Action

To confirm the above theories, the following was evaluated:

- First, whether gray-balance control can be used in sheet-fed offset on coated paper was tested.
- Secondly, the stability of ICC profiles was analyzed, from gray-balance controlled print runs.

It was found that the gray-balance method could be utilized in sheet-fed offset. Further it was evident that the same ICC profile could be used for similar papers, e.g. a gloss ICC profile on classic matte, dull (silk) and gloss papers, or classic matte ICC profile on classic matte, matte and dull (silk) papers. However, the subjective and objective results were a bit ambiguous. Consequently, no recommendations could be given regarding what paper the ICC profiles should be created from, to generate the same quality on all coated papers.

Present situation

Coldset (Newspress)

Today, many coldset printers work with gray-balance control. Primarily, this method makes it possible to use the same prepress for different printing houses, which is very useful for advertisers. Secondly, it makes it possible to shorten the make-ready time in press. Their way of working can be described with two different types of print runs: first a preparatory run and then the subsequent gray-balanced runs. In the preparatory print run, the CMY density levels are adjusted to achieve a neutral gray balance, which is measured with a spectrophotometer. From these sheets the correct screen value in black is determined. In the subsequent print runs the gray balance is set visually. (Tidningsutgivarna, 2003)

Sheet-fed Offset

A common way to control the inking level in sheet-fed offset is to decide upon target tone-value increase or density levels. These levels aim at getting the highest relative contrast, density and tonal range from each specific printing press. This is a result of an ambition to print the best subjective quality, even though the same quality might not always be reached in every print run.

However, today the ambition seems to be more and more focused on a predictable quality. Predictable quality implies more of a focus on process thinking, looking at the printing house as a process industry. Color management is one step towards predictable color quality, but a stable and repeatable process is necessary to achieve this. Key words are predictable, repeatable, stable and equal quality, which requires control and standardization. Working with calibrated equipment is a good way to achieve control of the process. A standardization of the calibration facilitates predictability and equality. Unfortunately, today there is no standard for calibrating a sheet-fed printing press (Kjellberg, 2003).

There are a number of organizations who give guidelines on control of offset printing, and how to work with ICC profiles. There are guidelines and specifications for solid densities, tone value increase, print contrast, trapping and/or CIELAB values for the solid colors. In the provided color bars/quality strips, gray-balance fields are present, however the neutrality of those is not specified.

- **ISO (the International Organization for Standardization)**: documents criteria and specifications regarding *e.g.* graphic technology (ISO 12647). Part two in this deals with the offset lithographic processes, and part three with the coldset offset lithography and letterpress on newsprint.
  The standard specifies dot gain, solid density, halftone values in the gray-balance fields, CIELAB values for the solid colors and the secondary colors (ISO, 1996).
- **IDEAlliance (the International Digital Enterprise Alliance)**: establishes guidelines, specifications and standards (IDEAlliance, 2004). One of those is GRACoL, with printing guidelines for commercial offset lithography. Aim points for solid density, dot gain and print contrast are recommended, from which each printer should develop their own standard (Kimmelman, Zucca, 2001).
- **UGRA/FOGRA**: two graphic technology research associations, the first one situated in Switzerland and the latter one in Germany. They develop control strips and offer aids for obtaining quality control. The guidelines are based on the ISO standard. In the control strips, there are patches for control of solid inking, dot gain, trapping and gray balance. Further control of the printing process is offered by means of test forms: control of the platesetter, the imagesetter and the balance between ink and fountain solution etc (FOGRA, 2004; UGRA, 2004).

- **GAIN (the Graphic Arts Information Network)**: GATF (the Graphic Arts Technical Foundation) and PIA (the Printing Industries of America). GATF provide quality control devices, such as test forms with diagnostic, process control and standardization targets. The latter type can be a color reproduction chart. These have *e.g.* gray-balance matrixes, from which the neutral CMY combination is determined when printing "normally". The process control includes color bars, with patches for control of ink densities, dot gain, trapping and gray balance (GATF, 2003).
- **ICC (the International Color Consortium)**: has given rise to the standardization of the cross-platform color management system, *i.e.* the ICC profile specification (ICC, 2002).
- **ECI (the European Color Initiative)**: creates media-neutral color preparations and processing, in accordance with the ICC profile specification (ECI, 2000).

