Gray Balance Control in Sheet-Fed Offset Printing

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Key words: Gray Balance, Sheet-fed Offset, Quality, Strip.

Abstract

Newspaper printing can be controlled by visual gray balance assessment, a procedure which is widespread among newspaper printers in Sweden. In sheet-fed offset today, there is no fast and efficient way to process control the sheet-fed offset-press during production without using advanced online-systems. The control patches which are used in sheet-fed offset during the production often lack the possibility to assess gray balance, these usually work to determine full-tone ink densities and dot gain.

The first objective of this study has been to evaluate the subjective quality experience (and objectively measurable factors) of print, where the quality control has been carried out based on gray balance control in sheet-fed offset. The second objective was to implement gray balance as a practical tool for the printers for a fast visual quality control in a sheet-fed offset printing.

The study has shown that:

1) The gray balance can be used as a control parameter for control of quality in sheet fed offset.

2) A faster start-up and a more reliable print quality (fewer variations during production) can be achieved. The printer and the customer have access to a tool which facilitates communication, generates fewer misunderstandings, leads to less product returns and less production losses.

With this tool it is easier for the printer to visually detect deviations without time consuming physical measurements. Also troubleshooting is easier; printers know instantly where the deviation is and can attend to it immediately.

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Background

Gray balance is critical for good color reproduction, and is a function of ink hue, ink film thickness and the percentage of dot area being printed. It is also affected by color sequence, ink trapping, press characteristics and dot gain. Proper gray balance ensures that a tone of appropriate cyan, magenta and yellow tint values is visually perceived as neutral gray (Flexographic Technical association, 1984).

The human eye is most sensitive to small changes in the color balance of neutrals and colors close to the neutral axis. As color become less saturated and closer to the neutral gray axis, the eye becomes more sensitive to even small changes in chroma (NAA, 2000). Due to the fact that as "the eyes are sensitive in detecting color differences within the gray zone, they can serve as a visual metering device" (ECI/bvdm, 2007).

Newspaper printing can be controlled by gray balance, a procedure which is widespread among newspaper printers in Sweden. Advertisers pushed this procedure forward 20 years ago to facilitate quality control in different papers and magazines. Today, the Swedish newspaper printing process is controlled by 25% of the tone value increase (TVI), chromatic gray 30-24-24 (CMY) and true gray (K), (TidningsUtgivarna, 2007). The Swedish daily press today therefore uses visual judgment of the chromatic gray patches, providing quick control of the production as the chromatic gray patches are linked to the print density (TidningsUtgivarna, 2007). The Swedish Newspaper Publishers' Association (TidningsUtgivarna, TU) is the trade and employers' association for Sweden's daily newspapers and other media companies.

During optimal light conditions and with fully functioning color perception, the human eye is a powerful tool when controlling gray balance in images/patches. This also generates advantages for the printing companies, as they obtain a more stable and more secure production procedure from a quality perspective.

In sheet-fed offset today, there is no fast and easy way to control a sheet-fed offset-press during production without using advanced time-consuming online-systems. At least in Sweden, the commercial offset printers have no special organization which could help implement such a method. The commercial offset printers often try to work according to the ISO-standard 12647-2:2004/Amd.1:2007(E), and look at GRACol (General Requirements for Applications in Commercial Offset) and ECI (The European Color Initiative) with bdvm (Bundesverband Druck und Medien = the German Printing and Media Industries Federation). These organizations have raised the gray balance to a new level, which is why this present work has been carried out.

The GRACol Committee has developed a new calibration method, the so-called G7 Method. The main benefit of G7 over traditional calibration methods is more constant gray-scale appearance. G7 is the basis for the latest SWOP 2007 and GRACol 2007 Specifications and has also been used successfully on newsprint, flexo, gravure, inkjet, dye-sublimation, and electro-photographic printing (IDEAlliance, 2006).

ECI has developed the ECI/bdvm Gray Control Strip. This strip has been developed for printers as an aid to help balance the press process in the best way possible by utilizing a standardized proof (ECI/bvdm, 2007). The strip contains gray balance patches that "allow a quick and convenient visual control" (ECI/bvdm, 2007).

Both specifications are detailed but complicated to understand and to put into practice. They also miss a clear connection to the previous step in the process chain - the photographers and the advertising agencies.

Image quality has been driven by higher resolution printing and improved color-calibration methods. As the image quality approaches photo quality, the neutral gray calibration becomes more critical (Huanzhao, 2003). For photographers there are check lists (for example www.blf.se, BLF=Bildleverantörernas Förening, Swedish Picture Suppliers Association) that describe the need for checking for sufficient detail in highlights and shadows, but also the need for checking for where it's relevant that the whites and grays are neutral. As the gray balance is important both for photo and print, one must consider the gray balance at the RGB-to-CMYK conversion.

Objective

The first objective of this study has been to evaluate the subjective quality experience (and objectively measurable factors) of print, where the quality control has been carried out with gray balance in sheet-fed offset. The second purpose was to try to implement the gray balance as a quality control tool for the printers in sheet-fed offset press.

Methodology

This study about printing by gray balance in sheet offset is based on objective evaluation (measuring of density, spectral measuring, creation and comparison of print profiles) and subjective evaluation (paired comparison, (Torgerson, 1958)). The study started with two test printings (Printing 1 and Printing 2) to check the printing parameters in the Heidelberg Speedmaster-74 (Spektra screening, a hybrid half-tone screening technology). The paper used in this study was a glossy paper 130g/m2. The print test form contained, in addition to different control strips, a color image and a neutral image which was printed by CMY. The print tests, Printing 3 (i.e. controlling by density) and Printing 4 (i.e. controlling by gray balance) were performed in two ways during the same day and Printing 5 (i.e. printing of the images separated by different profiles) was printed two months later.

a) the print which was controlled by density
(called Printing 3 in this study)

100 sheets among the accepted prints were randomly selected and measured (Techkon spectrophotometer, measuring of the ΔE_{ab}). Ten of these 100 sheets that had the best agreement with the ISO-standard 12647-2:2004/Amd.1:2007(E), were also measured by EyeOne (X-Rite). The subjective evaluation of the printed images was done by paired comparison. Print ICC-profiles based on the best sheets were created.

b) the print which was controlled only by gray balance
(called Printing 4 in this study)

The sheets which were needed by the printer to obtain an acceptable gray balance were collected and measured in order to control human eyes. 100 sheets from the accepted prints were randomly selected and measured (Techkon spectrophotometer, measuring of the ΔE_{ab}). Ten of these 100 sheets, which had the best agreement with the ISO-standard 12647-2:2004/Amd.1:2007(E), were also measured by EyeOne (X-Rite). The subjective evaluation of the printed images was done by paired comparison. Print ICC-profiles based on the best sheets were created.

