Colour Rendering Aspects in Digital Printing

Marianne Klaman*

Keywords: Colour, colour rendering, digital printing

Abstract

Colour control in digital printing is an area not yet as well penetrated as colour control and colour management for conventional printing in offset.

This paper presents results from a study concerning different aspects of colour rendering in digital printing. The study was carried out in co-operation between Framkom and representatives from Swedish media and paper institutions and industry. About 40 different paper qualities have been tested for aspects of print quality. The paper focuses on the results obtained from the study with respect to the influence of paper quality, press parameters and screening technology on the colour rendering and an attempt has been made to quantify these effects.

Attempts to control the colour in the different print trials have been made with the help of colour management and these results are reported in terms of measured colour and perceptually obtained quality. These results will be discussed according to technology and front-end solutions of the digital press, paper quality and estimated effect of the screening technology used.
The results showed that offset print quality on coated paper is still ahead of what is possible in digital print technology today. Slightly discernible to more accentuated differences between prints from the different presses were registered both for measured colour data and perceived colour. Differences exist

* Framkom. Research Organisation Media and Communication Technology

between offset and digital print technology and there is a difference between those and the way they depend of paper quality. Increased size of colour gamut does not always mean increased print quality. Certain colours are more difficult to reproduce and differences depend on print technology. Paper roughness influences the colour gamut, and dot gain has a strong impact on colour rendering.

Introduction

Colour Management and the establishment of ICC-profiles have progressed during the last few years. Several articles and reports have been published on the matter. The European Color Initiative (ECI, 1999) has drawn up guidelines for how colour data must be saved and processed device-independently. The guidelines give recommendations for the introduction of efficient ICC-workflows in reproduction technology based on the ICC-standard. Furthermore, the guidelines give advice on the automation of device-independent colour processing and how safe exchange of ICC-capable colour data can be organized. McDowell (2000) has analysed Colour Management potential benefits and/or impact on standardising, and stressed the need, for improved workflows in large printing and publishing companies. The workflow of Colour Management has also been the main issue in the work of The Graphic Arts Institute of Denmark, commissioned by IFRA, (2000). Kohler (2000) has outlined the achievements so far in the work of The International Colour Consortium and specified the remaining challenges.

Background

In response to the need for deeper knowledge on the handling of colour management in digital print technology, a major project was initiated, whose intention and goal were to control the colour flow with ICC-profiles, to choose appropriate paper grades for every single press and to compare the quality possible to achieve in digital printing with traditional printing techniques such as offset and flexographic printing.

This study was initiated by Framkom and DPC (Digital Printing Center) at Mid Sweden University involving STFI (Swedish Pulp and Paper Research Institute) and supported by paper suppliers in Sweden, part of the graphical industry in the region of Mid Sweden University and some of the digital printing equipment suppliers.

Extracted from the main project, the special colour issues were analysed and some tests were added to more specifically show the influence of certain press parameters on colour and colour rendering. In this paper I will present results from that special study. The main goal was to analyse the effects of colour control with ICC-profiles and to discuss the differences that will still exist and be visually discernible between prints from different digital print technologies.

The goal was also to create a model for colour analysis and point out relevant parameters affecting colour quality.

Materials and Methods

Printing presses and substrates

Totally 41 different substrates, paper and paperboard, were printed. They were made of chemical wood-free pulp. In order to evaluate the sensitivity of each printing process to substrate, all levels of surface treatment, from uncoated to fully coated gloss (see Table 1) were included in the study. To achieve optimal print quality, the substrate was as far as possible adapted to each printing process. The grammage of the papers were about 130 gsm and for the paperboard 220 gsm and 250 gsm. The difference between the paper qualities lay mainly in the surface treatment. The typical properties of each paper and paperboard are shown in Table 2.

Eight presses were used in the study: two electrographic high quality digital presses, one liquid toner high quality digital press, one common colour copier and one large format ink-jet printer. As a complement and a kind of reference, a sheet-fed offset press and two flexographic high quality presses were used.

Table 1. Surface treatment of printed substrates, totally 41 different papers and paperboards printed in eight presses.

Substrate / Printing press	Un-coated	Medium-Coated	Highly coated matte	Highly coated gloss	Highly coated matte Paper-board	Highly coated glossy paper-board
Offset	1	2	1	1	1	1
Colour copier	2	1	1	1		
Liquid toner	2	1	1	1	1	1
El.graph. 1	2	1	1	1		1
El.graph. 2	2	1	1	1	1	1
Inkjet				1		
Flexo UV			1	1	1	1
Flexo Water			1	1	1	1

Table 2. Typical properties of each paper and paperboard quality.

Quality / Property	Uncoated paper	Medium-Coated paper	Highly coated matte paper	Highly coated gloss paper	Highly coated matte paperboard	Highly coated glossy paperboard
Surface roughness (PPM)	5	3	2,5	1	1.5	0.8
Whiteness (CIE)	160	115	110	115	115	120
Grammage (g/sqm)	115/130/160	135	130	130	220	250
Thickness (um)	145/175	150	120	100	265	280
Gloss (TAPPI 75°)	7	15	25	70	35	75

Creation of the ICC-Profiles

ICC-profiles were created for every combination of paper and printing press, altogether 43 different ICC-profiles. In the creation procedure the printing trials were controlled according to standard density and dot gain. The most important task was to control those parameters in order to establish a stable and reproducible process.

For the calculation and creation of ICC-profiles ProfileMaker Pro 3.0 from LOGO was used. The measurements were performed with a Gretag Macbeth spectrophotometer, Spectrolino/Spectroscan. Photoshop 5.5 was used for implementation of the ICC-profiles in the test document. For the offset process and the liquid toner process the profiling was made in the same way but not performed by us but by the company that also performed the printing trials for these tests.

Density was measured with a Gretag densitometer according to ISO 12647-1 and colour failure was measured by a Gretag SPM 100 spectrophotometer, according to ISO 13655:1996.