Color Management

The importance of controlling and predicting the color reproduction increases, as the demands on the graphic quality increases. Color management and color management profiles can be useful when working with color quality, provided that the system in question has been created and maintained correctly. To achieve this the following three steps are recommended: 1) calibration, 2) characterization, 3) conversion (ICC, 2002).

Calibration

The first step, calibration, belongs to the basics of reproducing predictable colors. Without a correct calibration of the devices in the system, the next step characterization, will not be valid in future productions. With calibration, devices are controlled into working in one way every time. (Adams & Weisberg, 1998)

Characterization

The second step, characterization, is a way to find out how a device works and what it does with colors. Known color values are sent to the device, and the reproduced color values are measured. These tests give the characteristics for a specific device and will describe its color gamut. For this purpose, there are test charts with fixed sets of color patches. The number of patches depends on the range of application and also on the supplier. The test charts for scanners and displays consist typically of bright colors and only a few patches, and for a printing press the number varies from a couple of hundred to a thousand (Adams, Weisberg, 1998).

Conversion

The third and last step, conversion, is carried out with the help of color management profiles. These are created from the characterization, and are expected to result in accurate color conversions/separations. The goal is, that the reproduced (converted) colors shall match the original. The profiles are mostly created in accordance with the standard from the International Color Consortium (Adams, Weisberg, 1998).

ICC profiles

To fulfill the objectives, two ICC profiles are needed; one for the input and one for the output device. For example, when an RGB picture shall be separated into CMYK for printing, characteristics are needed for both the RGB-gamut (e.g. ColorMatch) and the actual printing press (ICC, 2002).

Profile Connection Space (PCS)

Since ICC profiles may be combined in many possible ways: the interface between the input and output needs to be unambiguous. This interface is the Profile Connection Space (PCS), which is encoded with CIEXYZ or CIELAB. When colors, independent of color space, have a defined counterpart in the reference space, conversions between all types of color spaces are possible. In the example above, the RGB values in the picture will be defined with the correct PCS values, which the output ICC profile translates into correct CMYK values (ICC, 2003).

Rendering Intent

Each device gamut needs to be encoded in the PSC, which can be done in four different ways, so-called rendering intents. There are perceptual, saturation and two colorimetric renderings: ICC-absolute and media-relative.

The color values for the media, will be normalized to the white point in the PCS (CIELAB 100, 0, 0) when using the media-relative and saturation rendering. In addition, all other values will be changed in ratio with the normalization. With the ICC-absolute rendering, the color values for the media will be retained, not normalized to the PCS white point. When using the perceptual rendering, a reference medium will be utilized to identify the needed corrections. The reference will be normalized to the

PCS white point, and the white point of the actual medium will be changed in ratio with this. Adding to the general confusion, ICC media-relative is defined as absolute by CIE.

This is one of the applications for the rendering intents. Furthermore, the rendering controls the gamut mapping during conversions/separations. The color gamuts of printing presses, displays, scanners and cameras, neither have the same shape nor the same size. When mapping gamuts of different sizes, parts of the output gamut may either not be utilized, or may not be able to reproduce all input values.

In the latter case; larger to smaller gamut (*e.g.* RGB to CMYK), there will most probably occur RGB colors which are impossible to reproduce within the CMYK gamut. To what CMYK values shall these CIELAB values be translated? One possibility is to shift these colors to the closest place inside the gamut. This corresponds to the two colorimetric renderings. Another alternative is to move both the colors inside and outside the gamut, as close to the gamut edges as possible, called saturation rendering (ICC, 2003). The third option is to shift all of the colors a little, with the intention of keeping the ratio between them: perceptual rendering. Both perceptual and saturation rendering are vendor specific (Adams, Weisberg, 1998).