The subjective evaluation was done using ten persons, students and teachers at a college department of Graphic Arts Technology. These persons were selected because of their depth of knowledge regarding graphic arts terminology, for example color cast and gray balance. The test persons could see and compare two images at a time-paired comparison. The evaluation was done as follows: the image which was judged as the best was given 1 point (100 points maximum) and the other one got 0 points. Based on the subjective evaluation, mean values and standard deviations were calculated. The test persons were instructed to judge the image quality regarding color cast and best gray balance. Prior to the paired comparison, every person was checked (on a calibrated computer screen) for color blindness using the Ishihara Test for Color Blindness (www.toledo-bend.com/colorblind/Ishihara.html). All ten test persons passed this test. The images from both prints, Printing 3 and 4 (i.e density versus gray balance) were also compared to each other.

c) the print which contains the different separated images (called Printing 5 in this study)

The images (the color image and the neutral image) were separated using the new ICC profiles (based on Printing 3 and 4) and printed in a new run. The results were evaluated subjectively and also compared with the same image separated by *ISOcoated_v2_300_eci.icc*. On the print test form, there were also different patches of gray in order to allow subjective and objective evaluation of the differences in the patches.

Implementation was carried out after the tests at the Company A. The Company A has 47 employees of which six were involved in the tests and the implementation. The desires from the company management were to make ready time shorter and to make a faster acceptable first sheet with preserved quality. Implementation started with education and semi-structured interviews with the printers (four printers).

The Company A *(*sheet- fed offset) :

Printing presses: Heidelberg Speedmaster-74, HP Indigo press 3050
Contract proofing system: Epson Stylus Pro 4800
RIP: EFI Colorproof˙ XF 3.1
CTP: PlateRite 4300 Thermal Plate Recorder
Work flow: Screen Trueflow with Spektra Hybrid Screening Technology
CMYK Optimizer: Alwan CMYK Optimizer

Specifications of the software and equipment used in this study:
Software: Adobe Illustrator CS3, Adobe Photoshop CS3, Adobe InDesign CS3, Gretag Macbeth ProfileMaker Pro 5.0.8, Techkon SpectroDense Connect 2.2
Measurement: Gretag Macbeth Spectroscan, EyeOne - X-Rite

The tests and their results

The results of this study are presented in six parts:

1) **test Printing 3 (P3), controlling by density,**
evaluation and measuring of the sheets
2) **test Printing 4 (P4,) controlling by gray balance**
evaluation and measuring of the sheets
3) **evaluation and comparison of printing by density and printing by gray balance (P3 versus P4)**
4) **creation of the profiles based on printing by density and on printing by gray balance**
5) **the Printing 5 (Printing number 5) of the images which were separated by profiles based on printing by density and by gray balance**
6) **implementation of the gray balance as a tool for the printers for quality control in sheet-fed offset press**

Test Printing (P3), controlling by density

A test form for printing by density was created, see figure 1. The test form contains IT-8 test target TC3.5 CMYK i1(A3) (ProfileMaker Pro 5.0.8), gray balance patches, the neutral image printed in CMY colors, the color image, media wedge control patches (www.fogra.org), dot gain patches, blur control patches. In order to get optimal quality, "calibration" prints were made before Printing 3. During these two printings, the cyan-curve was corrected and the printing parameters measured.

Figure 1: The created test form in Adobe InDesign.

For Printing 3, the printers were instructed to check the prints for density; the target density in this printing was: C 1.48-1.51 M 1.46 Y 1.30-1.32 K 1.89. After approval, 100 different sheets were taken. These sheets were measured and eight of the best sheets and two of the worst sheets were chosen for objective and subjective evaluation. The measured patches were placed directly below the images, see figure 2.

Figure 2: The measured area below the neutral image and the color image.

These patches were measured according to the ISO-standard 12647-2:2004, see figure 3, and the CIELAB ΔE^*_{ab} - values (Field, 2004) were calculated, see figures 4 and 5. The reference value was ΔE_{ab} =5, to the ISO-standard 12647-2:2004. The yellow ink showed the higst ΔE_{ab}, ΔE_{ab}=12, the lowest ΔE_{ab} had magenta and cyan which was within tolerances according to the standard. The sheets were described as P3 (=printing number 3) A-L. Ten sheets (A-L) gave 45 comparisons for every test person.

Parameter	Colour			
	Black	Cyan[a]	Magenta[a]	Yellow[a]
Deviation tolerance	5	5	5	5
Variation tolerance[a]	4	4	4	5

[a] The contribution of the hue difference shall not exceed 2,5.

Figure 3: CIELAB ΔE^*_{ab} tolerances for the solids of the process colors, ISO-standard 12647-2.

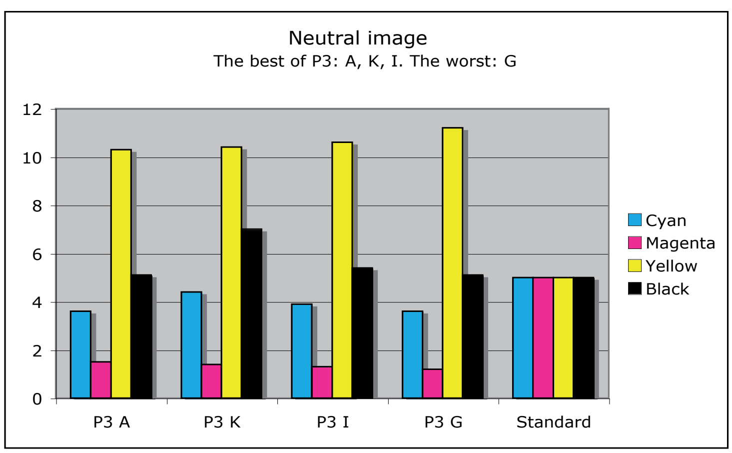

Figure 4: The measured ΔE_{ab} in CMYK colors below the neutral image - Printing 3. Y-axis = ΔE_{ab}, x-axis = the sheets and the standard values.