Colour gamut

Colour gamut was measured with an Elrepho 200 spectrophotometer. The gamut volume, V, was obtained by adding the volumes of tetrahedrons where the co-ordinates were CMY, RGB and the white and black co-ordinates. This equation was used in an earlier study (Klaman, M., 1995) and proved to be useful for this kind of test model.

For one tetrahedron the volume is calculated by:

$$V = \begin{vmatrix} L_0 & a_0 & b_0 & 1 \\ L_1 & a_1 & b_1 & 1 \\ L_2 & a_2 & b_2 & 1 \\ L_3 & a_3 & b_3 & 1 \end{vmatrix}$$

In addition L*, a* and b*-values were calculated for all paper and press combinations with the same equipment, Spectrolino/Spectroscan.

Difficult colours

To evaluate how different colours within the gamut could be reproduced, certain colours were chosen and measured in the IT8.7 test chart. These colours were considered to be critical to reproduce or sensitive to influencing parameters, They were: C7 (orange), E8 (green), J4 (blue) and C22 (skin tone). The measurements were made on one sheet. To calculate the colour difference, ΔE^*, for these values on different substrates the value from the highest ranked sample in the visual perception study was used as reference.

Comparison of ΔE^*-values for different presses

The software function that is included in ProfileMaker Pro and which enables the calculation of a total ΔE^*-value between different groups of ΔE^*-values has been used to compare the colour rendering for some of the presses. The colour values were measured for the TC 2.9 chart with 432 colour patches, included in the Profile MakerPro software and for the IT8.7 chart with 286 colour patches. The total ΔE^*-value expresses the difference between the reference and the proof. The maximum ΔE^*-values are also obtained for each combination.

Dot gain and ICC-profiling

In order to analyse the influence of different dot gain in digital presses a simulation test was made in one of the electrophotographic digital presses where the dot gain values were increased and decreased from the "normal" setting. The L*, a*- and b*-values were calculated with Spectrolino/Spectroscan.

Relationship between the measured data and the perception data

Data from the main study was used in order to analyse the influence of certain paper properties such as whiteness and roughness. Results have been obtained earlier for studies concerning offset in this respect (Klaman, Anderson, 1999) and for digital printers (Klaman, 1999). The relationship between assessed print quality and assessed colour failure has been analysed.

Dot Reproduction

Since the type of screening, the different RIPs used for the presses and the different front end solutions are all supposed to influence the way the dots (whether they be conventional dots as in offset and flexo or more unspecified dots as in printers, copiers and also high quality digital presses) will reproduce, and thereby also influence the colour rendering, the dot reproduction was studied. Images were captured and analysed.

Apparatus

The Dage MTI-DC330E 8-bit, a CCD-camera mounted on a Nikon SMZ-U microscope, was used to acquire the images (1.26x0.94 mm^2 imaged by 768x572 pixels; 0.164 µm/pixel). The digital images were handled with the Optimate 6.2 software.

Procedure

Images of black 40% (K40) dots were acquired with the CCD-camera fitted on the microscope to illustrate the dot reproduction of the prints. The images were stored in 8-bit greyscale tiff-format. (These tests were performed at STFI).

Perceptual evaluation - observation settings, procedures and assessments

One sheet of size A3 was designed for evaluating print quality. Two images were used, one of which was a still life "silverware", representing a low-key image with a homogeneous neutral grey background and silverware for reproduction and evaluation of highlights, sharpness and gloss. The other motif was a portrait of a girl representing a medium- to high-key image for reproduction of skin tones and fine details in hair and dress. None of the images were ISO standard images (ISO, 1997) but were chosen to be as similar as possible to these. The main reason for not using the ISO standard images is the fact that they are delivered in CMYK, already compensated for a standard offset dot gain of 20 %. They were therefore not suitable for this study with different kinds of electrophotograhic presses, liquid toners, and even copiers as well as offset presses, all with different dot gain.

The pictures were attached on a grey paper with Y-value 60, by means of corner slips, with two unprinted papers as backing.

The printed images were presented in standard daylight viewing equipment (Just Normlicht 5000) placed in a light grey painted experimental room illuminated with daylight-simulating light tubes (Philips TLD 36W/95, "Natural Daylight 5300"). The illuminance at the picture location measured by a Hagner Universal Photometer Model S1 was 2000 lux with variations over the table from 1750 to 2000lux (ref].

Results

Colour gamut

In Figure 1 the calculated values for the colour gamuts are shown for the different press and paper combinations. The colour gamut, as expected increases on highly coated paper and decreases on uncoated paper. This is true for offset but not very accentuated for the electrophotographical presses or the liquid toner press. The colour gamut in this study showed the highest values for the liquid toner press, the flexo presses used and for the copier.

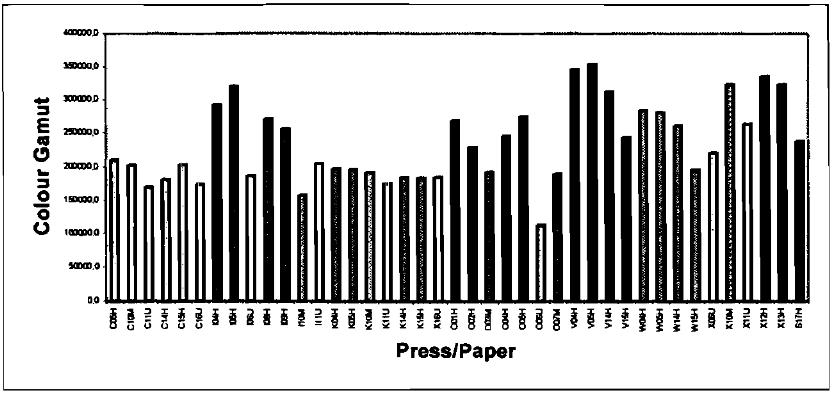


Figure 1. Calculated colour gamuts for each combination of press and paper.

In Figure 2 the a*- and b*-values for five of the presses are visualised in a diagram representing the colour plane of the CIELAB. It is very clear that some of the presses (or the toner or ink) have the potential for a large gamut with respect to the hue values for each primary and secondary colour.