Color Management Module (CMM)

The conversion between two ICC profiles is dependent on the chosen rendering intent, as well as the Color Management Module (CMM). The CMM is the mathematical engine that carries out the actual calculations (ICC, 2002).

Experimental

To carry out these evaluations, at the least two print runs were needed. To be able to use gray-balance control, the gray-balance field had to be specified. The composition of the three-color gray was given in the ISO standard, for quarter, mid and three-quarter tones. For each of those the correct black halftone had to be identified. This was one of the objectives with the first print run. Secondly ICC profiles should be created from this print run.

After the gray-balance fields were set, the gray-balance method could be evaluated in the following print run. Even though fields for quarter mid and three-quarter tones were used, the focus was on the mid tone.
Since only two print runs were carried out, the stability of the ICC profiles could not be evaluated with regard to similarity between several

print runs or presses. Instead stability was assessed from the similarity on various papers. ICC profiles were created from four, and later used on five, different coated papers. Would the ICC profiles give similar results on these papers?

Evaluation of Paper Properties

Five woodfree coated papers were used, *Table 2*. The two matte papers were single-coated, whereas the other three were multi-coated. Premium silk was only used in the second print run, and then with the same settings in the press as the dull (silk) paper.

The PPS surface roughness [µm] was determined according to SCAN-P76:95 and ISO 8791-4 at a clamping pressure of 1 MPa. The instrument used was an L&W PPS calibrated to the master instrument at Lorentzen & Wettre, Sweden.
The paper and print gloss at 75° were determined according to TAPPI T480. A Zehntner three-angle instrument was used for all measurements. The CIE-Whiteness was obtained with an L&W Elrepho 3000 instrument, calibrated using ISO Level 3 reference papers from STFI. Both C illuminant (Indoor Whiteness) and D65 illuminant were used for determination.
CIELAB values for the papers were determined with a Gretag Macbeth Spectrolino spectrophotometer, using illuminant D50, geometry 2º, density DIN NB, absolute white point and no polarizing filter. These settings were used, whenever this device was used during this project.

Color Management

The printing press was calibrated by means of color-balance control, and from this it was characterized. For characterization the test chart TC 6.02 was measured with ProfileMaker 4.1 and Gretag Macbeth Spectrolino. An average of five consecutive sheets was calculated for each paper.

Table 2 Paper properties and print gloss

	PPS	CIE-Whiteness		CIE-LAB	Gloss (TAPPI 75 %)		
	µm (1.0)	(D65)	(C)	L* / a* / b* (D50)	Paper	K100 %	400 %
Gloss *(130 gsm)*	0,5	121,4	107,4	95.7 / 1.6 / -3.0	72,1	90,0	85,1
Dull (Silk) *(130 gsm)*	1,6	119,3	105,6	95.2 / 1.1 / -3.9	30,4	58,1	70,1
Matte *(130 gsm)*	1,7	118,0	105,2	95.3 / 1.0 / -3.7	23,5	51,0	60,8
Classic Matte *(130 gsm)*	2,6	117,5	103,7	94.6 / 0.9 / -4.1	16,0	36,2	51,1
Premium Silk *(150 gsm)*	1,2	127,0	108,3	96.1 / 1.3 / -3.9	55,1	83,5	82,3

From this, four ICC profiles were created. The settings in ProfileMaker 4.1 are specified in *Table 3*.

Two images and one test chart were CMYK separated in Adobe Photoshop 6.0, with the four ICC profiles. Skin tones were predominant in one of the images and dark tones in the other. Both images and the test chart were initially defined in CIELAB. The test chart was originally a scanner test chart, which had to be digitally defined with the correct CIELAB values. CMYK separations were carried out with Apple CMM and the media-relative colorimetric rendering. The media-relative rendering would only make normalization to the PCS white point. After printing, there were a total of 20 combinations of ICC profiles and papers.