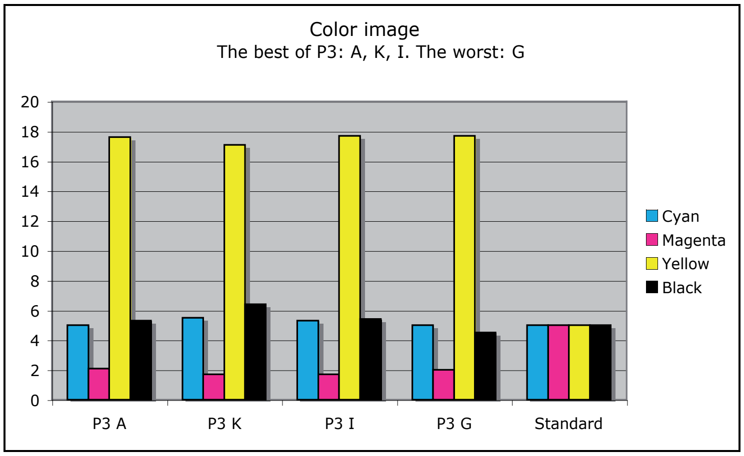

Figure 5: The measured delta E_{ab} in CMYK colors below the color image.

The measured density can be seen in figure 6. The printers had a problem with the density of yellow ink; the measured density in yellow is lower than the target density, figures 4, 5 and 6.

	Neutral image				Color image			
	C	M	Y	B	C	M	Y	B
A	1.3	1.45	1.16	1.91	1.23	1.43	1.01	1.56
K	1.27	1.44	1.15	1.87	1.22	1.41	0.99	1.53
I	1.28	1.45	1.15	1.87	1.23	1.41	0.99	1.55
G	1.31	1.47	1.14	1.89	1.24	1.42	0.99	1.66

Figure 6: The measured density in sheets A, K, I (example on the best sheets) and G (example on the worse sheet) from Printing number 3.

The result of the subjective evaluation:
The evaluation gave the distribution of points between the sheets. The mean value and the standard deviation have been calculated, see table 1. Values in the black column (i.e. the first and the third column) indicate the color image; and values in the gray column (i.e. the second and the fourth column) indicate the neutral image.

neutral image:

Sheets with the highest number of points: sheet A=81p, sheet H=80p,

Table 1: The calculated mean values and standard deviations (SD), Printing 3. Black = the color image, gray = the neutral image.

Sheets	Mean		SD	
A	7.1	7.1	1.7	2.4
B	5.7	6.8	1.6	2.4
C	7.2	6.3	1.5	2.4
D	5.6	5.8	1.2	1.5
E	2.1	3.0	1.4	1.5
F	6.1	1.6	2.9	3.0
G	1.4	1.4	0.7	1.2
H	6.6	8.0	1.3	2.2
I	7.6	7.4	1.1	1.1
J	2.2	3.8	2.6	2.0
K	8.0	7.4	1.1	2.3
L	7.1	7.1	2.3	2.3

sheet I=74p, sheet K=74p, sheet L=71 and the lowest number of points had sheet G=14p.

color image:

Sheets with the highest number of points: sheet K=80p, sheet I=76p, sheet C=72p A=71p, L=71p and sheet G=14p had the lowest number of points.

The sheets with combinations of the highest number of points for both the color image and the neutral image became A, K, I. Together with sheet G (the lowest number of points), these sheets were selected for the following tests.

The IT.8 target TC3.5 CMYK i1(A3) was measured and the profiles for the printing were created (ProfileMaker). The difference in size between the profiles based on different sheets is shown in figure 7. The sizes of sheets A, K , I and G are almost similar.

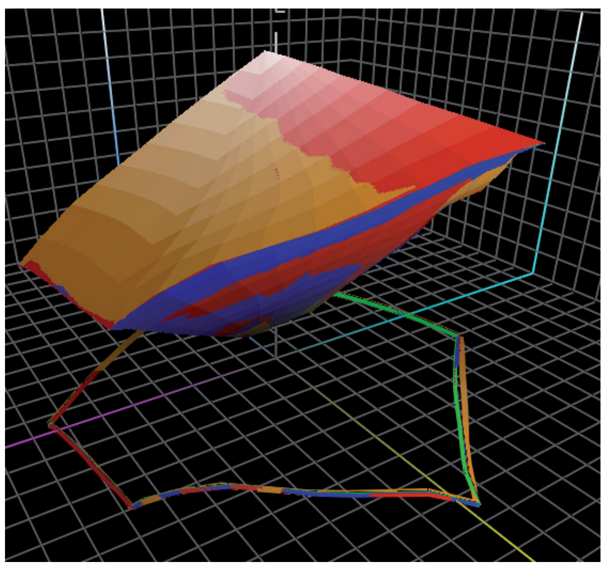

Figure 7: The color gamut of P3 A (red color), P3 K (green color), P3 I (blue color) and T3G (orange color).

The measuring of TC3.5 CMYK i1(A3) gave the possibility to compare the dot gain curves in ProfileMaker, see figure 8. Sheet G has the biggest problem with dot gain in all colors. The subjective evaluation showed that the test persons discovered the quality problem with sheet G, which got the lowest number of points.

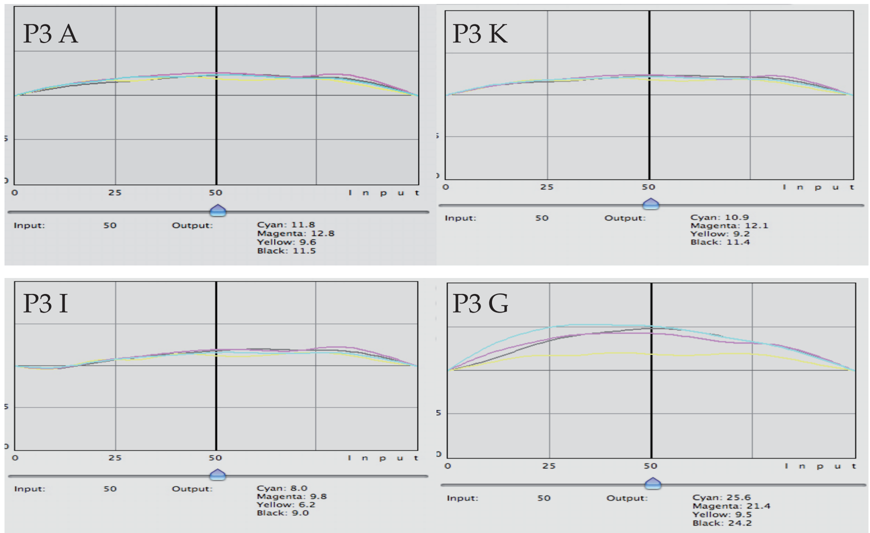

Figure 8: The pictures of the dot gain in sheets A, K, I and G

Summary - Printing 3

Ten sheets in Printing 3 have been evaluated. The subjective evaluation identified the three best sheets A, K, I, as well as sheet G which got the lowest number of points in the paired comparison. These sheets were selected for the following tests. The reason for selecting sheet G for further tests is that we wanted to "test" the observers in their judgments and as a control of the instructions given to the test persons. There is a significant (95% level) difference between sheet G and the sheets A, K and I. However, the sheets showed an almost similar gamut. Sheet G had the biggest problem with dot gain, which the observers noticed in the subjective evaluation with the commentary that "something is wrong in this image". The density varied across the sheets - the best density and the $\Delta E_{ab} \leq 5$ was in the left part of the test form, below the neutral image was density higher and ΔE_{ab} lower than below the color image.