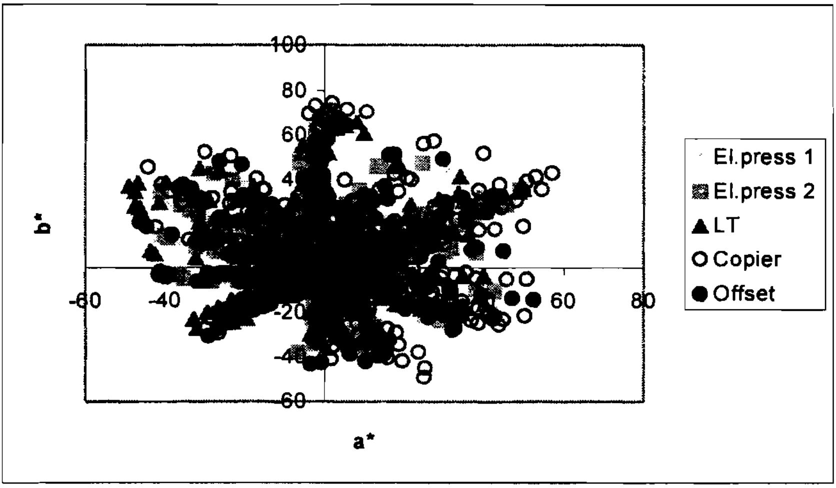


Figure 2 .a and b*-values for the colour patches of the IT8.7 for prints from five of the presses.*

In order to analyse whether a large colour gamut also rendered a good print quality the relationship between gamut and the perceptionally gained print quality was analysed. The result is depicted in Figure 3. A very weak correlation was found between gamut and the corresponding perceptionally assessed print quality.

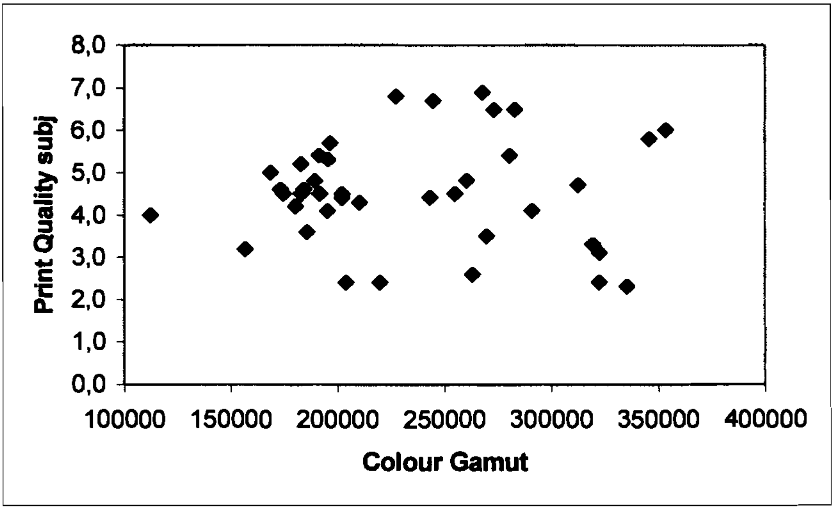


Figure 3. Relationship between colour gamuts and the corresponding print quality values obtained in the perception study.

However, each press was further analysed and the correlation calculated within each group. The relationship was found to be either very weak or at the level of r =0.70 –0.80 as for offset, flexo and one of the electrostatic presses (Table 3).

Performing the same analyse for the relationship between the colour gamut and the perceptually assessed colour failure the correlation was weak except in one case where the correlation coefficient reached the value 0.70.

Table 3. Correlation coefficients for the relationship between the colour gamut obtained for each press/paper combination and the assessed print quality within each group.

Press	Corr. coeff
Liquid toner	0.14
Electrostatic press 1	0.35
Electrostatic press 2	0.71
Offset	0.81
Flexo UV	0.82
Flexo Water	0.71
Copier	0.03

Colour rendering of the colour patches in the IT8.7

To evaluate the colour differences, the a*- respectively b*-values, were plotted. In Figure 4a-b and 5a-b they are shown for one of the electrophotographic presses and the copier and the electrophotographic press and the offset press respectively in each diagram. Although ICC-profiles have been used, there are discernible differences, and the figures show these differences, which seem to be evenly distributed, in the colour space, apart from some distinct peaks.