Test Printing

Printing trials were performed in April 2003 in a Heidelberg SpeedMaster 6-color sheet-fed offset press at Stora Enso, Falun Research Centre. The

Table 3 Settings used in ProfileMaker 4.1 when creating ICC profiles

ProfileMaker 4.1	Settings	Motivation
Size	Large	The most accurate encoding and calculations
Perceptual Intent	Paper Gray Axis	Since perceptual intent will not be used, this setting wil not have any influence
Gamut Mapping	LOGO Classic	Preserves details throughout the tonal range
Viewing Light Source	-	This option was not available
Correction Optical Brightener	-	This option was not available
Separation	GCR 1	Gives a more stable color balance than UCR. Avoids black in sensitive colors (*e.g.* skin tones)
Total Ink Coverage	320%	Normal for sheet-fed offset
Total Black Coverage	100%	Achieves saturated dark tones
Black Start	30%	Avoids black in quarter tones, which otherwise will appear dirty
Black Width	Max	Recommendations from Gretag Macbeth
Balance Black Point	Yes	Recommendations from Gretag Macbeth
Balancing CMYK	*Classic Matte*	*79, 67, 74, 100*
	Matte	*80, 66, 74, 100*
	Dull (Silk)	*83, 68, 70, 100*
	Gloss	*83, 71, 66, 100*

automatic press control system for control of print density and dot gain was used to adjust the inking levels. The printing conditions are summarized in *Table 4* and the trial procedures in *Table 5*. Premium silk was printed immediately after the dull (silk) paper, and without any changes in press settings.

Inking levels were adjusted using the automatic press control-system, on sheets taken directly from the press. The starting point in the first print run was to print all papers to target density levels: C 1.50, M 1.40, Y 1.40, K 1.90 (with polarization filter). From this the gray-balance was adjusted, and consequently new density targets were created.

Print Forms

The print forms used in the two print runs were created in QuarkXPress 4. For the first print run, the print form contained technical areas; the test chart (TC 6.02) and gray-balance fields. The latter ones were square shaped, with a surrounding black halftone frame. For each of the quarter, mid and three-quarter three-color gray halves, a series of frames were defined with increasing black screen value.

The second print form contained the correct gray-balance fields, which had been specified from the first print run. Four different ICC profiles

Table 4 *Printing conditions in the trials*

Parameter	Conditions
Press room climate	21°C/5% RH
Ink	LithoFlora NT (Vegetable oil based ink from Akzo Nobel Inks). "Ductor stable" with an "open time" of 25-35 h
Dampening solution	8% IPA, 2% Aqualith Z, 0,5% hardness regulator (PR9750)
Plate	Kodak Polychrome Graphics (thermal CTP plates, electrochemically grained and anodized). 150 lpi.
Blanket	David M QL Blue Saturn, a 1,97 mm thick, compressive blanket with a microground surface
Anti set-off spray powder	Starch 20 µm, S-5 KSL Staubtechnik
Color sequence	Black, Cyan, Magenta, Yellow
Speed	9000 sheets/h
Impression	0,18 mm (blanket-paper)
Press room climate	21°C/50% RH

Table 5 Trial Procedures

First Print Run	ICC Profiles
1 Adjustment to target density levels.	1 Creating four ICC profiles and CMYK separating (two images & one test chart) with them.
2 Manual change of inking levels, until gray balance was reached (CIELAB measurements).	**Second print run**
3 New target density levels identified.	1 Adjustment to new target densities.
4 The black halftones were determined visually and by means of a Gretag Macbeth Spectrolino; the luminance should correspond to the quarter, mid or three-quarter three-color-gray.	2 When the gray balance was not neutral, further adjustments of the inking levels were made.
5 Measurement of density, contrast, dot gain and CIELAB values for the solid process colors.	3 Measurement of density, contrast, dot gain, CIELAB values for the solid process colors and print gloss.
6 Measurement of the test charts.	4 Measurement and comparison of the test charts.
	5 Visual evaluation of the two images.

were applied to two images and one test chart. All of these combinations were present in the second print run.
The two print forms contained patches for control and evaluation of slur, doubling, register, dot gain, contrast and trapping.