Test Printing (P4), controlling by gray balance

Gray balance strips were added to the test form from Printing 3. The printers were instructed to print only by looking at the gray balance strip. However, they measured density in black ink and then compared visually the strip which contained only K with the strip which contained the chromatic gray CMY. The strip contained patches of chromatic gray CMY 50 40 40 and the true gray K=67%, figure 9.

The measured density can be seen in figure 10. The same trend (as in Printing 3) of unequal distribution of density across the sheet could be seen.

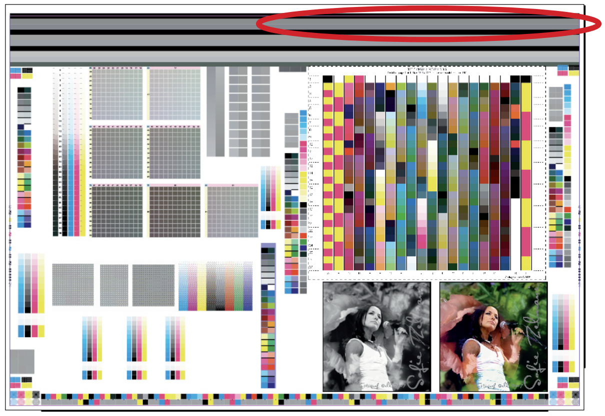

Figure 9: The created test form in Adobe InDesign for controlling by gray balance. The red circle shows the strips which were used of the printer for the controlling of printing.

	Neutral image				Color image			
	C	M	Y	B	C	M	Y	B
H	1.23	1.33	1.38	1.92	1.32	1.27	1.28	1.75
I	1.22	1.31	1.38	1.89	1.28	1.23	1.26	1.7
J	1.2	1.32	1.37	1.84	1.26	1.2	1.25	1.7
L	1.21	1.3	1.15	1.9	1.16	1.21	0.99	1.64
B	1.2	1.31	1.37	1.77	1.27	1.23	1.25	1.7

Figure 10: The measured density in the evaluated sheets in Printing 4: H, I, J, L and B

The method for objective and subjective evaluation was the same as in Printing 3.

The result of the subjective evaluation:

The evaluation prided a distribution of points between the sheets. The mean value and the standard deviation have been calculated, see table 2. Values in the black column (i.e. the first and the third column) indicate the color image and values in the gray column (i.e. the second and the fourth column) indicate the neutral image.

Table 2: The calculated mean values and standard deviations (SD), Printing 4. Black = the color image, gray = the neutral image.

Sheets	Mean		SD	
A	5.3	2.7	2.3	1.9
B	5.2	2.2	1.8	2.8
C	4.4	3.3	2.2	2.7
D	6.2	5.0	1.5	1.4
E	5.9	5.7	0.9	0.8
F	6.0	5.9	1.6	1.7
G	5.9	5.9	1.9	1.9
H	7.6	7.4	1.8	2.1
I	7.8	7.3	1.0	1.8
J	6.2	6.2	1.8	1.8
K	3.0	2.5	3.1	2.1
L	2.5	2.1	3.1	2.4

neutral image:

Sheets with the highest number of points: sheet L=83, J=78p, H=74p, I=74p, K=66p. Sheet B=22p had the lowest number of points.

color image:

Sheets with the highest number of points: sheet I=78p, H=76p; J=62, D=62p, F=60p. Sheet L=25p had the lowest number of points

The sheets with combination of the highest number of points for both the color image and the neutral image were H, I, J. Together with sheet B (which had the lowest number of points) these sheets were selected for the following tests.

The measurements of ΔE_{ab} in CMYK colors (below the neutral and the color images) according to the standard are shown in figures 11 and 12.

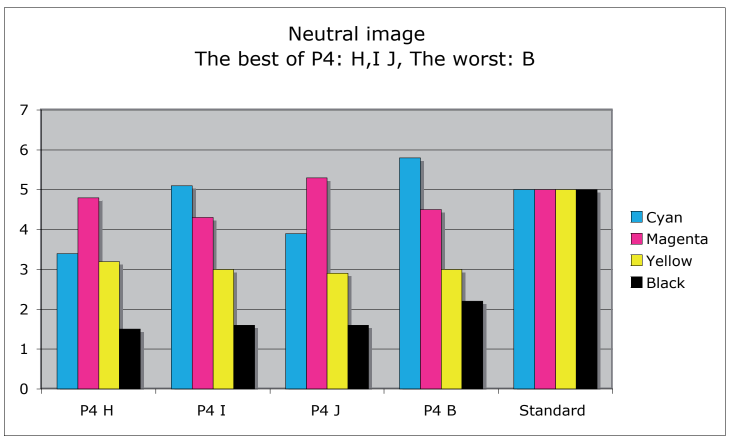

Figure 11: The measured ΔE_{ab} in CMYK colors below the neutral image.

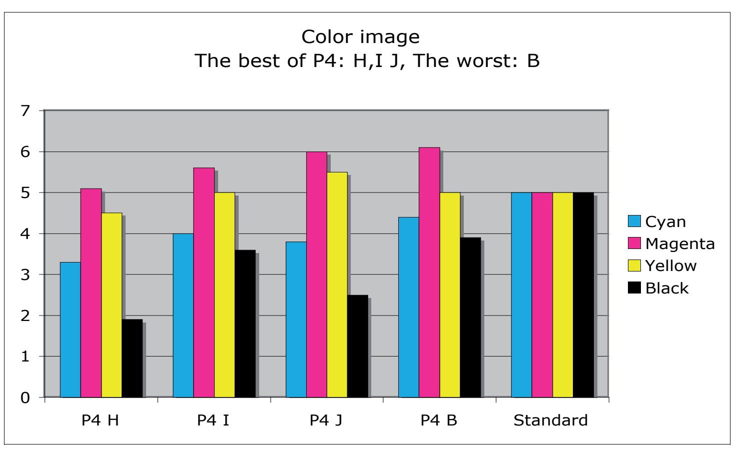

Figure 12: The measured ΔE_{ab} in CMYK colors below the color image.