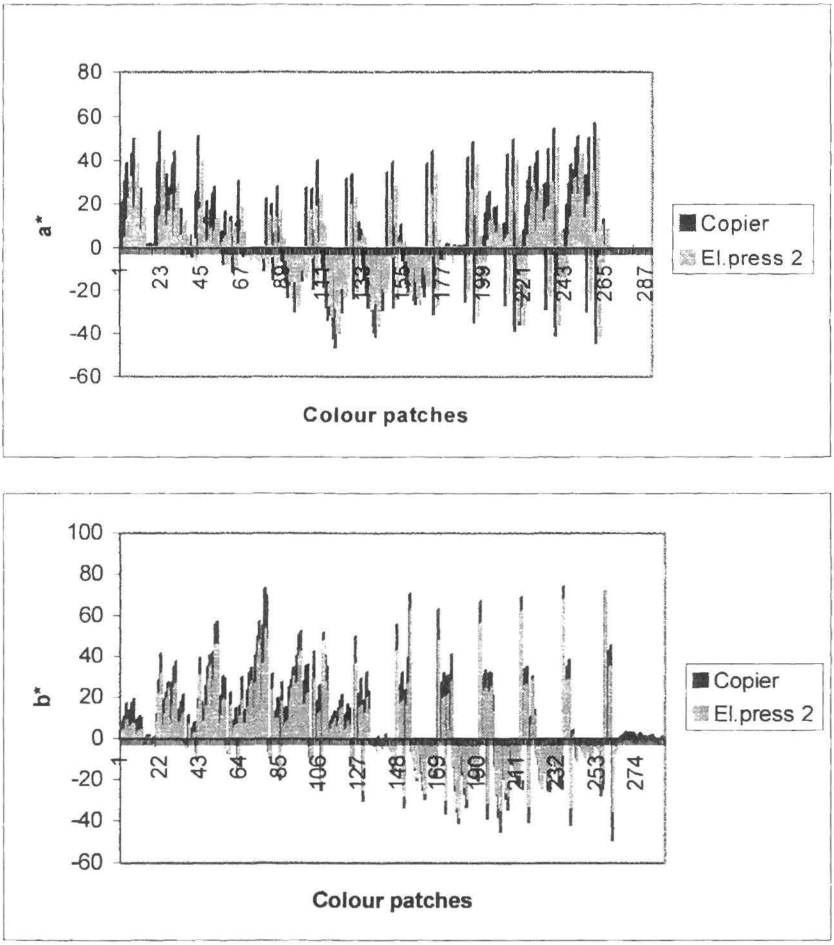
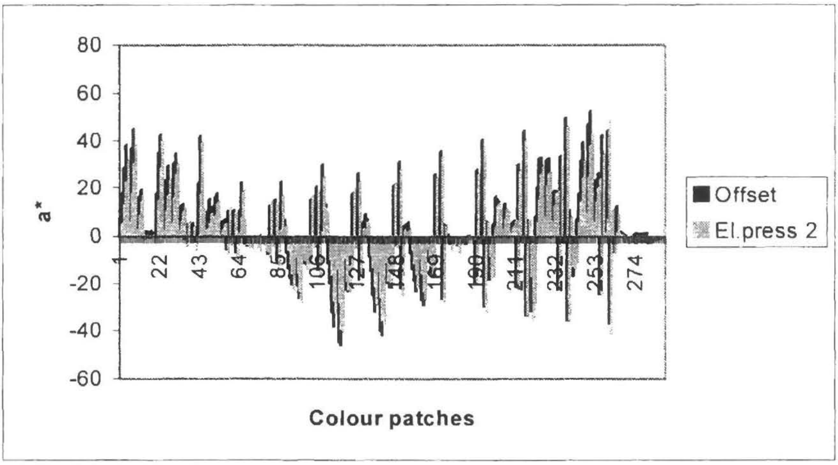


Figure 4 a-b. The colour rendering, expressed in terms of a and b*, of colours from prints of one electrophotographic press and the copier, is shown for all the colour patches included in the IT8.7test chart. The print substrate was a medium coated paper.*



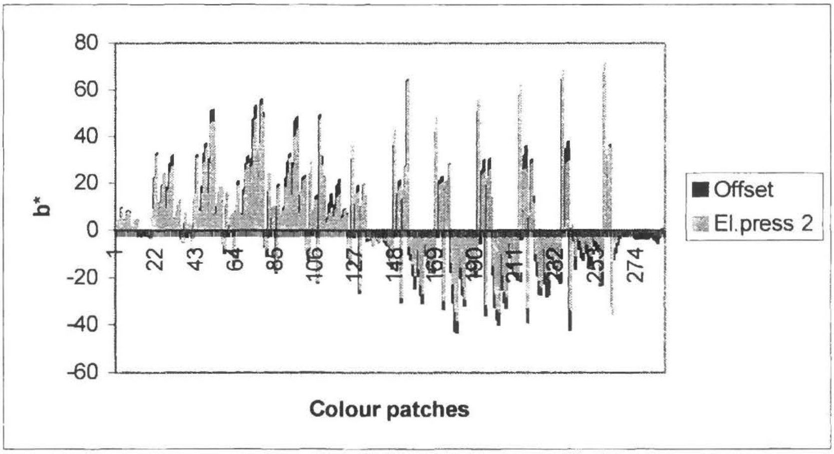


Figure 5 a-b. The colour rendering of colours, expressed in terms of a and b*, from prints of one electrophotographic press and offset press, is shown for all the colour patches included in the IT8.7test chart. The print substrate was a medium coated paper.*

Difficult colours

An analysis of the difficult colours chosen gave the result expressed in Figures 6-9. The reference for the difference evaluation was the L*a*b*-values for the highest ranked sample in the perception evaluation. In the diagrams the values for highly coated, medium-coated and uncoated papers were the calculated mean values for the papers in each group and for each press.

The blue colour was in general the most difficult colour to reproduce. The most dramatic deviation, expressed as ΔE^*, was obtained for the uncoated papers printed in offset. The papers printed in the electrophotographic presses showed the next highest values and the paper printed in ink-jet the lowest. However for the prints from the electrophotographic presses the difference between highly, medium- and uncoated papers were much smaller than for offset and not as pronounced as for offset.

For the green patch the uncoated paper in offset together with the uncoated papers in liquid toner and the papers printed in the electrostatic presses showed the highest ΔE^*-values.

The orange colour was the most difficult to reproduce in the copier. For all the other presses, it was reproduced with almost the same deviation value compared with offset. But as for the blue colour, the differences between the different paper grades were not very pronounced for the electrophotographic presses. For the copier, the result was in fact quite the opposite, with the best result for the uncoated paper. Lastly, the skin tone was best reproduced in offset for all paper types and least acceptable for the copier.

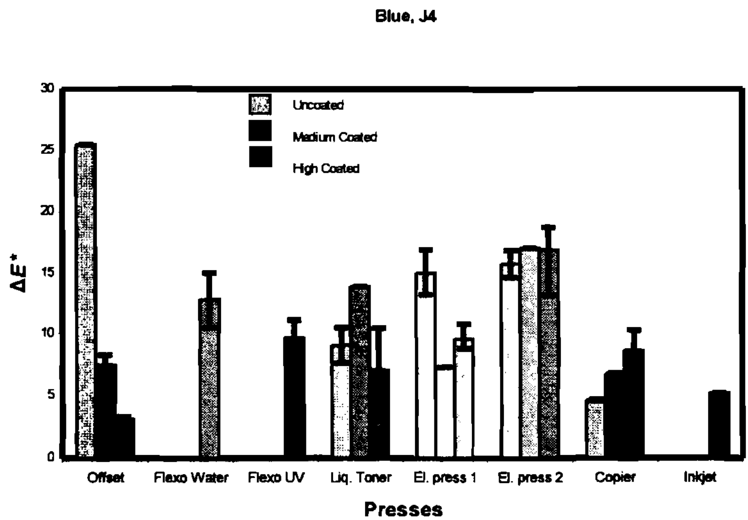


Figure 6. The blue colour patch and its colour deviation for the prints from the different presses compared with the highest ranked sample in the perception evaluation.