Evaluation of Print Quality

Quality control was done on five consecutive sheets. Measurements were carried out a couple of hours, as well as a couple of days, after printing.
The print gloss at 75° was determined according to TAPPI T480. A Zehntner three-angle instrument was used for the measurements. Print gloss was measured in solid areas of black (K100) and areas of all four process colors (400%).
Print densities and CIELAB-values for the solid colors as well as the test charts were determined with the Gretag Macbeth Spectrolino and KeyWizard on dry prints. Dot gain and relative contrast (CMYK) were determined in the 80% and 40% areas. The color values in the test charts were compared with the MeasureTool in ProfileMaker 4.1. The same application was used when creating averages.

Visual Evaluation

From the second print run, there were 20 combinations of each of the two images; four ICC profiles and five papers. For each of the 20 combinations, the similarities were assessed by 10 persons. The similar combinations were grouped together, and the results were scaled down to three dimensions. The multidimensional similarity scalings were made wiht Proscale 5.0 (Domderi, 2001).

Results

Gray-Balance Control in Sheet-fed Offset

It was possible to use the gray-balance method in sheet-fed offset. However, the focus had to be set on one of the three gray-balance fields, since neutrality could not be acquired simultaneously in all three fields, *Figure 1*. In these print runs, the mid tone was primarily used for the gray-balance adjustment.

*Figure 1 CIELAB a*b* changes by gray-balance adjustment on the Classic Matte paper.*

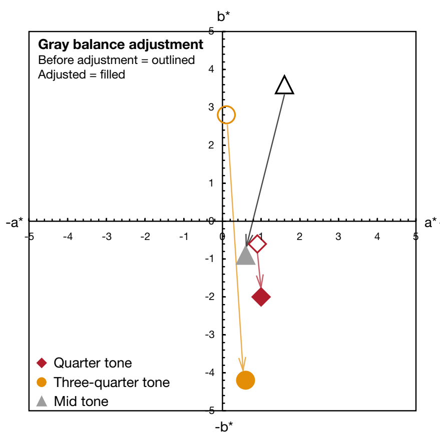
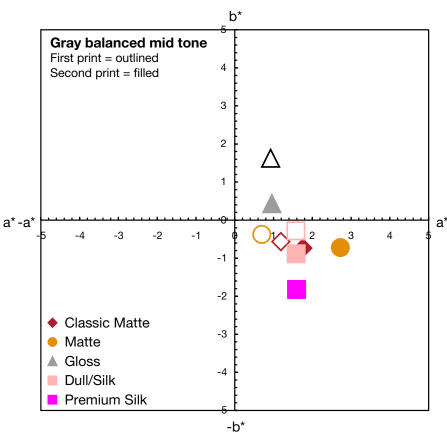


*Figure 2 CIELAB a*b* values for the mid tone gray-balance patches. Both print runs.*



The mid-tone neutrality improved noticeably when adjusting the gray balance, *Figure 2*. No changes in density levels were needed for the gloss paper. In the three-color patches, the divergence from neutral gray was rated as ΔE_{ab}, *Table 6*. ΔE_{ab} for the mid tone only exceeded 2 on two papers in one of the print runs. Deviations greater than one are in some cases visible, and greater than three are supposed to be a clearly visible difference. For both print runs, the CIELAB values for the solid process colors were kept constant and well within the ISO tolerance, except for the yellow on the gloss paper. The solid densities and dot gain fluctuated a little.

Primarily, the yellow target density was adjusted to achieve a neutral gray balance. In the first print run, the yellow density was decreased by 14-16% (-0.2 units) on all papers except on the gloss. Cyan was decreased by 4% (-0.05 units) on the matte paper. In the second print run, adjustment was needed only on the classic matte paper, where yellow density was increased by 6% (0.7 units).