As seen in figures 11 and 12 the printer had the same problem with the yellow ink as during Printing 3. The IT8 test targets were measured and the profiles for the printing were created, see figure 13. The sizes of the profiles were also almost identical in Printing 4. The measured profiles gave information about dot gain, see figure 14.

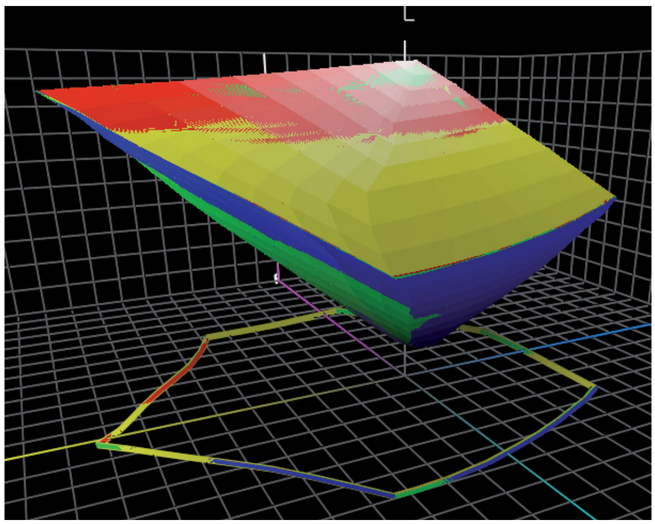

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Figure 13: The color gamut of P4 J (red color), P4 I (green color), P4 H (blue color) and P4 B (yellow color).

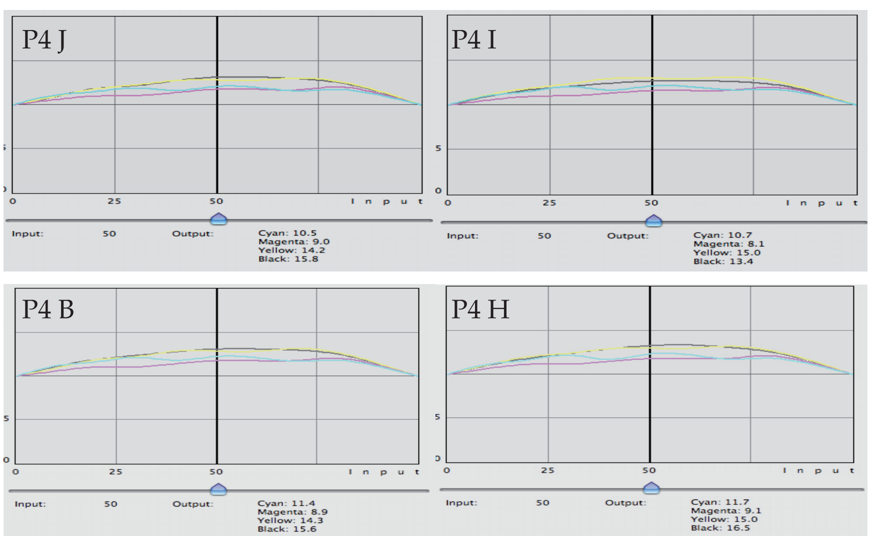

Figure 14: The pictures of the dot gain in sheets J, I, B and H.

As described before, Printing 4 was checked only by gray balance. The printer was asked to only check the printing by eye and by looking at the gray balance strip - the chromatic gray CMY (50 40 40) and the true K=67%. To achieve an, acceptable for him, gray balance (i.e. an OK print), the printer needed 26 sheets for controlling and adjusting. Every fourth sheet of these 26 was measured and evaluated objectively (ΔE_{ab}) and subjectively (paired comparison). The measurements of ΔE_{ab} are presented in figures 15 and 16.

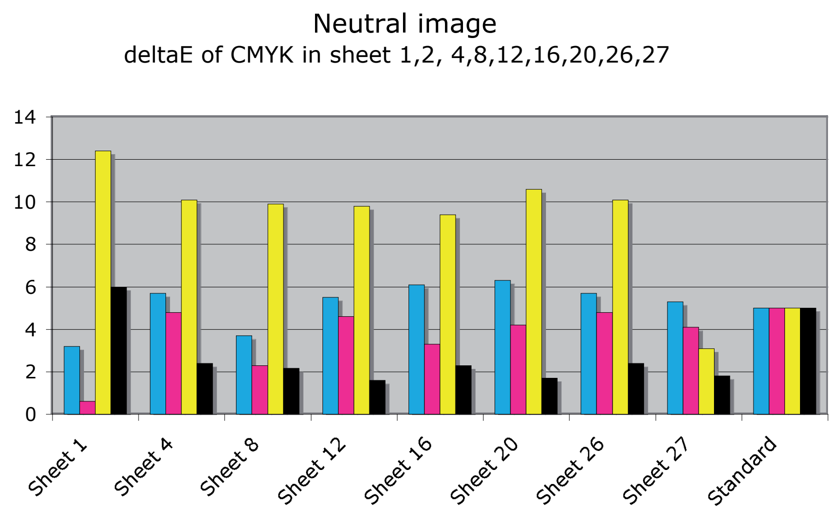

Figure 15: The measured ΔE_{ab} in CMYK colors below the neutral image. The sheet 27 is the sheet labeled as P4 H.

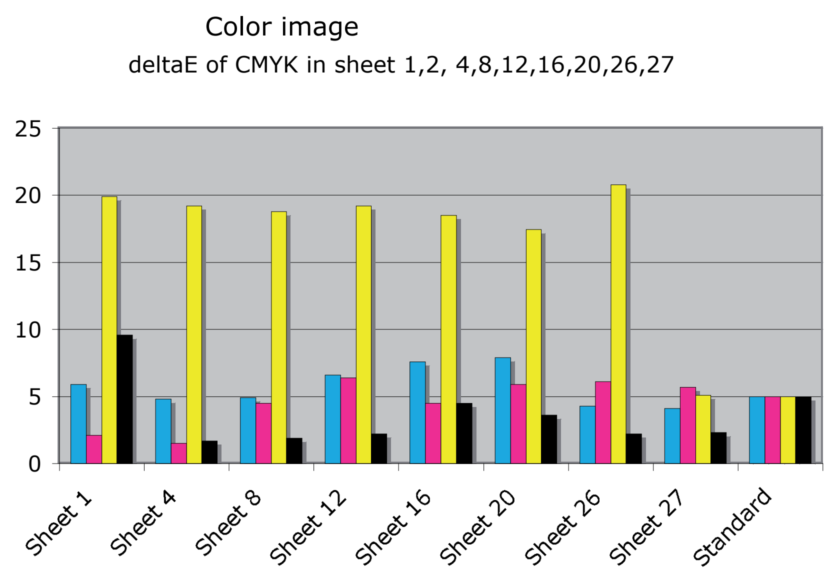

Figure 16: The measured ΔE_{ab} in CMYK colors below the color image. The sheet 27 is the sheet labeled as P4 H.