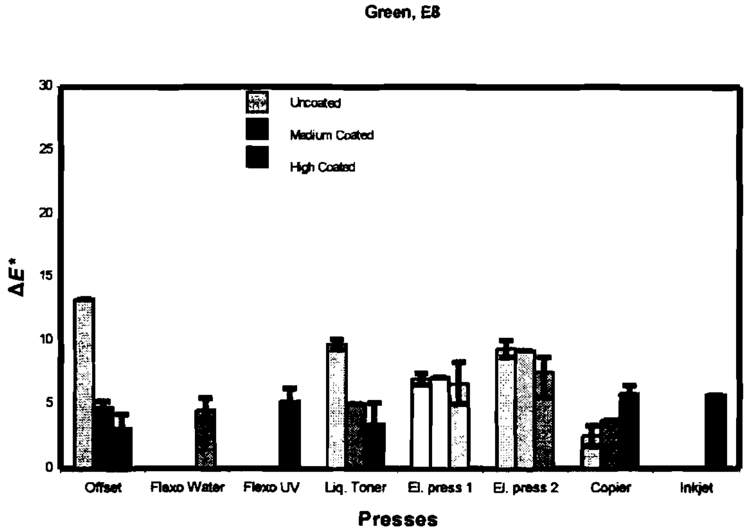


Figure 7. The green colour patch and its colour deviation for the prints from the different presses compared with the highest ranked sample in the perception evaluation.

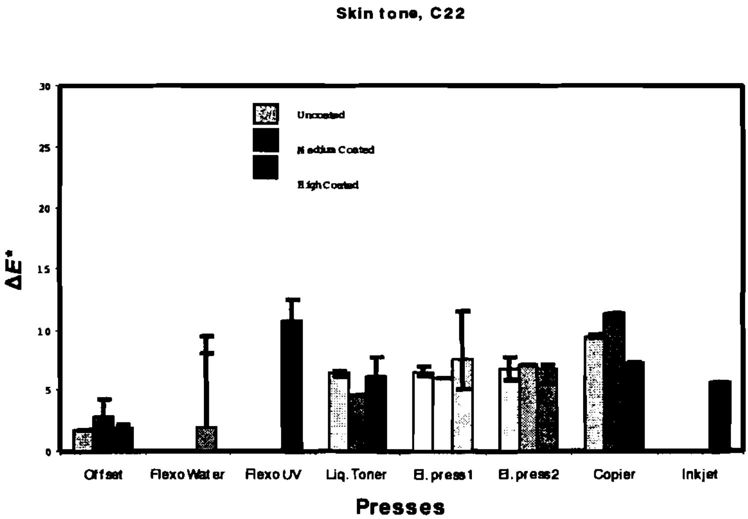


Figure 8. The colour patch representing a skin tone and its colour deviation for the prints from the different presses compared with the highest ranked sample in the perception evaluation.

Orange, C7

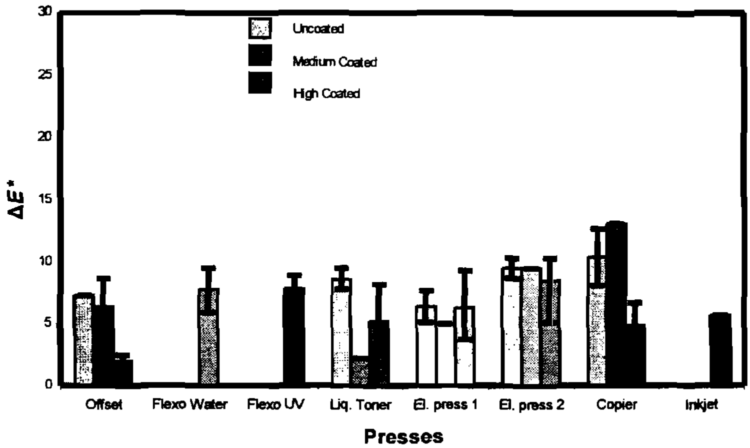


Figure 9. The orange colour patch and its colour deviation for the prints from the different presses compared with the highest ranked sample in the perception evaluation.

Comparison of ΔE*-values for different presses and different paper grades

The software function that is included in ProfileMaker Pro and which enables the calculation of ΔE^*-values between different groups, was used for comparison of the L*-, a*- and b*-values for different press and paper combinations. Figure 10 shows, for three different press types, the ΔE^*-values related to each press and paper combination. In each group the reference is one of the coated papers. The colour deviation increases from a rather small value for highly coated papers compared with the reference highly coated paper to a deviation of about $\Delta E^* = 5$ for the uncoated papers. For one of the electrophotographic presses, again, this difference is not very obvious.

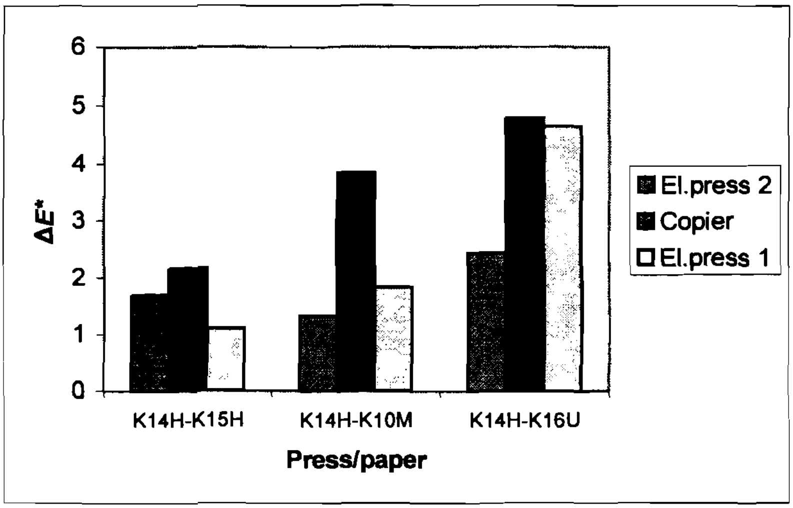


Figure 10. The ΔE-values for three different press types and three different papers Every paper was compared with one of the highly coated papers within each group.*

Prints on three different paper grades, highly coated, medium coated and uncoated, printed in electrophotograhpic process and offset were compared with respect to a*-values. Figure 11 –12 show very clearly the dependence for offset of substrate and on the contrary the independence of the electrophotographic process.