Table 6 *Neutrality in gray-balance fields and similarity between the two print runs*

ΔEab	Divergence from gray (both print runs)	First print run compared with the second
Quarter tone	1.8 - 3.7	0.7 - 1.7
Mid tone	0.8 - 2.8	0.6 - 2.1
Three-quarter tone	0.8 - 4.2	3.5 - 4.5

Gray-balance Control as Press Calibration

A reasonable gray balance was achieved on all papers in both print runs, *Table 6*. In the quarter and mid tone the divergence between the two print runs was very low on classic matte and dull (silk), and a bit higher on gloss and matte. For the three-quarter tone the divergence was significantly higher.
The color gamuts in the first print run were estimated from the test charts. The largest gamut was found on the gloss paper. The printable gamuts on classic matte, matte and dull (silk) were quite similar. On average the color values did not deviate more than ΔE 2.5 between the papers. For the worst 10% of the patches ΔE was less than 6.0. Between the printed colors on the gloss paper and the other papers, there was a ΔE deviation in the range of 7-13, for the worst 10%.

Robust ICC profiles

A robust ICC profile gives equal results between several print runs and also on various papers. To evaluate this, images in the second print run were assessed visually and the test charts were measured. From this the similarity between the 20 combinations of ICC profiles and papers was assessed.

Objective Evaluation

The color values for the 20 different test-charts were compared with each other. The deviations were calculated as ΔE for an average of all patches and for the worst 10% of the patches. For each ICC profile, pair wise comparisons of the papers were made, *Chart 1a-d*:

- All papers could be combined with all ICC profiles except the one for classic matte, with a $\Delta E_{average}$ less than 3. When only using the dull (silk) ICC profile all papers gave a ΔE_{worst} that was less than 4.
- The dull (silk), matte and classic matte papers could be combined with any of the ICC profiles to achieve ΔE_{worst} 4 and $\Delta E_{average}$ 2. If the classic matte profile was excluded, combinations of dull (silk), classic matte and gloss also gave this result.
- The color values were most similar when the dull (silk) ICC profile was used, resulting in ΔE_{worst} values in the range of 2-4. For five out of the six paper combinations (not gloss together with matte), $\Delta E_{average}$ never exceeded 2.
- The smallest pair-wise deviations were formed between the dull (silk) and classic matte paper.
- The largest ΔE deviations appeared between the gloss and matte paper.

The premium silk paper was printed with the same press settings as the dull (silk). This resulted in high similarity between the color values on the two papers: ΔE_{worst} was approx. 3.0 and $\Delta E_{average}$ approx. 1.5.

Chart 1a Divergence between the test-charts with the classic matte ICC profile.

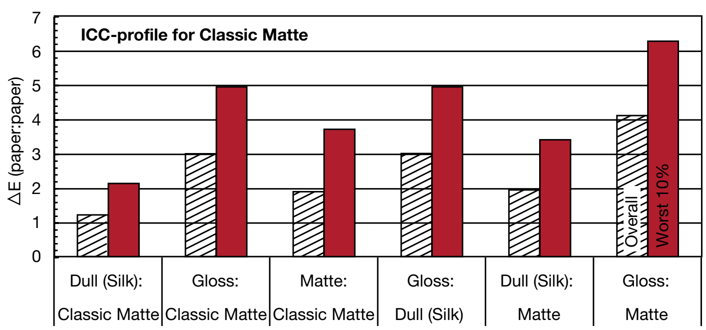


Chart 1b Divergence between the test-charts with the matte ICC profile.