The result of the paired comparison is presented in figures 17 and 18 for the neutral images and in figures 19 and 20 for the color images. Sheet number 27 is sheet P4 H (sheet H from Printing 4) which was collected after the printer was satisfied with the visual judgment of gray balance and this sheet represented the accepted print. The ANOVA (Johnson, 2005) calculation showed that there is no significant difference between the samples at 95% level - within neutral images and for the color images the ANOVA (ANalysis Of VAriance) showed that there is a significant (95% level) difference between at least two of the samples.

Figure 17: The result of the paired comparison - the number of points for the neutral image.

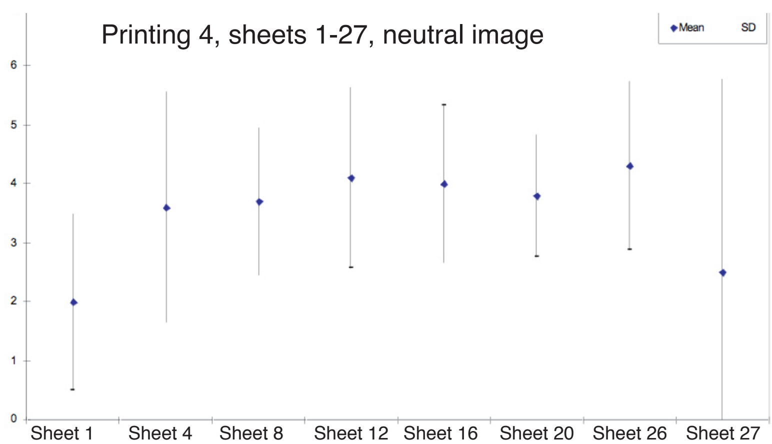

Figure 18: There is no significant difference between the samples at the 95% level.

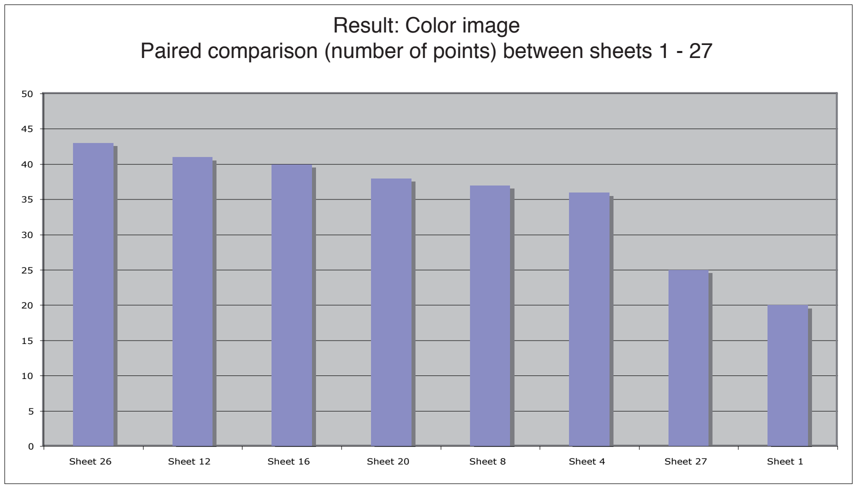

Figure 19: The result of the paired comparison - the number of points for the color image.

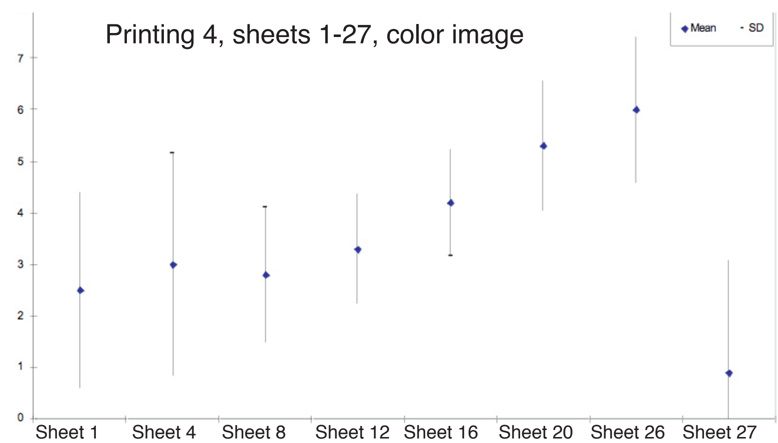

Figure 20: The graph shows that there is a significant (95% level) difference between at least two of the samples.

The profiles for every fourth sheet of the 26 were created and the comparison between them can be seen in figure 21. Sheet 27 shows a bigger area in the yellow part of the gamut.

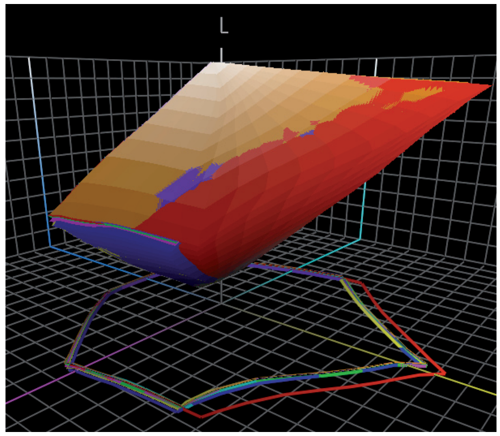

Figure 21: The comparison of profiles based on the sheets 1,4,8,12,16,20,26 and 27 The sheet 27 has a bigger size in the yellow area.

Summary - Printing 4

Printing 4 was checked only by gray balance evaluation. The printer needed 26 sheets to finish the check. Ten sheets in Printing 4 have been evaluated. The subjective evaluation identified the three best sheets, H, I, J. Sheet B got the lowest number of points in the paired comparison. The printer had the same problem (density in the yellow ink) during the printing by gray balance as during Printing 3. As during the other printing tests, the density varied across the sheets. After sheet 26, the following sheets had ΔE ab ≈ 5. In spite of this fact, sheet 27 (i.e. sheet P4 H) got the lowest number of points for the neutral image in the subjective evaluation and the next lowest number of points for the color image. However, three out of ten persons have judged sheet 27 as the best. The last sheet which was checked by the printer, sheet 26, got the highest number of points. The profiles based on the sheets are almost identical, except sheet 27, which has a bigger gamut in the yellow area.