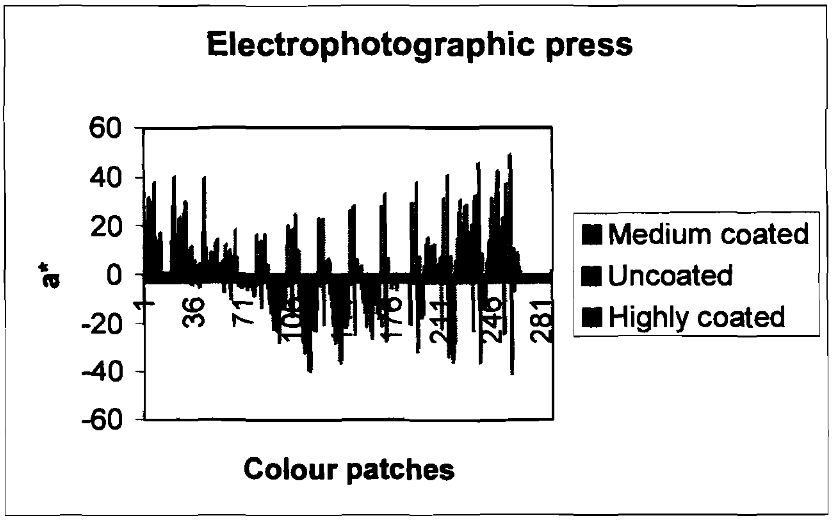


Figure 11. The a-values for three different paper grades prnted in an electrophotographic press.*

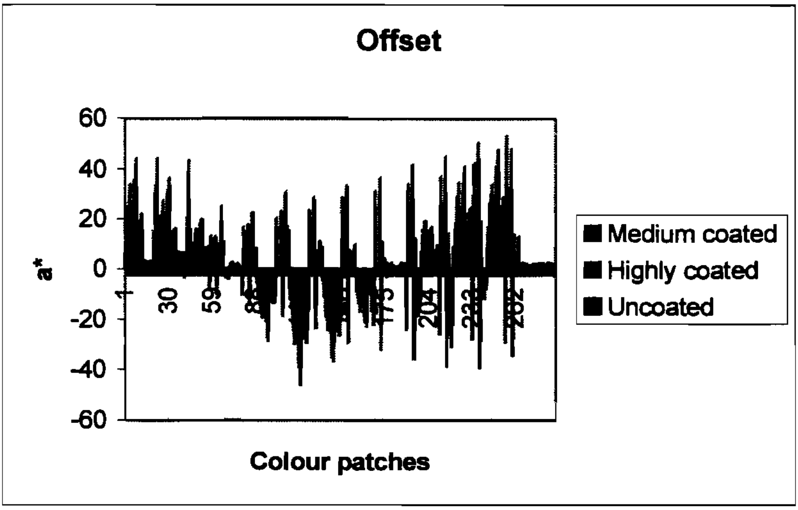


Figure 12. The a-values for three different paper grades prnted in an offset press.*

Perception study

The main results from the perception study can be summarised as follows:

- The best results concerning print quality were gained for the conventional processes with offset still performing the best overall quality followed by the flexographic process.
- Interesting to note was that the electrophotographic processes, although performing in the mid-quality range, appeared to perform equally well on both assessed images and also on all paper grades from glossy to uncoated.
- The samples printed in the copier and with liquid toner showed an overall low quality.

ICC-profiles and dot gain

A test trial was made where an IT8.7 test chart was converted to CMYK with an ICC-profile. The ICC-profile was made for the normal standard setting for the dot gain. The test was performed in one of the electrophotographic presses with a highly coated gloss paper. The dot gain was then changed stepwise upwards and downwards, and the change in colour value was measured as an total ΔE^*-value for the IT8.7. In figure 13, showing the colour difference for each process colour, cyan, magenta and yellow, CMY is plotted as a function of the dot gain difference There is almost a complete linear relationship between the difference in dot gain and the achieved colour difference.

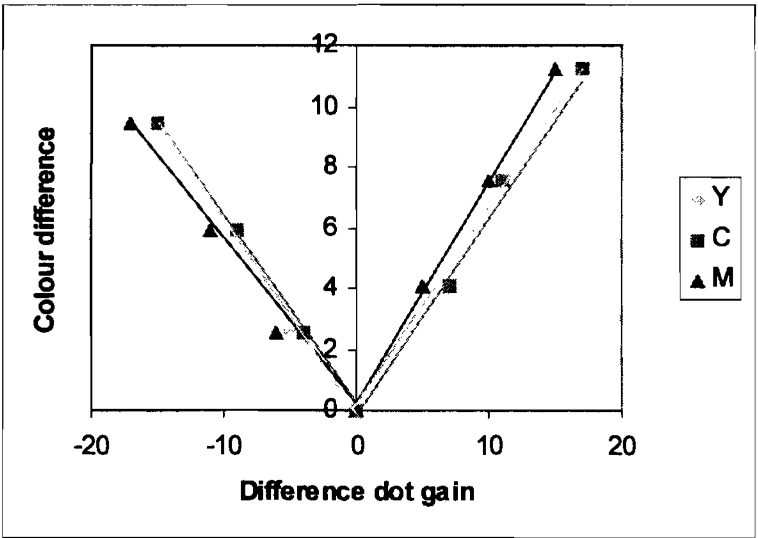


Figure 13. Colour difference, expressed as the total colour difference for the IT8.7 when dot gain is changed upwards and down from the standard value.