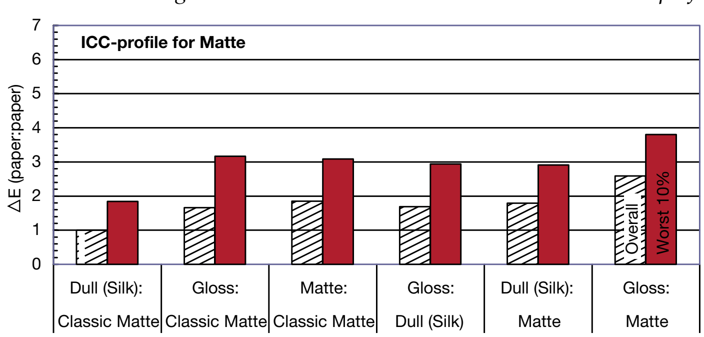


Chart 1c Divergence between the test-charts with the dull (silk) ICC profile.

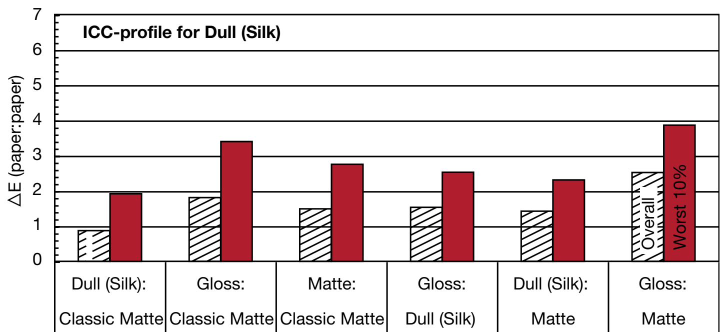
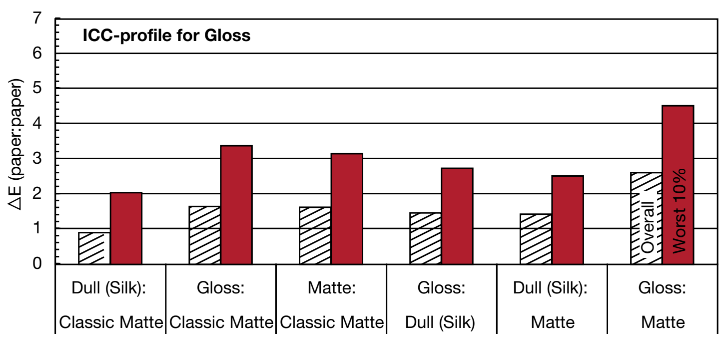


Chart 1d Divergence between the test-charts with the gloss ICC profile.



There was no evident relation between the matching of color values and the combination of ICC profile and paper, the ICC profiles printed on their source paper did not result in a better matching. In general, the differences between original color values and the colors in print were quite high, ΔE 8-9, *Table 7*.

Table 7 Matching of color values. The worst ten combinations are highlighted.

ICC-profile \ Paper	Classic Matte	Matte	Dull (Silk)	Gloss	Premium Silk
Classic Matte	8,9	8,5	9,0	9,6	8,3
Matte	8,8	8,5	8,8	8,8	8,2
Dull (Silk)	9,1	8,3	8,6	8,6	8,4
Gloss	9,3	9,0	8,6	8,5	8,4

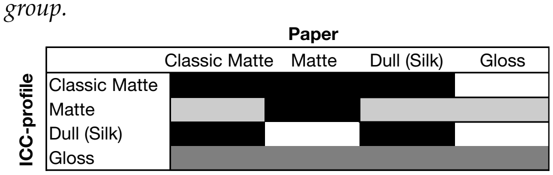
The images were evaluated visually, and the similarities between paper/ICC profile combinations were assessed. The results were down-scaled to three dimensions, which were less accurate for the portrait than the dark image. From the three dimensions, groups of papers and ICC profiles could be identified. There was a tendency, that the ICC profiles gave similar results on various papers. However, it was also common with similarities between the ICC profiles on one paper.

Three groups of similar combinations were formed from the dark image and two from the portrait, *Table 8a and 8b*. In general, the prints with the gloss ICC profile were assessed as similar on all papers. The ICC profiles on the gloss paper tended however not to be like any other combinations.