Printing 3 versus Printing 4
(controlling by density versus controlling by gray balance)

A subjective evaluation and comparison between the sheets from Printing 3 (checked by density) and Printing 4 (checked by gray balance) was made. The results show that the Printing 3 was judged as the best for printing of a neutral image, see figure 22. Printing 4 was judged as the best for printing of a color image, see figure 23. Sheets A, C, G, I, L and K from Printing 3 were chosen for this evaluation. Sheets B, G, H (i.e. sheet 27), I, J and K represented Printing 4.

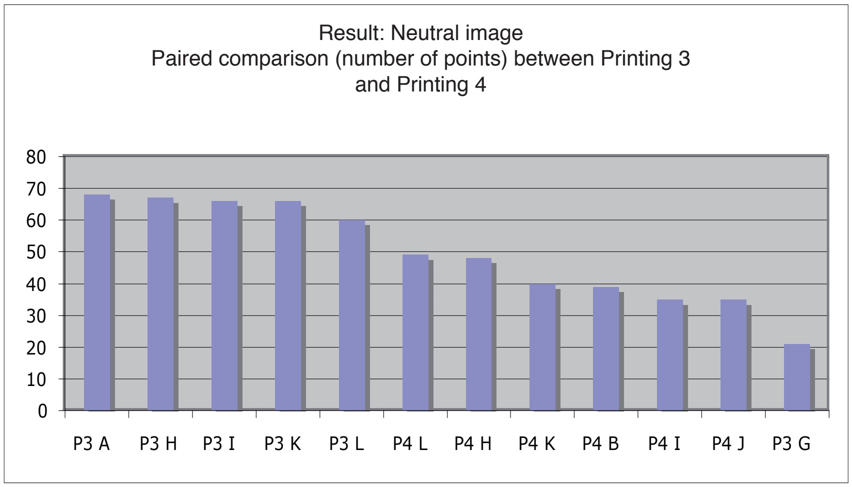

Figure 22: The result of paired comparison for the neutral images.

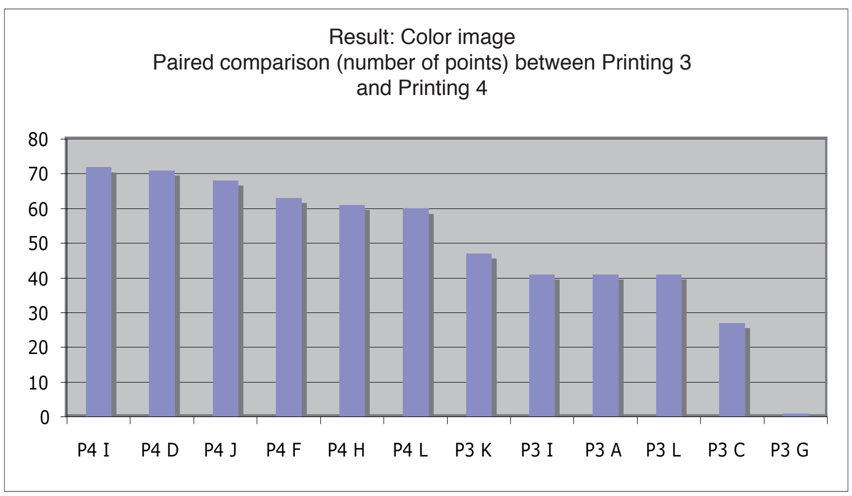

Figure 23: The result of paired comparison for the color images.

A comparison between the profiles based on Printing 3 (sheets A, I) and Printing 4 (sheets H, I J) is shown in figure 24. The comparison shows that the sizes in the same printing are almost identical and coincide. The bigger profile sizes are profiles based on Printing 4 - sheets H, I and J coincide.

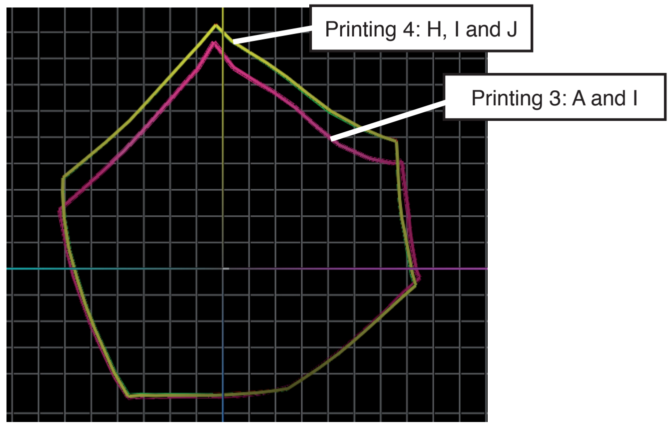

Figure 24: The comparison of the profiles, Printing 3: sheets A and I, Printing 4: sheets H, I and J.

New profiles were created and compared with each other and with *ISO-coated_v2_300_eci.icc.* (www.eci.org), see figure 25. The profile which represented Printing 3 (controlling by density) at a new printing (called Printing 5) was the average from sheets P3 A and P3 I. The profile which represented Printing 4 (controlling by gray balance) was the average from sheets P4 I and P4 J. The profile based on Printing 4 and the ISO-profile have similar sizes. The profile based on Printing 3 has a smaller size in the yellow area. The images were separated with the new profiles (based on Printing 3 and Printing 4) and printed again, Printing 5.

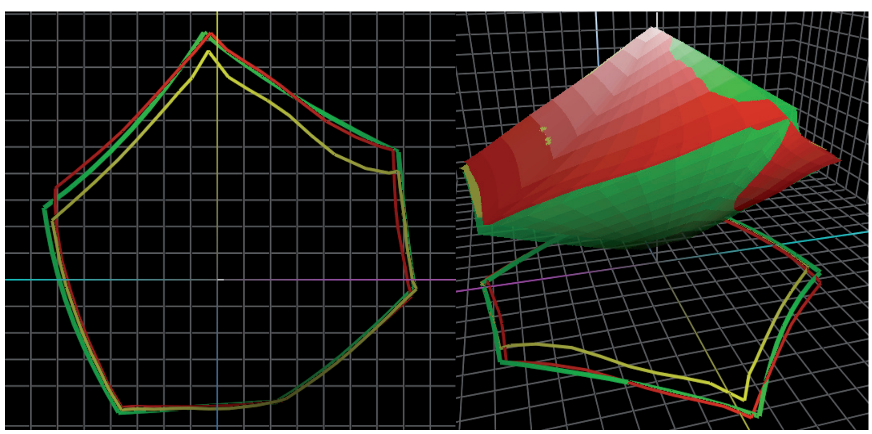

Figure 25: The comparison between the profiles: the red profile is Printing 4, the yellow profile is Printing 3 and the green profile is *ISOcoated_v2_300_eci.icc*.profile.