Relationship between measured colour data and perception data

Paper surface roughness, paper whiteness, measured colour gamut, print quality and assessed colour failure for skin tones were analysed and compared with each other in order to find the existing relationship, if any. In Figure 14 the values for the colour gamuts are plotted as a function of the paper surface roughness. For all the presses, except for the electrophotographic ones, there is a trend that with increasing paper surface roughness the colour gamut is decreasing. The electrophotographic presses are not influenced at all of the paper roughness. Exactly the same trend is found for colour gamut and whiteness except that for the flexographic process the trend is dramatically changed so that with increasing whiteness the colour gamut is also increased, see Figure 15. These findings are further analysed in Figure 16 where whiteness is plotted against roughness. This allows us to conclude that papers with the highest whiteness values also have the highest values for paper surface roughness. For the flexographic processess, however the papers with the highest whitenessvalues also are the smoothest (lowest paper surface roughness). These factors are probably the most crucial.

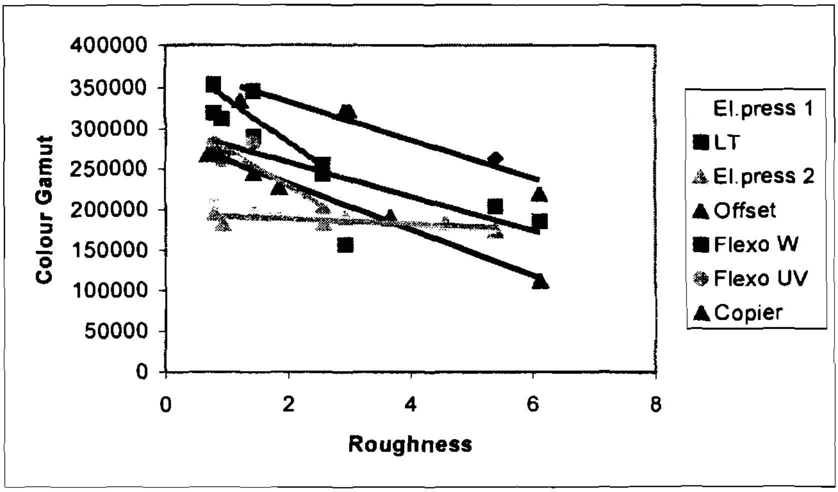


Figure 14. Colour gamut values for the different processes as a function of paper surface roughness.

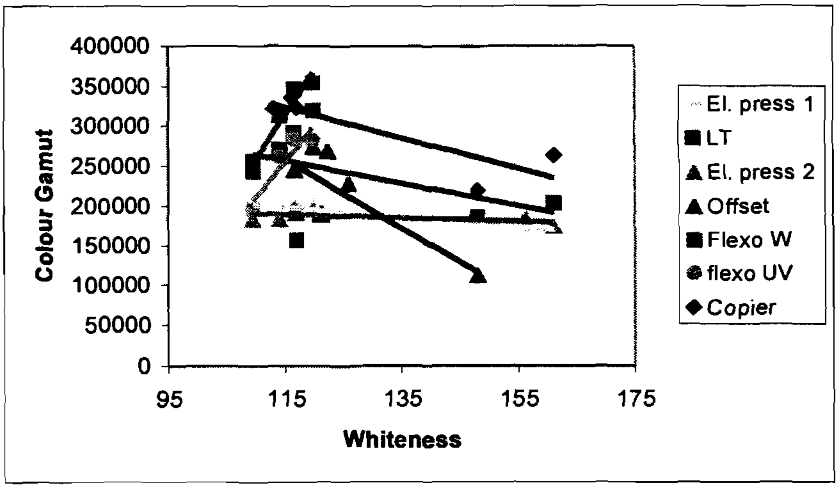


Figure 15. Colour gamut values for the different processes as a function of paper surface roughness.

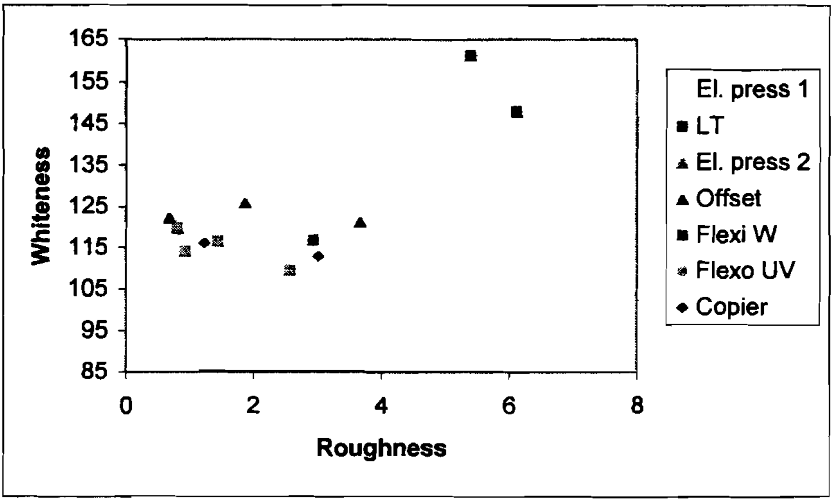


Figure 16. The relationship between paper surface roughness and paper whiteness.

Analysing the perception data for print quality as a function of measured difference in skin tone, a correlation is found (r = 0,53) when taking all the processes together (Figure 15).