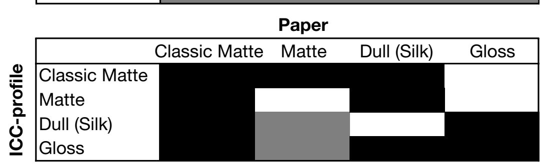
For both of the images, combinations with the classic matte ICC profile, on the classic matte, matte and dull (silk) paper were assessed as similar. As for the objective evaluation, prints on premium silk and dull (silk) were regarded as similar.

Table 8a,b *Similar ICC profile/paper combinations for each image are marked: one gray level for each group.*

a *Dark image*



b *Portrait*



Discussion

Gray-Balance Control

After gray-balance adjustments in the first trial, new target density levels were identified. These were later applied in the second print run, where further gray-balance adjustments were needed on only one paper. Though, the neutrality was slightly lower in the second print run than in the first. This indicates that gray-balanced densities from one print run can be used in subsequent print run. However, it is of utmost importance to check the gray balance and if necessary adjust the densities.

When adjusting the gray-balance, visual assessment was the starting point, which was followed by measurements with a spectrophotometer. The latter, in most cases was only a very small fine-tuning. However, this implied standardized viewing conditions with a color temperature of 5000 K. When the illumination diverged from this, the visual gray balance shifted significantly. This might lead to questioning of gray-balance control as a universal tool. As a calibration tool it is however still valid, and the similarity between print runs will remain.

Since it was not possible to reach equal CIELAB-values for all three gray-balance fields, the focus during these print trials was on the mid tone. If this is the case in all printing presses, it might be advisable to try with other CMY screen values.

Robust ICC profiles

The exactness of the color match, between source values and the printed colors, was not as high as one could have hoped for. This was mainly due to the large amount of out-of-gamut color values. The color match can never be exact for colors outside the printable gamut. Depending on the rendering intent, the match can be more or less exact for the printable colors. Even though the exactness of color matching was relatively low for the test charts, quite similar results were achieved on different combinations of ICC profiles and papers.
When it comes to visual evaluation of images, the resemblance with the original can be perceived as high, even though the color match is not exact. When there are many out-of-gamut colors, which are merely shifted to the closest position inside the gamut, the resemblance with the original might not be perceived as very high.

In general, the visual evalutions of the portrait and dark image were similar but not identical. The evaluation of the dark image was more unambiguous than that of the portrait. Further, the multidimensional similarity scaling for the dark image was more accurate than for the portrait.
The classic matte ICC profile was in the subjective evaluation the common denominator, while in the objective evaluation it was in many cases causing greater dissimilarities than the other ICC profiles. On all papers, this ICC profile had among the worst matching of original color values, and for the dark image the quality was assessed as low. Could it be that the tolerance increases as the image quality decreases?

Conclusions

The print trials made it evident that gray-balance control can be utilized in sheet-fed offset. The printable color gamuts and the neutrality in the three-color gray were sufficiently similar between papers and print runs to enable gray-balance control. However, in sheet-fed offset gray-balance control should be used in combination with target density levels; the "gray-balanced" targets have to be controlled and if needed adjusted in each print run.

The ICC profiles created from the gray-balanced print run were found to be quite robust. Combining the results from the objective and subjective evaluation, the following three conclusions could be drawn:

- The printed results were similar when using the *gloss* or *dull (silk)* ICC profile on the *classic matte, dull (silk)* and *gloss* papers.
- The printed results were similar when using the *classic matte* ICC profile on the *classic matte, matte* and *dull (silk)* papers.
- If $\Delta E_{average} \leq 3$ and $\Delta E_{worst} \leq 5$ is considered to be good enough, one ICC profile for coated (fine) paper ought to be enough, preferably created from gloss or dull (silk) paper.

Further studies

It is advisable to carry out further print trials:

- Printing of ICC-converted images and test charts, which are defined within the printable gamut.
- Printing on a production printing press. Is it possible to stay on neutral gray balance outside the laboratory-like environment of our Research Centre?

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