The adjustments for the profiles in ProfileMaker 5.0 were Perceptual rendering intent: Neutral Gray, gamut mapping: LOGO Chroma Plus, separation: GCR 3, black start: 0, black max 100, TIC (total ink coverage): 290%, black width: 100 (Documentation/English/ProfileMakerPro_5_0).

Summary - P3 versus P4

The subjective evaluation showed that all sheets from Printing 3 except sheet G got a higher number of points in the paired comparison than sheets from Printing 4 for the neutral image. All sheets from Printing 4 got a higher number of points for the color image. The profile based on Printing 4 is more similar in size to *ISOcoated_v2_300_eci.icc* than the profile based on Printing 3.

Test Printing (P5) and the results

A new test form was created for Printing 5, see figure 26. The test form contains the neutral and the color images separated with the *ISOcoated_v2_300_eci.icc* (www.eci.org) and the profiles based on Printing 3 and Printing 4. There is also, on the test form, an image built up with chromatic gray CMY 50 40 40. Inside the patches are the hidden words written in different combinations of 50 40 40 (for example 50 40 38), see the red circle in figure 26.

Figure 26: The new test form for Printing 5, the red circle shows the hidden words inside the patches.

Figure 27: The new strip for Printing 5 - the combination of controlling by density and gray balance.

A new control strip based on checking density and gray balance was created for Printing 5, see figure 27. The strip is based on the Heidelberg strip SM74. The printer had the possibility to see and visually check the gray balance across the sheet but he also had the possibility to measure the density. The chromatic gray patches consist of 50 40 40 and the true K is 67%. A subjective comparison and evaluation was done between the printed images (the neutral and the color images). The first evaluation was done between the printed images separated with a profile based on Printing 3 and Printing 4. In a second evaluation, the test persons had to decide which of the images were more similar to the image that was separated using *ISOcoated_v2_300_eci.icc:*

1) the test persons evaluated (paired comparison) the neutral images and the color images. These images were separated by profiles based on Printing 3 and Printing 4

2) the test persons evaluated (paired comparison) the neutral and the color images which were separated by profiles based on Printing 3 and Printing 4 with the neutral and the color images separated by *ISOcoated_v2_300_eci.icc*.

All test persons preferred both the color image and the neutral image which were separated with profile based on Printing 4 more than the images separated with the profile based on Printing 3, see the results in figure 28. However, all test persons said that both images (neutral and color) from Printing 4 were most similar to the image, which were separated by *ISOcoated_v2_300_eci.icc*.

Neutral image	**Color image**	**Similarity with ISO**
Printing 4 = 10 points	Printing 4 = 10 points	Printing 4 = 10 points
Printing 3 = 0 points	Printing 3 = 0 points	Printing 3 = 0 points

Figure 28: The result from the subjective evaluation. The Printing 4 is the "winner".

The hidden words were written with the differences of the "base patch" CMY 50 40 40). The evaluation showed that the test persons could read the words there ΔE between the word (CMY=50 40 38) and the base patch (50 40 40) was 1.47, see figure 29.

CMY	ΔE	CMY	ΔE
50 40 38	1.47	50 38 40	3.92
52 40 43	2.54	54 40 40	3.03
51 41 41	2.65	50 38 38	3.66
53 40 40	2.78	49 39 39	3.68
50 39 47	2.88	50 38 39	3.91

Figure 29: The simulated example on the "hidden" word and the calculated ΔE values between the chromatic gray CMY patch 50 40 40 and the differences of this patch.

Summary - Printing 5

The neutral image and the color image were printed and separated with profiles based on Printings 3 and 4. The paired evaluation gave an unambiguous winner, Printing 4. The test persons preferred the images separated with the profile based on Printing 4 and these images were also most like the image separated by ISOcoated_v2_300_eci.icc. The lowest ΔE (between the patches) which test persons noticed was 1.47.

Implementation of the gray balance as a tool for the printers for quality control in sheet-fed offset-press - results

The implementation at Company A started directly after the tests, education of the printers and interviews with the printers. Interviews with the printers confirmed that the printers accepted and understood the point of gray balance and the new working procedure. The new strip (see figure 27) from Printing 5 was used for further printing at the Company A. Basic conditions for the usage of gray balance were more efficient measurements, preserved or better quality, and easier communication. The printers measure density in the black ink. When the target density for the black ink is achieved, the printers look at the patches with the gray balance and true gray. They compare the patch which contains true gray (K=67%) with the patch which contains the chromatic gray CMY (50 40 40). The strip also contains the patches with cyan, magenta and yellow (because of the possibility of measuring if the need will arise) but the number of patches has been decreased by 50% to make room for gray balance patches.

The results:

- interviews with the printers (four printers) confirmed that the printers accepted and understood the point of gray balance and the new working procedure
- interviews with the printers showed the agreement with each other
- fewer time-consuming measurements due to fewer patches, i.e. shorter make ready time
- preserved good quality

The comments from the printers:

- “fewer time-consuming measurements”
- “sometimes I am still unsure of myself”
- “I have a possibility to focusing on the special area on the sheet
- “we can manage the sheets faster”
- “I can see a deviation on the sheet and I can do the correction very fast in the right area”
- “I didn´t know that gray balance could be a fast control tool of

the quality and of the measurements, also I need to measure the density"

- "it is easier to communicate with the involved parts"

Conclusion

The study shows that the human eye is a very good instrument for seeing differences in gray balance. The results show that the sheet-fed offset process can be controlled in same way as the newspaper process. The images which were separated with the ICC-profile "based on the eye" (Printing 4) showed in the subjective evaluation better agreement with the *ISOcoated_v2_300_eci.icc.*

This study about gray balance has shown that:

1) The gray balance can be used as a control parameter for control of quality in sheet-fed offset. This assumes of course that the printer has proper visual color vision.

2) A faster make-ready time and more reliable print quality (fewer variations during production) can be achieved.

The new strip which is based on gray balance is in use today at the printing house where it was tested. However today, the strip also contains the patches with cyan, magenta and yellow but the number of patches has been decreased by 50% to make room for gray balance patches. The results of this study show that the effectiveness has increased due to the fact that the number of measurements on the control-strip has decreased by 50%. It is easier for the printer to visually detect deviations without time-consuming measurements and without waste of paper, especially if press is running during evaluations and adjustments.

3) The printer and the customer have access to a tool which facilitates communication, generates fewer misunderstandings, leads to less product returns, etc.

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