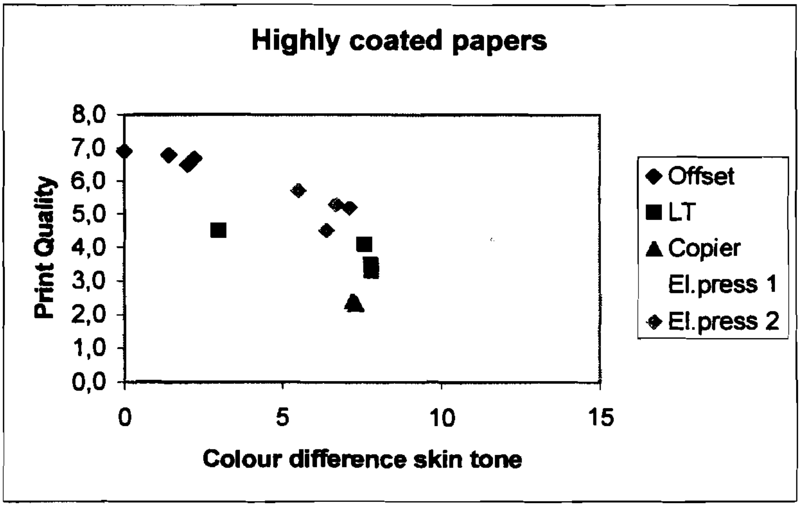


Figure 17. The relationship between measured colour difference and assessed print quality for prints on high-coated papers.

Dot Reproduction

The enlargements of the dot reproduction images can be seen in Figure 18. An attempt was made to categorise and grade the different "screenings" and dots from these according to the form, edge sharpness and distinctness of the dot. In Table 4 the values for the dot characterisation and the corresponding values for the print quality are listed. In a colour quality model such a characterisation must be established to evaluate the influence of the dot reproduction. Correlation between these values was r = 0.26.

Table 4. Assessed values for screening and print quality

Sample code	Point screening	Mean value Perception girl
Offset	6.5	5.7
Flexo	9.5	5.2
LT	8.5	3.5
El press	4.5	4.8
Copier	2	2.6

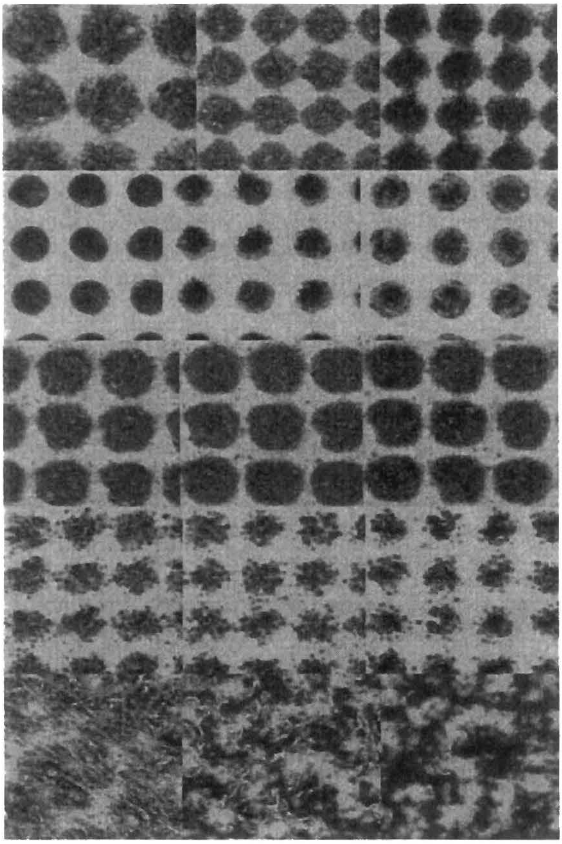


Figure 18. Dot reproduction. Enlargements of dots printed in black 40% (K40). The height of each image corresponds to 0.526 mm (i.e. the total height is 5x0.526=2.63 mm) The images are, from the top left to the bottom right:

Offset	Uncoated	Medium Coated	Highly Coated Gloss
Flexo	Water, High Coated Gloss	UV, High Coated Gloss	UV, High Coated Mate
Liquid Toner	Uncoated	Medium Coated	Highly Coated Gloss
El Press 1&2	Uncoated (1)	Medium Coated (1)	Highly Coated Gloss (2)
Copier	Uncoated	Medium Coated	Highly Coated Gloss

Discussion

It is not self-evident how colour management can be improved. Although the prints were profiled to limit the colour differences the fact remains that there are discernible to fully visible differences between prints from the very different processes, as are demonstrated in this test.

The causes are probably very complex. The processes themselves influence the colour rendering by the technique, the toners and pigments involved, as do the screening technique used and the dot reproduction caused by these parameters. The dot gain, as has been shown in one of the tests, has a very strong influence on the colour.

There are certainly differences between the digital printing techniques themselves and compared with the traditional techniques an even larger difference. The limits in colour management can certainly be improved by even more strictly defining the settings of each printing press (density level, dot gain and other parameters) before creating the ICC-profiles. The algorithms for profiling can possibly be improved. In digital printing technology there are probably other demands on the creating of ICC-profiles than in the traditional printing technology.

Although some techniques seem to have a large colour gamut this is not a guarantee for a good printing result. The size of the gamut depends of course on factors like ink or toner density, which in some cases may have been too high. This is probably the case for the copier, which in turn means that the inner part of the gamut is also influenced. If the density is too high it can be difficult to make the correct compensations and the colour correction will fail.

Conclusions

The following conclusions can be drawn:

- Offset print quality on coated paper is still ahead of what is possible in digital print technology today.
- Although ICC-profiles were used, the result showed slightly discernible to more accentuated differences between prints from the different presses. This was true both for measured colour data and perceived colour.

- Offset quality is to a large extent dependent on the paper quality following the order highly coated, medium- and uncoated.
- Electrophotographic quality is not as high as the offset quality and is not dependent on the paper quality.
- The largest colour gamuts were obtained in the colour copier- and flexographic process.
- No relationship was found between large colour gamut and print quality in respect to digital print technologies. However, for offset and flexo, there was a clear relationship between a large gamut and a high print quality.
- The most critical colour to reproduce was the blue colour. Skin tones were best reproduced in offset.
- Colour gamut increases with decreasing paper surface roughness and depending on the roughness increases or decreases with whiteness.
- The importance of establishing relevant standard settings for each process is crucial if the goal is to obtain similarity in colour rendering.

Acknowledgements

I want to express my gratitude to the Print Evaluation 2000 project group for co-operation in the major project and to Ingrid Andersson for help with complementary measurings. Finally my gratitude to Sandra Brunsberg, KTH (The Royal Institute of Technology in Stockholm) for her valuable assistance in linguistic and scientific matters.

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